

## AI and Machine Learning III

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**Session Chair:** Ilia T. Bagov, Karlsruhe Institute Of Technology, Karlsruhe, Germany

**Session Vice Chair:** Shuangbiao Liu, Northwestern University, Evanston, IL

**8:00 - 8:40 am**

### **4210708: Tribo-Informatics: The Systematic Fusion of AI and Tribology**

Zhinan Zhang, Nian Yin, Xin Wang, Shanghai Jiao Tong University, Shanghai, China; Shuaihang Pan, University of Utah, Salt Lake City, UT

Advancements in AI have greatly improved our ability to calculate, design, simulate, and test tribo-systems. Tribo-informatics, which integrates tribology with informatics for efficient research, focuses on five key information types in tribo-systems: input data, system properties, output data, tribological data, and derived state information. It employs both traditional data processing and advanced machine learning techniques such as linear regression, Gaussian models, support vector machines, and random forests. This study explores the application of AI in diverse aspects of tribology, spanning from component-level tribological systems to intelligent tribology systems. Case studies will illustrate the practical implementation of tribo-informatics. By using information technology, tribo-system complexity can be reduced, and research timelines can be shortened, promoting tribology innovation.

**8:40 - 9:00 am**

### **4199278: AI-Driven Rapid Prediction of Elastohydrodynamically Lubricated Contacts**

Max Marian, Josephine Kelley, Leibniz University Hannover, Hannover, Germany

The prediction of lubricated tribo-contacts is crucial for optimizing mechanical system performance, but it remains complex and computationally intensive. Artificial Intelligence (AI) and Machine Learning (ML) techniques offer efficient and accurate solutions. This presentation explores ML algorithms, particularly artificial neural networks, for modeling lubricated tribo-contact behavior. One focus is on elastohydrodynamically lubricated (EHL) contacts, where ML algorithms trained on extensive numerically generated data efficiently capture complex patterns using input parameters like lubricant properties and operating conditions. This allows streamlining detailed information of EHL contact conditions in higher level system simulations of machine elements or entire drive systems. In the presentation, we demonstrate the fundamental modeling aspects as well as the exemplary usage for predicting rolling and sliding friction as well as electrical capacitance in cylindrical roller bearings.

**9:00 - 9:20 am**

### **4188903: Symbolic-Regression Based Extended Hertz Theory of Coated Bodies**

Brian Delaney, Shuangbiao Liu, Q. Jane Wang, Northwestern University, Evanston, IL

This work presents an application of symbolic regression to extend Hertz theory toward coated bodies through new functions of the ratio of Young's modulus of the coating to that of substrate ( $E$ ) and non-dimensional coating thickness ( $H$ ). Hertzian theory can predict two asymptotic contact performance values (maximum contact pressure, contact radius, and contact approach) in situations of uncoated bodies or coated bodies with sufficiently large coating thickness. Contact performance functions of  $E$  and  $H$  were constructed, and the parameters were obtained via symbolic regression. The learned functions were responsible for mapping the non-linear transition

of the behaviors of contact parameters from that of the pure substrate to that of a sufficiently thick coating. The new explicit model provides a theoretical framework through which accurate predictions of contact performances can be made over a range of coating-substrate modulus ratios and film thickness-contact radius ratios.

**9:20 - 9:40 am**

**4202140: Multi-Modal Prediction of Friction Evolutions**

Nathan Brown, John Curry, Frank DelRio, David Adams, Tomas Babuska, Brad Boyce, Sandia National Laboratories, Albuquerque, NM; Kookjin Lee, Arizona State University, Tempe, AZ

Determining surface friction evolution typically involves resource-intensive experiments, particularly for complex materials like platinum-gold (Pt-Au) alloys, where variability arises from intricate properties and surface interactions. This study applies multi-modal machine learning models to predict the cycle-dependent friction evolution of Pt-Au films, using modalities such as modulus and hardness measurements, X-ray fluorescence (XRF) spectra, and SimTra analysis. We compared the performance of a feedforward regression model and an autoencoder, revealing that certain input modalities significantly enhance predictive accuracy. The most effective models achieved errors comparable to the experimental variance in friction trials, demonstrating their ability to reveal relationships between surface characteristics and friction behavior, thus facilitating more efficient material characterization. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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

**4205290: Structural Semantics and Machine Learning-based Investigation on the Superior Aspects of PTFE as a Tribological Filler in High-Performance Engineering Polymer Composites**

Tanil Ozkan, Steve Pouliot, Jonathan Penaranda, Burak Bekisli, Dover Innovation Laboratory, Houston, TX

This study employs a structural semantics-based approach, leveraging co-occurrence frequency based categorization capability of artificial intelligence to identify the most critical attributes of PTFE that make it an ideal tribological filler. The analysis highlights rapid fluorination of metallic countersurfaces and resilient transfer film formation as the two most critical attributes giving rise to wear resistance. To substantiate this finding, an adaptive machine learning approach was utilized to interpret ab initio simulation results with monolayer level FeF<sub>2</sub> and FeF<sub>3</sub> clusters. Our findings reveal that the formation of FeF<sub>2</sub>-type localized surface domains is more likely to contribute to intrinsic mechanical resilience. This work underscores the importance of understanding the fundamental interactions at play to optimize the use of PTFE in tribological applications, particularly in light of evolving regulatory standards and ongoing development of alternatives.

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

**10:40 - 11:00 am**

**4218541: Shifting from Paper to Digital: Bridging the Gap in Knowledge Digitalization**

Nick Garabedian, Ilia T. Bagov, Datin Company, Karlsruhe, Germany

Despite advances in computing and AI, effectively integrating digital tools into scientists' workflows remains a challenge. To harness these advancements, digital systems must grasp the conceptual models that tribologists rely on for critical decisions. This presentation explores practical methods for organizing knowledge to make data findable, accessible, interoperable, and reusable (FAIR). It addresses key misconceptions about FAIR data and reveals unexpected benefits of connecting knowledge and data in AI applications, highlighting how R&D knowledge graphs can drive faster, cross-disciplinary discovery and collaboration.

**11:00 - 11:20 am**

**4205412: Predictive Models in Tribology Using Machine Learning**

Nuria Espallargas, Nicolai Olsen, NTNU, Trondheim, Norway; Wahyu Wijanarko, Norwegian University of Science and Technology, Trondheim, Norway

Tribology is vital for optimizing engineering materials. Traditionally, empirical methods have been used to analyze tribological performance, but advances in machine learning have transformed the field. This work utilizes molecular descriptors from AlvaDesc to predict key tribological metrics like the coefficient of friction (COF) and wear rate. These descriptors are derived from the Simplified Molecular Input Line Entry System (SMILES), which encodes chemical structures. By correlating these descriptors with in-house experimental data, we developed machine learning models to forecast lubricant behavior. We tested various algorithms, including Linear Regression, Decision Trees, Random Forest, SVR, AdaBoost, XGBoost, MLP, RNN, and CNN. Boosting algorithms like AdaBoost and XGBoost excelled in managing data imbalances and outliers. This predictive capability based on molecular structure streamlines the development of high-performance lubricants and reduces the need for extensive testing.

**11:20 - 11:40 am**

**4204871: Machine-Learning Models for Predicting Friction from Roughness**

Lars Pastewka, Johannes Hörmann, Paul Strauch, University of Freiburg, Freiburg, Germany; Antoine Sanner, ETH Zürich, Zürich, Switzerland; Kurt Beschorner, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Surface roughness plays a critical role in determining properties like adhesion and friction, but achieving quantitative predictions from topographic measurements has remained challenging. Here, we demonstrate how statistical machine learning can establish strong correlations between roughness measurements and surface properties, enabling predictive data-driven models. Our approach is based on a novel class of statistical descriptors, called scale-dependent roughness parameters (SDRPs), which capture surface roughness across multiple scales and allow combining multiple measurements on the same specimen into single statistical descriptor. These SDRPs are used as features in Gaussian process classifiers and regressors to predict surface properties. We apply this to predict friction coefficients in shoe-floor interactions, modeling the complex tribosystem of viscoelastic rubber soles sliding on rough surfaces, enhancing our understanding of friction behavior in practical applications.

**11:40 am - 12:00 pm**

**4270715: A Computer Vision Tool for Automatic Recognition of Bearings Failure Modes**

Marco Van Zoelen, Christine Matta, Stephan Baggerohr, Sebastian Echeverri Restrepo, Mourad Chennaoui, Cees Taal, SKF B.V., Houten, Netherlands

Industrial users increasingly rely on advanced digital technologies to monitor the health of their equipment. Modern condition monitoring systems apply advanced analytical techniques to detect the early signs of wear or damage in bearings and other critical parts. Once an issue has been identified an experienced application engineer is called on-site. Accessing a skilled bearing analyst isn't always easy. To address this issue, we developed a computer vision model that can evaluate bearing damage using digital photographs. The model is based on CNN and can classify and detect failure modes on images of roller bearings components. In this study, we will present the model, the approach taken to identify different failure modes from actual bearing applications. The model is a valuable tool for detecting and classifying bearing failures, helping to improve equipment maintenance, prolonging the life of critical machinery, and contributing to improving their global carbon footprint.

## Commercial Marketing Forum III

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**Session Chair:** TBD

**8:00 - 8:20 am**

**4309901: SI Group : Developing an Additive to Address Impending Regulatory Challenges of Substituted Diphenylamine-Based Antioxidants**

Timothy Chipuk, SI Group, The Woodlands, TX

The development of alkylated aromatic amine antioxidants began in 1930s. Substituted diphenylamine antioxidants (SDPAs) continue to be regarded amongst the most important single purpose, ashless antioxidants in many lubricant applications with annual usage volume exceeding 100 kT globally. The latest challenge facing SDPA technology comes in the form of regulatory scrutiny, primarily chemical reprotoxicity. Two CLH dossiers have been submitted to the ECHA regarding the widely used C4/C8 and C9 alkylated DPA materials. Reclassification of the materials to Repro 1B CLH triggers restriction on professional uses and potentially industrial uses. SI Group will present the results of a multi-year research project detailing the development of a new diphenylamine reaction mass that looks to mitigate the risk of current regulatory scrutiny whilst maintaining the usability and performance expected from the SDPA chemistry.

**8:20 - 8:40 am**

**4301789: Nouryon: Advanced Solutions for Friction Mitigation**

Alina Filin, Ezio Amerio, John Dixon, Nouryon, Deventer, Netherlands

Mitigating friction and wear in automotive and industrial oils is crucial for enhancing performance and extending equipment lifespan. With a rich history of providing organic friction modifiers and phosphorus-based anti-wear additives, Nouryon leads in innovative lubrication solutions. Nouryon's progressive polymeric friction modifiers feature multiple functional groups within a single molecule, achieving remarkable friction reduction at low treat rates. Additionally, Nouryon has developed a new generation of friction modifiers with advanced solubility in low polar base stocks, expanding their applicability in modern lubricants used in automotive and industrial applications. Overall, Nouryon's anti-wear additives and friction modifiers represent a significant advancement in lubrication technology, offering effective friction reduction, compatibility with other additives, and improved solubility, contributing to optimal lubricant performance.

**8:40 - 9:00 am**

**4301579: Evonik: Three Step Approach to Improve Fuel Economy in Engine Oils**

Mark Petit, Sabrina Strube, Rhishikesh Gokhale, Seemann Michael, Evonik, Rochester Hills, MI

Improving fuel efficiency is a major goal of the automotive industry to reduce the consumption of fossil fuels and CO<sub>2</sub> emissions. Lubricants, in contrast to personal driving style, can deliver a constant contribution to vehicle efficiency. One way to achieve efficiency with lubricants is by adopting an engine oil with a flat viscosity profile.

This approach maximizes engine oil efficiency within the same SAE grade. Evonik has identified three steps to improve efficiency in this fashion. They can be applied as single steps or combined together to maximize the effect.

The three-step approach provides maximized fuel economy within the same SAE grade by over 1% based on an optimization of the viscometric properties. Such a lubricant delivers highest efficiency for new engine technologies, such as hybrid and hydrogen technologies, as well as for existing engine designs.

**9:00 - 9:20 am**

**4301538: Lubrizol Hybrid Grease System - A Lithium Alternative**

Timothy Saari, Lubrizol, Rochester Hills, MI

As demand for lithium expands with the growing global EV market, the cost of lithium has been dynamic over the last several years. In addition, lithium is under regulatory pressure in Europe and elsewhere. In an effort to mitigate the ever-changing cost landscape of lithium and simultaneously address expected product hazard changes, Lubrizol has developed a lithium free thickener system which is cost competitive with current lithium complex and standard lithium greases. This development together with a novel manufacturing process yields hybrid greases which achieve comparable performance to lithium based grease systems.

**9:20 - 9:40 am**

**4299914: NYCO: Expanding Synthetic Lubricants through NYCO's High-Performance Specialty Esters**

Kyle Elgert, NYCO America, Newnan, GA

NYCO, a global leader in the design and production of high-performance synthetic esters, is a renowned partner known for expertise in aviation, defense, industrial, and automotive lubricants. With over 70 years of innovation, NYCO excels in creating high-performance ester chemicals structures and finished specialty lubricants. Users will benefit by reducing carbon emissions, improving wear, and extending the lifespan of lubricants and equipment through superior thermal oxidative stability, excellent low-temperature properties, and enhanced frictional benefits. Whether considering eco-friendly or food grade approvals, NYCO's customized solutions deliver. These enticing features substantiate the industry growth for synthetics and esters in the marketplace. Recently, NYCO completed a greenfield project in Newnan, GA to make it easier to supply high-quality products locally. Thereby reinforcing its position as a trusted technical advisor and reliable partner in the lubricants industry.

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

**4319164: Biosynthetic Technologies: Estolides - High-Performance Sustainable Base Oils for Lubricant and Metalworking Formulations**

Matt Kriech, Biosynthetic Technologies, Indianapolis, IN

Biosynthetic Technologies delivers high-performing and innovations for a sustainable future. As such, we offer products that are bio-based and readily biodegradable yet also deliver superior performance characteristics. In this session, we will discuss our expanding product line of sustainable base oils which are made from derivatized organic fatty acids. These oils provide excellent hydrolytic stability, oxidative stability, seal compatibility as well as other superior performance characteristics. This 30-minute session will be a must for anyone looking to develop a high-performance EAL product line.

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

**10:40 - 11:00 am**

**4269606: ChainCraft: Upcycling Waste into Fatty Acids: A Sustainable Path to Advanced Synthetic Esters**

Dilek Ersu, ChainCraft, Amsterdam, Netherlands

The fatty acids used in polyol esters (POEs) come from petroleum or vegetable oils as castor, coconut, palm kernel oil, etc. Although vegetable oils are considered a greener alternative, they often have an equal or higher carbon footprint than petroleum and present environmental challenges. Caproic acid (C6) has not been commonly used for POE synthesis due to its historic

scarcity. However, the unique chain length of C6 could bring many functional benefits. ChainCraft is ready to provide a large and stable supply of C6 produced by proprietary fermentation of organic residues from the food industry. This novel technology leads to production of lower carbon footprint, circular fatty acids, does not compete with food production and EUDR exempt. In this presentation, after briefly explaining ChainCraft's technology for fatty acids manufacturing, we will focus on the role and potential of C6 in POE production and discuss how it compares to commonly used C5- and/or C7-based POEs.

**11:00 - 11:20 am**

**4299878: MÜNZING's New FOAM BAN® 439: MOSH/MOAH Free, Organo-Modified Siloxane Antifoam for Non-Aqueous Lubricants**

Safia Peerzada, MUNZING CHEMIE GmbH, Bloomfield, NJ; Stefanie Velez, Munzing North America, Bloomfield, NJ

There is a shift in the non-aqueous lubricants market towards sustainable and synthetic fluids. Two big issues regarding sustainability of these fluids are PFAS and MOSH-MOAH chemistries. FOAM BAN® 439 is a PFAS free, MOSH-MOAH free antifoam designed for synthetic Group III+, PAO, PAG and Ester base fluids that provides improved performance. The MOSH-MOAH free carrier in FOAM BAN® 439 allows for improved stability and compatibility in these lubricants while maintaining good foam control and low impact on air release. The performance of FOAM BAN® 439 in multiple applications and fluid types, including gear oil, hydraulic fluid and EV Fluid, will be discussed.

**11:20 - 11:40 am**

**4301631: BASF Corporation: Discover BASF's Expanding Line of Industrial Additive Packages Designed to Meet the Highest-Level OEM Requirements**

Daniel Niedzwiecki, Eugene Scanlon, BASF Corporation, Florham Park, NJ

BASF's Fuel and Lubricant Solutions is committed to developing products that meet the emerging needs of our customers. This session will highlight our industrial additive packages portfolio, which includes Hydraulic (IRGAPAC® H), Turbine (IRGAPAC® T) and Gear (IRGAPAC® G) packages, with a special focus on our latest innovations. Designed to meet the highest-level OEM approvals, our new premium ashless hydraulic package delivers on performance. It offers superior wear and extreme pressure protection across FZG, Conestoga, and Bosch Rexroth pump tests. Formulated with our customers' environmental, health, and safety objectives in mind, our new hydraulic package will not impart any hazard labels on the finished fluid at the recommended treat rate. This is one of our latest innovations covered in this presentation. As a leading global supplier of lubricant base stocks and additives, BASF is proud to offer additive package solutions to help you tackle the challenges of today and tomorrow.

**11:40 am - 12:00 pm**

**4301645: Coast Southwest: Integrated Technology, Innovation, and Solutions**

Anthony Cimo, Coast Southwest, Inc., Paso Robles, CA

Coast Southwest is a leading full-service chemical manufacturer, distributor, and ingredient technology company. Starting from humble origins as a distributor in southern California, Coast Southwest has expanded its capabilities in manufacturing, R&D, and innovation. This vertical integration has allowed us to offer a wide variety of products and services to formulators of lubricants and metalworking fluids, from product sourcing and logistics, custom manufacturing, and technical expertise. Our team of highly experienced formulators will assist with solutions from start to finish on any lubricant application. In October 2023, Coast Southwest acquired the Paso Robles manufacturing plant from the Lubrizol Corporation, where we produce a variety of surfactants for metalworking applications, and our partnership with MFG Chemical allows us to provide a near-universal line of additives, including corrosion inhibitors, anti-wear additives,

## Condition Monitoring I

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**Session Chair:** Alfredo Garcia, Luval SA, Santiago, Region Metropolitana, Chile

**Session Vice Chair:** Misty Bickerdyke, Empire Fluid Analysis, Dayton, NV

**8:00 - 8:40 am**

**4200450: Asset Reliability Through Integration: Setting the Standard for Success**

Dave Tingey, POLARIS Laboratories®, Indianapolis, IN

In today's landscape of asset reliability, the term "integration" is frequently associated with data-driven approaches. However, reliability extends beyond mere data; it is a comprehensive process that encompasses insights from various sources, including vibration analysis, thermography, fluid monitoring, telematics, and operational observations. Currently, these technologies often function in isolation, limiting their ability to share critical data and diminishing overall reliability effectiveness. This presentation will explore the common advantages and disadvantages of each technology and demonstrate how their integration can enhance reliability outcomes by fostering collaboration and maximizing data utility.

**8:40 - 9:00 am**

**4200314: Filtration and Characterization of Sub-Micron Contaminants in Used Lubricants.**

Myrna Cortes Morales, Aldara Naveira Suarez, SKF RecondOil, Stockholm, Sweden; Vicente Benavides, Laboratorio GMAS SAS, Bogotá, Colombia; Roland Larsson, Par Marklund, Luleå University of Technology, Luleå, Sweden

Correct lubricant operation in industry highly depends on the control of contamination levels. Particle contamination will increase wear in mechanical systems and accelerate the degradation of lubricants. Most filtration systems and techniques focus on removing particles larger than 4 µm, overlooking the potential risks posed by sub-micron contaminants. This work focuses on the qualitative analysis of recovered contaminant particles from used commercial lubricants, after being treated with different depth filtration methods. Results suggest that conventional depth-filtration systems are not enough to remove sub-micron contaminant particles and should be combined with other technologies to enhance their removal. Findings indicate that the composition of contaminant particles consists of a mixture of wear metals from the operation and common additive elements, which highlights the importance of their removal to extend the lubricants' service life.

**9:00 - 9:20 am**

**4205405: Monitoring Lubricant Quality by Applying Machine Learning to Acoustic Emission Signals from Rubbing Contacts**

Tom Reddyhoff, Robert Gutierrez, Mein Yeak Siow, Imperial College London, London, United Kingdom

Acoustic Emission (AE) – i.e., high frequency stress waves caused by micro deformations of component surfaces that propagate through material – is a rich source of tribological information. AE monitoring is non-invasive, relatively low cost, and therefore well suited to condition monitoring of sliding contacts. However, this has yet to be used extensively in practice, since the relationship between friction behavior and sound is highly complex. The approach taken in this work is to

conduct sliding tests, while measuring both friction and AE. Machine learning algorithms are then applied to process the high frequency sound emitted and correlate this with the measured friction and also lubricant properties. Results show that machine learning can accurately predict friction and also provide information on lubricant quality and composition based acoustic emission data, provided the correct algorithms and preprocessing methods are applied.

**9:20 - 9:40 am**

**4202012: Ultrasonic Reflection Measured Oil Film Thickness on Slipper Bearings of an Axial Piston Pump**

Min Yu, Pan Dou, Tonghai Wu, Xi'an Jiaotong University, Xi'an, China; Tom Reddyhoff, Imperial College London, London, United Kingdom

Axial piston pumps are critical power elements in hydraulic systems, the performance in energy efficiency and endurance is reflected by lubrication health of key tribo-pairs in slipper-swashplate, piston-cylinder, and valve plate-cylinder interfaces. Ultrasound reflection is an effective non-destructive method for in-situ oil film thickness measurement, however, the complex geometry of groove-textured slipper surface and the high rotational speed present significant challenges. To address these problems, finite element method is used to simulate wave propagation through a lubricated slipper-swashplate contact, the results of which compensate for the effect of surface textures; high-pulse repetition frequency of ultrasound equipment is established to identify the angular position of a slipper with respect to the sensor. An aviation fuel piston pump is adopted for in-situ ultrasound measurements, where ultrasound measured oil film thickness are consistent with theoretical calculations.

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

**4189335: Comparison of Traditional and Remote Inline Continuous Condition Monitoring Methods for Air Compressor Fluids**

Joseph Schultz, David Aaserud, Kris Clark, Kevin Manouchehri, Lubrizol Corporation, Wickliffe, OH; Alex Pelkey, Poseidon Systems, LLC, Victor, NY

Maintaining the integrity of the lubricant is vital to industrial equipment. The standard suite of tests in a typical oil condition monitoring program consists of viscosity, acid number, metals & water content, and particle count. Advanced tests can also be included depending upon the application and desires of the requester. Each result is merely a snapshot of the system, and trends need to be analyzed to fully obtain a benefit. Companies spend a great deal of time, money, and effort to take, send and test samples that ultimately show no deviation from their standard used oil specifications. Delays in shipping samples and getting results, however, can be detrimental to equipment in peril. This work describes two methods for inline, continuous monitoring of different chemistries of air compressor lubricants. Sensor responses and trends from the continuous monitoring data are compared to both traditional wet chemistry testing and more advanced formula component analysis.

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

**10:40 - 11:00 am**

**4302466: Prediction of Physical Properties and Composition of Used Lubricants Using Near-infrared Absorption Spectra**

Kyoko Kojima, Hitachi, Ltd., Kokubunji, Tokyo, Japan

From the near-infrared absorption spectra of lubricants, information on the type of lubricants, physical properties and composition of lubricants can be easily obtained using regression and classification machine learning. Spectroscopy has the advantage of being able to measure without contact with lubricants. Near-infrared spectroscopy has the advantage of cheaper sensors



compared to mid-infrared spectroscopy. So far, the results of evaluation using model oils in which additives and water are added to the base oil have been presented. In this presentation, examples of predicting the water content, acid number, and viscosity of the used oils using a small sensor will be presented.

**11:00 - 11:20 am**

**4177421: Innovative Tools for a Better Prevention of Organic Fluids Oxidation and Varnish Build up**

Marie Roucan, Jérémy Pallas, ANTARA GROUPE, Chateaudun, France, France

Degradations pathway, mainly caused by oxidation, have been seen in lubricants application to often result in systems failure. Oxidation induces the formation of soluble and insoluble contaminants leading in varnish build up. Tracking species responsible for systems failure is of interest although appears to be difficult, and direct method to detect these chemical species has not yet been found. The main issue lies in the numerous and different species formed. We design nanocomponents to separate the various unstable entities, such as radicals or oxygen containing molecules, generated by oil oxidation. Coupled with EPR technics, it allows for the identification of the diverse species. Along with the spin trapping method, we were able to identify several degradations residues which can be utilized as quality indicators in the monitoring of oil oxidation. Moreover, the fine tune of nanocomponents chemical structures is opening a new lead to develop specific adsorbents for oil treatment.

**11:20 - 11:40 am**

**4205265: Vibration-Based Detection and Classification of Compound Gear and Bearing Faults Using Ensemble Learning**

Vishwadeep Handikherkar, Vikas Phalle, Veermata Jijabai Technological Institute (VJTI), Mumbai, Maharashtra, India; Ramesh Bhandare, K.K Wagh Institute Of Engineering Education and Research, Nashik, Maharashtra, India

Compound faults, arising from simultaneous damage to both gears and bearings, pose a significant challenge in vibration-based fault diagnosis due to the complex interaction of multiple fault sources. This paper presents a novel approach for detecting and classifying compound gear and bearing faults through vibration signal analysis enhanced by ensemble machine learning techniques. Time and Frequency Domain features were extracted from collected vibration signals. An ensemble model, incorporating Random Forest, Gradient Boosting, and Support Vector Machine classifiers, is proposed to improve classification accuracy. The model is evaluated on experimental datasets, showing superior performance in distinguishing between normal and faulty conditions. Results demonstrate that the ensemble approach achieves higher classification accuracy and robustness compared to individual classifiers, highlighting its potential for reliable fault diagnosis in complex industrial machinery.

**11:40 am - 12:00 pm**

**4204902: Laboratory and Field Trials of a Railway Wheel Mounted Ultrasonic Sensor for Contact and Lubrication Detection**

Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom; Henry Brunskill, Hary Shackleton, Peak to Peak Ltd, Sheffield, United Kingdom; Andrew Little, LB Foster Rail Technologies Corp, Surrey, British Columbia, Canada

Railway wheels move laterally on track during vehicle curving; to avoid damage caused by sliding particularly sharp curves are greased. The location of the wheel on rail and presence of grease are important parameters. In this work we have built and field-tested ultrasonic sensors to detect both. Ultrasound is partially reflected at a rough surface contact. The proportion of wave amplitude reflected depends on the stiffness of the interface. Addition of grease into asperity gaps makes the

contact slightly stiffer and a resulting change in reflection can be detected. Using this approach, we assess the size of the wheel rail contact and if it is lubricated. Arrays of small ultrasonic sensors were bonded onto both a lab-based wheel-rail simulator and a train wheelset on a heritage line. Tests on the former assessed contact and lubrication under controlled conditions of load and lubricant application. Tests on the latter showed the practical capability of the method as a train-based sensor.

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## Metalworking Fluids II

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**Session Chair:** Stephanie Cole, Munzing North America, LP, Bloomfield, NJ

**Session Vice Chair:** Stefanie Velez, MUNZING CHEMIE GmbH, Bloomfield, NJ

**8:00 - 8:40 am**

**4203455: A Seminal Tribological Study of Chlorinated Paraffins and Alternative Chemistries for Extreme Pressure and Anti-Wear.**

Robert Stepan, Univar Solutions, Strongsville, OH

A seminal tribological study of chlorinated paraffins and alternative chemistries for Extreme Pressure and Anti-Wear. Regulation of Chlorinated Paraffins (ECHA and future limitations MCCC). Scope of Work: A comparative tribological study of 3 commercially chlorinated paraffins and a wide spectrum of alternative additives. Project Overview: The purpose of this project is to evaluate the performance characteristics of specific mid-chain chlorinated paraffins against a selection of industrial additives. The testing is conducted using established tribological testing methods: the 4-Ball Extreme Pressure (EP) & Wear, the Falex Pin & Vee Block, the Mini-Traction Machine (MTM), SRV with 3D polarimetry, Micro Tapping-Torque, and Timken OK Load. Finally, Report outcomes in a comparative matrices between the large sample population of alternative chemistries v. chlorinated paraffin

**8:40 - 9:00 am**

**4201733: Effect Cooling-Lubrication Condition and Abrasive Grit Size and on Tribological Behavior of SAE 52100 Hardened Steel after Grinding**

Rosemar Batista da Silva, Bruno Souza Abrão, Mayara Fernanda Pereira, Federal University of Uberlandia, Uberlândia, Minas Gerais, Brazil; Raphael Lima de Paiva, Federal University of Piaui, Teresina, Piaui, Brazil; Alisson Rocha Machado, Pontifícia Universidade Católica do Paraná, Curitiba, Parana, Brazil; Mark James Jackson, Kansas State University, Salina, KS; Rogerio Valentim Gelamo, Federal University of Triângulo Mineiro, Uberaba, Minas Gerais, Brazil

Coolant in grinding is delivered generally at high flow rates that can reach up to 300 L/min (18000000 mL/h). However, due to environmental, social, and economic issues, research has been carried out to reduce fluid volumes, without compromising functionality of ground components. The addition of solid particles to the coolant combined with the minimum quantity of lubricant technique (< 500 mL/h) has shown promising results in grinding processes, improving the tribological conditions. This work evaluated the effect of adding multilayer graphene particles to the cutting fluid on the surface integrity of the SAE 52100 hardened steel. Combination of 2 aluminum oxide grinding wheels (46 and 60 meshes) with coolant delivered under the conventional, MQL and MQL+Graphene cooling-lubrication conditions were tested. Roughness and surface texture of workpiece were investigated. Presence of graphene particles lead to improved tribological behavior providing low roughness and better texture.

**9:00 - 9:20 am**

**4201177: The Challenge to Determine Anti-Wear and Extreme Pressure Properties of Dry Lubricants in Industrial Lubrication Applications.**

Dirk Drees, Lais Lopes, Pedro Baião, Michel De Bilde, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium

Dry lubricants are in industrial forming processes, notably wire drawing. Consisting of flakes, pellets, or powders, they stick to the workpiece and pass through a die or forming tool, where localized high pressure melts them. Characterizing their EP and Anti-wear properties in a lab test is challenging: a constant supply of particles into a standard tribological geometry needs to be achieved. Four ball wear/ep tests fall short.

Further, the aspect of cooling needs to be addressed, in the industrial setting the cooling is done by workpiece mass transport, but this cannot be simulated in a lab test. In this presentation, the method to apply a consistent and systematic amount of dry lubricants into the tribological contact of a Pin&Vee block setup is shown, as well as how test conditions can be modified to obtain a repeatable and useful test method that correlates with expectations of the products under test. This opens an avenue to a standardized QC test for solid particle lubrication.

**9:20 - 9:40 am**

**4200903: Boundary Lubricant Additive Multimetal Boundary Lubrication Optimization Using Twist Compression Tests (TCT) and Combination DOE**

Ted McClure, Alexes Morgan, Joseph Chiarelli, Sea-Land Chemical Co., Cleveland, OH

Materials and manufacturing processes continue to evolve in response to changing requirements. Electric current and thermal management are important considerations for EVs, contributing to increasing use of copper and aluminum. Metalworking fluid end users also require fluids performing with multiple metals, for improved efficiency and inventory control. The Twist Compression Test (TCT) is used to evaluate the boundary lubrication performance and galling resistance of material couples. High performing additives with AISI 1018 steel, 5182-0 aluminum, and Copper 110-H02 were identified and TCT results presented earlier. A combination mixture DOE, with the metal type as a three level categorical factor, along with three selected additives, was designed. The resulting matrix was tested using TCT. The test results and DOE analysis will be presented. The aim is to provide useful data, and one possible process, for formulation of lubricants in applications involving multiple metals.

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

**4202870: Advancing Sustainability in MWFs with High Renewable Content Amino Alcohol Derivatives**

Richard Butler, Kathleen Havelka, Advancion, Buffalo Grove, IL

A novel fatty acid AMP alkanolamide emulsifier with high renewable content has been developed through the covalent coupling of a renewable fatty acid with an amino alcohol. This innovative amide broadens the formulation possibilities for water-dispersible fluids containing carboxylic acids and amino alcohols. Formulations incorporating both ionic and covalent coupling of these components exhibit exceptional heat removal and lubrication properties.

This presentation will systematically explore the use of a fatty acid AMP alkanolamide alongside conventional emulsifiers and other fatty acid alkanolamides. Structure-property relationships that highlight the advantages of an AMP alkanolamide and amino alcohols for creating high-performance, sustainable metalworking fluids are discussed. The unique multifunctionality of AMP alkanolamide, combined with amino alcohols creates new opportunities for optimizing next-generation metalworking fluids.

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

**10:40 - 11:00 am**

**4205066: Development and Performance Testing of Dicarboxylic Acid Replacements**

Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

MWF formulations need to be specifically designed for a given metalworking operation such as cutting, grinding, drawing, stamping, sawing, tapping, milling, drilling, and cleaning. Metalworking fluids formulations regularly requires the addition of a dicarboxylic acid additive that functions as a coupler, emulsifier, anti-corrosion inhibitor, and provides lubricity. Most importantly, this multi-functional additive must allow formulations to be ultimately stable for long durations and deliver suitable performance during the machining of metal specimens. Within this talk, a new series of a dicarboxylic acid replacement additives for the metalworking fluid industry has been evaluated and details around the analytical and performance testing results will be discussed.

**11:00 - 11:20 am**

**4200245: EP Additives with Enhanced Sustainability for Water-miscible Metalworking Fluids**

Salvatore Rea, Kevin DiNicola, John Williams, LANXESS Corporation, Naugatuck, CT; Wilhelm Rehbein, Isabell Lange, LANXESS Deutschland GmbH, Mannheim, Germany

Extreme pressure additives are an essential component for many water-borne metalworking fluids. They generate protective layers on metal surfaces in heavy duty cutting and forming processes. Compared to other types of EP additives, sulfur carriers can be used in a broad range of metalworking processes to reduce friction and prevent adhesive wear. They can be easily emulsified and are suitable components for soluble oils and semisynthetic metalworking fluids. Some sulfur carriers are even water-soluble and work as excellent EP additives for synthetic cutting and forming fluids.

Sulfur carriers are very low in toxicity, hydrolytically stable and non-corrosive to ferrous metals. Many sulfur carriers are based on renewable raw materials and can be used as components in eco-friendly formulations.

Based on tribological tests, the presentation demonstrates the possibility to increase the performance and sustainability of water-borne metalworking fluids by adding sulfur carriers as EP additives.

**11:20 - 11:40 am**

**4199298: Innovative Mineral Oil Free Water Based Synthetic Cutting Fluid With Improved Performance**

Simmi Datta, Ramababu Bolligarla, N Sivasurian, Kavita Rai, Subinoy Paul, A Arora, Mukul Maheshwari, Indian Oil Corporation Ltd., Delhi, India; M Dubey, IOCL R&D Center, Faridabad, Haryana, India

Water based synthetic cutting fluid is free of mineral oil, emulsifier, conventional EP & AW additives which provide excellent biostability but less lubricating property as compared to mineral oil containing emulsifiable oils. This paper describes the development of an innovative mineral oil free water based synthetic cutting fluid having improved tribological properties than conventional water based synthetic cutting oil. The product exhibits excellent biostability, corrosion inhibition and at par lubricity characteristics as compared to emulsifiable cutting fluids. The paper also describes the field performance of developed products in auto ancillary industries for ferrous machining ranging from mild steel, cast iron, hardened alloy steel, stainless steel.

## Rolling Element Bearings III

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**Session Chair:** Daulton Isaac, AFRI Turbine Engine Division, Wright Patterson Air Force Base, OH

**Session Vice Chair:** Ujjawal Arya, Purdue University, West Lafayette, IN

**8:00 - 8:40 am**

**4205539: Micropitting Damage in Lubricated Contacts**

Amir Kadiric, Pawel Rycerz, Mao Ueda, Benjamin Wainwright, Imperial College London, London, United Kingdom

Micropitting is a type of surface fatigue damage that occurs due to asperity stress fluctuations in lubricated contacts operating under thin film conditions. Despite its growing significance, the physical mechanisms behind micropitting are poorly understood. This paper presents results of several experimental and numerical studies into micropitting conducted over the past decade at Imperial College. A triple-disc contact fatigue rig is used to investigate the effects of roughness, slide-roll ratio, specific film thickness and contact pressure on micropitting. The effect of lubricant formulation is studied using a separate ball-on-disc set-up which allows for simultaneous observations of micropitting damage and tribofilm growth. Finally, an in-house numerical model for rough surface contacts is used to predict the onset and progression of micropitting by analysing the asperity stress history. The findings are discussed in relation to physical mechanisms responsible for micropitting.

**8:40 - 9:00 am**

**4173730: Identifying Facts from Failure in Forensic Bearing Investigations**

Thomas Russell, Exponent, Natick, MA

Although bearing failure modes are generally well-understood, the root cause diagnosis of a failed bearing in a forensic investigation is not always straightforward. Secondary damage caused after initial bearing failure, i.e., damage occurring from surrounding machinery or post-accident rescue/containment events, can and often does, obfuscate the root cause of failure. Incorrectly attributing bearing failure to a secondary damage mechanism can result in the implementation of ineffective solutions to prevent subsequent failures. This presentation will provide a general overview of best practices for conducting effective forensic bearing investigations in real-world applications and highlight common evidentiary features in failed bearings that are similar in appearance but different in cause.

**9:00 - 9:20 am**

**4185168: Metastudy of Deep Groove Ball Bearing and Cylindrical Roller Bearing Fatigue Testing Relative to Various Fatigue Life Models**

Jason Brady, Jonathan Adler, Mike Venier, SKF, Plymouth, MI; Jack Gayney, General Motors, Warren, MI

In automotive powertrain applications, fatigue testing is often specified during the design verification phase. This testing is often run under constant operating conditions unrepresentative of the actual application and consumes considerable resources and time. This study surveys historical fatigue testing and presents a statistical analysis of deep groove ball bearing (DGBB) and cylindrical roller bearing (CRB) performance against various predictive bearing fatigue life models to understand design margins and the value of continued fatigue testing in retiring risk to the application.

**9:20 - 9:40 am**

**4200695: Influence of Initial Kinematic Conditions on Bearings Subject to Shock Loads.**

Scott Hart, Rex Swindoll, Ryan Schaeffler, Schaeffler Group USA, Inc., Fort Mill, SC

This study summarizes the influence of a bearing's initial kinematic operating conditions on the likelihood that either surface damage or damaging cage stresses will occur when transient speed and load conditions of interest are applied. The rolling element bearing multibody simulation tool CABA 3D was used to model 4 different bearing types in various applications where the initial kinematic conditions resulted in high slippage. In each different bearing application, when traction forces in the contacts increased and the expected kinematic conditions were achieved, both surface-initiated damage and excessive cage stresses were predicted as observed in tested components. Actions to prevent both types of damage were assessed and compared with the original cases.

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

**4205695: Enhancing the Fatigue Life of Rolling Element Bearings by Using Layered Cylindrical Hollow Rollers**

Mitul Solanki, Dr. Vishwanath Karad MIT World Peace University, Pune, Maharashtra, India; Dipak Vakharia, S. V. National Institute of Technology, Surat, Gujarat, India

Fatigue life is a crucial factor in the selection of rolling element bearings. Hollow rollers were introduced to enhance fatigue life, but their thin cylindrical walls often led to catastrophic failures under moderate loads. To address this, the layered cylindrical hollow roller (LCHR) was developed. This paper presents a numerical investigation of the LCHR, which shows increased contact width, reduced Hertzian contact stress, and greater resistance to failure, promising higher fatigue life compared to solid and hollow rollers. Using the Ioannides-Harris (IH) theory, the fatigue life of LCHR was predicted, and finite element analysis in ANSYS revealed its superior performance under varying loads.

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

**10:40 - 11:00 am**

**4205098: Electromechanical Dimension Value Against Fluting**

Simon Graf, Oliver Koch, RPTU Kaiserslautern Landau, Kaiserslautern, Germany

Combined electrical and mechanical loads on highly loaded tribological contacts can cause characteristic damage. These include grey frosting, possible lubricant changes, and electrically induced fluting on the metallic contact bodies. This damage can occur in various machine elements such as roller bearings and gears. In this context, the article focusses on experimental investigations into factors influencing the formation of fluting. Furthermore, a hypothesis for the dimensioning of tribological contacts against the occurrence of fluting under electromechanical load is derived and presented.

This dimension value combines the electrical load applied to the contact with the lubricant film height. By applying this parameter over the time axis, curves can be derived for the analyzed influencing factors, which allow an approximation of the time of fluting formation.

**11:00 - 11:20 am**

**4205699: Rolling Contact Tribological Study of ATSP Vitrimers Coated Surfaces Under Varying Slide, Load, and Abrasive Conditions.**

Jack Sorrell, Andreas Polycarpou, The University of Tulsa, Tulsa, OK; Vasilis Tsigkis, ATSP Innovations, Inc., Houston, TX

Vitrimer tribopolymers in the ATSP family have shown low friction and wear under sliding and abrasive conditions. Yet, there is little information on the rolling performance of these materials. The goal of this work is to better understand the performance regime of ATSP vitrimer coatings in mixed rolling and sliding contact. Potential applications of these coatings include lunar conditions; thus, we aim to determine the coatings abrasive tolerance with respect to the standard performance regime. Our results show no measurable wear for lower loading conditions regardless of slide ratio, and minimal wear at higher loads when in favorable sliding conditions. The addition of lunar dust simulant increases wear and friction for all testing conditions but does not significantly disturb the surface at lower loads. This study shows the use and viability of roller bearings using dry vitrimer lubricants and their ability to extend the lifespan of bearings in harsh environments.

**11:20 - 11:40 am**

**4203089: Improved Tribological Performance of Ball Bearings with 3D Printed Cage Designs**

Rahul Dahiwal, Christoph Bayer, Thomas Kreis, Gebr. Reinfurt GmbH & Co. KG, Rimpar, Bavaria, Germany

The cage not only separates the rolling elements but also acts as a lubricant reservoir and guides the elements through no-load zones, playing a critical role in the overall bearing dynamics. An optimized cage design can significantly reduce friction, wear, and heat generation, thereby improving tribological performance.

This study investigates and proposes an optimized geometric cage design specifically for miniature ball bearings to improve tribological characteristics and ensure better running stability to minimize vibrations. Traditional manufacturing methods struggle to produce complex cage geometries, so additive manufacturing (3D printing) was employed.

A series of performance tests, including start-up and dynamic friction torque and noise tests, were performed on various cage designs. Based on the dynamic simulations, the influence of geometric, material and dimensional parameters on the overall bearing performance was investigated.

**11:40 - 12:00 pm**

**4283043: Influence of Steel on RCF Life of Bearings under Current Flow**

Monica Ratoi, Grigore Cernalevschi, Brian Mellor, University of Southampton, Southampton, United Kingdom; Yuxue Cai, ESSO Deutschland GmbH, Hamburg, Germany

Steel particularities such as elemental composition, inclusions, hardness etc. along with lubricant formulation have been universally acknowledged as being the most influential factors controlling the RCF life and wear mechanisms of bearings. Bearings employed in applications subjected to current flow undergo a complex array of wear mechanisms and the steel makeup can play an important role. This study ran MPR tests with rollers made of AISI52100 bearing steel from two suppliers. The rollers were lubricated with a gear oil in the boundary regime and were neutral (absence of electrical fields) or positively (anodic) / negatively (cathode) polarized using an electrical setup. The relationship between the roller polarization, steel makeup and lubricant tribofilm formation provide critical insights into the wear mechanisms and RCF life of bearings

## Sustainability in Motion II

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**Session Chair:** Shubhamita Basu, Perstorp Polyols, Inc., Toledo, OH

**8:00 - 8:40 am -**

**4246564: Sustainability Regulations: A New Operational Framework**

Vasileios Bakolas, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany

A significant number of new regulations regarding sustainability in general have been introduced during the last years. These regulations affect the way companies and organizations operate, the data that they are reporting and also the way they are communicating among themselves and with their customers. These regulations pose a variety of new challenges but also provide the opportunity of innovation. In this talk, an overview of the major sustainability-related regulations will be presented along and the implications that they have on everyday operations will be discussed.

**8:40 - 9:20 am - Invited Talk 2**

**9:20 - 10:00 am - Invited Talk 3**

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

**10:40 am - 12:00 pm - Moderated Panel Discussion**

## Materials Tribology III

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**Session Chair:** Kylie Van Meter, Sandia National Laboratories, Albuquerque, NM

**Session Vice Chair:** Craig Barbour, Florida Agricultural and Mechanical University, FL

**8:00 - 8:40 am**

**4201954: Toward Sustainable and Hydrogen Compatible Sealing Materials**

Geraldine Theiler, Natalia Cano Murillo, BAM, Berlin, Germany; Yoshinori Sawae, Hironori Shinmori, Kyushu University, Fukuoka, Japan; Hikaru Hashimoto, Ayako Aoyagi, NOK Corporation, Fujisawa, Japan; Emiel Dobbelaar, Freudenberg Technology Innovation SE & Co. KG, Material Technologies, Weinheim, Germany

As sealing components, polymeric materials are used in a wide range of applications e.g., as O-rings and piston rings in high-pressure and/or cryogenic hydrogen. For these extremely demanding application, PTFE or PPS based materials are often used as high-performance polymer matrix. This project aims to provide a safe and sustainable sealing solutions for hydrogen applications. New materials with improved sustainability were investigated and compared with conventional grades. Tests were performed in hydrogen over a wide range of temperature and pressure (0.1 MPa to 40 MPa, and 100°C down to -150°C) at Kyushu University and BAM using a pin-on-disk apparatus in a continuous sliding motion. Polymer samples ran against 316L disk at 0.5 m/s and 3 MPa contact pressure. Based on the tribological results and surface analyses, promising candidates are



suggested along with friction mechanisms in both high-pressure and low temperature hydrogen.

**8:40 - 9:00 am**

**4199846: Impact of Temperature on the Tribological Behavior of DLC Coatings in Hydrogen-Containing Atmosphere**

David Zeradjanin, Tina Hirte, Robert Bosch GmbH, Stuttgart, Germany; Thorsten Staedler, Xin Jiang, University of Siegen, Siegen, Germany

Hydrogen-containing atmospheres have a positive influence on friction and wear during tribological load on hydrogen-containing, amorphous carbon coating (a-C:H). A specially converted oscillating wear test rig is operated with a gas mixture consisting of 5% hydrogen and 95% nitrogen, to use a gas that is not classified as flammable. During the tribological tests, the coated body is tempered to temperatures between 300 K and 420 K, while the gas is passed over the contact at 300 K. The *cof* decreases with increasing temperature while neither the distance that the upper body covers until a stable low *cof* is reached nor the wear volume is changed by the temperature variation. However, an influence on covered distance till run-in and wear is shown by changing the sliding frequency, whereas the *cof* after run-in remains unchanged regardless of the frequency. In addition, it is observed that the wear mainly occurs during run-in-phase.

**9:00 - 9:20 am**

**4203937: Hydrogen Embrittlement on Microstructural, Tribological, and Mechanical Behavior of Refractory Alloys**

Catherine Fidd, Craig Barbour, Sam Mao, William Oates, Fumitake Kametani, Brandon Krick, Florida State University, Tallahassee, FL; Yan Xin, National High Magnetic Field Laboratory, Tallahassee, FL; Kari Johnson, Florida International University, Miami, FL; Prashant Singh, Duane Johnson, Gaoyuan Ouyang, Hailong Huang, Rameshwari Naorem, Nicolas Argibay, AMES Lab, Ames, IA

As hydrogen becomes an increasingly viable clean energy source, questions arise on the longevity of the mechanical components required to produce and use it. Hydrogen diffusing into a material microstructure can detrimentally affect mechanical properties such as reduction in ductility, increased susceptibility to cracking, and increases in friction and wear. Refractory alloys have been investigated as structural alloys in applications with hydrogen exposure due to their ability to absorb hydrogen with minimal loss in mechanical properties. This project examines hydride formation, in refractory metal alloys using XRD corroborating with diffraction patterns to analyze changes in the crystal structure after hydrogen aging. TEM is also used to visualize the effects of hydride penetration in the alloy microstructure on the nanoscale. Paired with mechanical testing, such as scratch testing, we examine the mechanism of hydrogen aging on the micro and nanostructure of refractory metal alloys.

**9:20 - 9:40 am**

**4204518: Tribo-Film Formation at Polymer/metal Sliding Interface in Hydrogen - Effects of Gas Pressure and Temperature -**

Yoshinori Sawae, Hironori Shinmori, Qian Chen, Wenxiao Li, Kyushu University, Fukuoka, Japan; Geraldine Theiler, Natalia Cano Murillo, BAM, Berlin, Germany; Hikaru Hashimoto, Ayako Aoyagi, NOK Corporation, Fujisawa, Kanagawa, Japan; Emiel Dobbelaar, Freudenberg Technology Innovation SE & Co. KG, Weinheim, Germany

The energy density of gaseous hydrogen is so small that it should be compressed or cooled to increase the volumetric density in case it can be used as a fuel in the transportation sector. Therefore, tribological elements comprising the hydrogen supply network should be able to operate properly over a wide range of gas pressure and gas temperature. Polymer composites are used as piston rings and rod packings in the oil-free reciprocating hydrogen gas compressor and sliding against the metal cylinder in hydrogen gas environment during the compressor operation. In this

study, sliding tests of polymer composites/316L stainless steel were performed in hydrogen over a wide range of temperature (-150 °C to 100 °C) and pressure (0.1 MPa to 40 MPa) at Kyushu University and BAM. Dedicated surface analyses were conducted to explore the effects of high-pressure and low temperature hydrogen on the tribo-film formation at the sliding interface and the subsequent wear mechanism of polymer composites.

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

**4204745: Friction and Wear of High-Temperature Hydrogen-Aged DLC**

Santiago Lazarte, Thomas Lockhart, Brandon Krick, Florida State University, Tallahassee, FL; Tomas Babuska, Kylie Van Meter, John Curry, Steven Larson, Alexander Mings, Sandia National Laboratories, Albuquerque, NM; Matthew Besser, Trevor Riedemann, Nicolas Argibay, AMES National Laboratory, Ames, IA

Diamond-like carbon (DLC) coatings are often used for their low-friction and low-wear properties for automotive engine components or high-pressure mechanical seals. With the current interest in hydrogen as a cleaner energy source, the need for structural materials and coatings that can perform in extreme environments is rapidly increasing, including high hydrogen concentrations at high (>1000°C) and low (cryogenic) temperatures. This work explores the effect of variable temperature hydrogen aging on the properties of DLC coatings. Tribological properties and microstructures were characterized before and after 1 atm H<sub>2</sub> aging at 300°C, 500°C, and 700°C. This resulted in a significant difference in the early-stage (run-in) friction behavior and wear rate. Samples aged at 500°C showed a decrease in cycles needed to reach steady-state behavior and a wear rate of  $8 \times 10^{-8}$  mm<sup>3</sup>/(N·m). Additional aging conditions were used to explore microstructure and properties evolution in DLC coatings.

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

**10:40 - 11:00 am**

**4205403: Promising Prospect of MBene as a Solid Lubricant Showcasing Superlubricity**

Sai Varun Sunkara, Subramanian Sankaranarayanan, University of Illinois Chicago, Chicago, IL; Shiba Adhikari, Zachary David Hood, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Transition metal carbides and nitrides, called MXenes, have been widely studied due to their 2D structures and exceptional physical and chemical properties. In this work, we explored MBene (Mo<sub>2</sub>B<sub>2</sub>) as a solid lubricant spray-coated onto a stainless-steel substrate and studied its tribological properties using ball on disk experimental setup in ambient air and dry nitrogen environment with different counterface balls such as stainless steel and diamond-like-carbon (DLC) coated stainless steel. The lubricant has shown excellent lubricious behavior with DLC coated steel tribo-pair in nitrogen with coefficients of friction reaching superlubricity in some cases and wear rates as low as in the magnitude of  $10^{-9}$  mm<sup>3</sup>/(N·m). This is an interesting behavior unlike other MXene (such as Ti<sub>3</sub>C<sub>2</sub>T<sub>x</sub>) where they degrade even in dry nitrogen environment unless coupled with other 2D materials. More studies are in progress to understand the exact mechanism of lower friction and wear.

**11:00 - 11:20 am**

**4216116: Water-Induced Entropy Reduction and Its Impact on Friction and Hardness of Alumina Borate Solid Lubricant**

Sung-Yup Kim, Eunja Kim, University of Texas at El Paso, El Paso, TX

This study investigates the intricate interplay of chemical reactions, mechanical dynamics, and material properties in friction simulations, focusing on Alumina borate as a solid lubricant. Contrary to conventional expectations, our findings reveal that specific combinations of temperature and velocity lead to unexpected increases in the coefficient of friction (COF),

influenced by the elemental distribution in the lubricant's surface layer. While Alumina borate generally maintains its structure across various conditions, certain thermal and mechanical environments cause deviations that negatively affect COF and hardness. Notably, the introduction of water molecules to the lubricant surface improves both COF and hardness, a result linked to the reduction of system entropy through water-lubricant interactions. This mechanism, which counters the typical trade-off between friction and hardness, introduces two saturation points where optimal performance for each property is observed.

**11:20 - 11:40 am**

**4201938: Enhancing the Efficiency of Biomass Preprocessing of Shredders by Utilizing Wear-Resistant Tool Materials**

Tomas Grejtak, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; Miranda Kuns, Jeffrey Lacey, Idaho National Laboratory, Idaho Falls, ID; Oyelayo Ajayi, George Fenske, Argonne National Laboratory, Lemont, IL; Peter Blau, Blau Tribology Consulting, Enka, NC

Shredders are commonly used to process biomass and municipal solid waste into the desired particle sizes. The size reduction is achieved through the tearing action between the cutter teeth, which can be prone to wear and damage due to contaminants in the feedstock. This study investigates the performance of a small-scale shredder by utilizing more wear-resistant cutter materials. A series of shredder tests were conducted for size reduction of a high-ash corn stover feedstock using cutters fabricated from D2 tool steel (baseline), M42 tool steel, and iron-borided-D2 steel. The cutter performance was evaluated based on the measured wear rate, feedstock throughput and power consumption. Worn surface characterization of the cutters was conducted to identify the dominant wear mode(s) for each tool material. The experimental results were used as input for a techno-economic analysis to estimate the economic benefits of the shredder operation with using the more wear-resistant materials.

**11:40 am - 12:00 pm**

**4171792: On the Friction and Wear Aspects of Fabric Pilling**

Kenneth Budinski, Bud Labs, Rochester, NY

Pilling is the formation of macroscopic protuberances composed of tangled fibers of varying size and density on the surface of fabrics. Pilling is caused by the fabric rubbing against itself or a foreign surface and friction and wear are important factors in different stages of pilling, fuzz entanglement, pills that the pilling tendency of fabrics.

The purpose of this study was to understand the correlation between the static friction and wear behavior of fabrics with their pilling tendencies. ASTM G219 inclined plane friction tests were conducted, under selfmated conditions as well as against various counterfaces to determine if the static coefficient of fabrics correlates with their pilling tendencies. Oscillating wear tests after ASTM D4157 were performed on test fabrics with a silicon rubber counterface. It was concluded that breakaway friction is not a good predictor of pilling tendencies but an oscillating wear test was successful in identifying pilling tendencies in fabrics.

3H

Regency VI

**Aerospace I**

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**Session Chair:** Wai Mak, University of California, Los Angeles (UCLA), Inglewood, CA

**Session Vice Chair:** Piali Das, Iowa State University, Ames, IA

**8:00 - 8:40 am**

**4200763: Thin Film Coatings for Aerospace Applications**

Peter Schmidt, United Protective Technologies, Locust, NC

Thin film coatings have evolved significantly since their introduction. Modern nanocomposite coatings can significantly reduce surface wear when employed with low-viscosity lubricants. Some thin films can be formulated to achieve coefficients of friction as low as 0.05. This work provides an overview of current capabilities and recent developments targeted at aerospace applications, such as gears, bearings, and valve mechanisms. Tribological test results are presented, along with case studies of potential interest to designers.

**8:40 - 9:00 am**

**4205496: Investigation of MoS<sub>2</sub>-Coated NITINOL60 In Low-Temperature Dry Environments**

Adam DeLong, FAMU-FSU College of Engineering, Tallahassee, FL; Tomas Babuska, John Curry, Steven Larson, Sandia National Laboratories, Albuquerque, NM; Christopher DellaCorte, University of Akron, Akron, OH; William Scott, Marshall Space Flight Center, Huntsville, AL; Catherine Fidd, Thomas Lockhart, Brandon Krick, Florida State University, Tallahassee, FL

60NiTi is a pseudo-shape memory alloy with excellent corrosion resistance, high strain to failure, and a hardness of 60HRC (~8GPa). These properties give 60NiTi the potential to be used in triboelements for space environments. MoS<sub>2</sub> has low vapor pressure, low operating temperatures, and long life making it an ideal space lubricant. MoS<sub>2</sub>-coated 60NiTi has shown comparable tribological properties to MoS<sub>2</sub>-coated 440C in a dry nitrogen environment at room temperature but has not been investigated at temperatures below 0°C. The tribological performance of MoS<sub>2</sub>-coated 60NiTi at temperatures below 0°C is investigated to continue previous efforts to characterize lubrication methods for 60NiTi. In the same deposition run, 60NiTi and 440C stainless steel substrates were coated in pure MoS<sub>2</sub> on top of Ti adhesion layers with magnetron-sputtering to produce comparable coatings. Friction and wear experiments were conducted in a temperature-controlled tribometer, and measured results are reported.

**9:00 - 9:20 am**

**4203680: Novel Application Method of Burnished MoS<sub>2</sub> Coatings for Springs in Solar Arrays Release Mechanisms and Testing Campaign.**

David Kostal, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czechia

Application of burnished films on the frictional surfaces is usually done by hand work. This work consists of mechanical shearing of the MoS<sub>2</sub> powder against the surface of the part thus creating rather thick film. However, this method has low productivity and repeatability. Novel highly productive approach with high energy vibration deposition was used and tested on coil springs used in deployment mechanisms for solar panel arrays. Newly created coatings were thoroughly tested on the vacuum pin-on-plate tribometer in wide range of temperatures to ensure its performance and inspected with SEM to check MoS<sub>2</sub> flakes distribution. Also entire coated component was tested to ensure safety of the procedure for its reliability.

**9:20 - 9:40 am**

**4202813: Low-Temperature Mechanism of MoS<sub>2</sub> Dry Film Lubricants**

Abrar Faiyad, Daniel Miliate, Samuel Leventini, Ashlie Martini, University of California, Merced, Merced, CA; Duval Johnson, Jet Propulsion Laboratory, Pasadena, CA

MoS<sub>2</sub> is the most widely used dry film lubricant in space applications due to its resilience in extreme environments. However, its performance is highly temperature-dependent, with significant degradation in cold temperatures. In this study, we integrate tribometer experiments, surface characterization techniques, and reactive molecular dynamics simulations to explore the

mechanisms driving MoS<sub>2</sub> performance deterioration at low temperatures. Our results confirm the lubricant's degraded performance in cold temperatures. Utilizing microscopy techniques reinforced by simulations we provide key insights into the mechanisms responsible for the DFL's degraded tribo-properties in cold.

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

**4205099: Effect of Substrate and Environment on Solid Lubricant Performance**

Andrew Clough, Wai Mak, The Aerospace Corporation, El Segundo, CA

The space environment poses unique challenges to the effective lubrication of mechanical systems. Extreme temperatures can render liquid lubricants ineffective, dramatically shortening the operational lifetime of mechanisms. In this work we explore the impacts of temperature and material selection on lubricant performance. Novel lubrication strategies were evaluated using pin-on-disk vacuum tribometer testing. The results inform considerations for the robust lubrication of moving mechanical assemblies in space.

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

**10:40 - 11:00 am**

**4205508: Development of a High-Vacuum Pin-on-Disk Test Instrument for Aerospace Applications**

Juan Bosch Giner, Hannah Liggett, Leon Burky, Christopher DellaCorte, University of Akron, Akron, OH

We present an in-house developed vacuum pin-on-disk test instrument for aerospace applications, adaptable to multiple configurations such as pin-on-disk and ball bearings. The chamber offers easy access via a removable top plate, with a high-capacity pumping system achieving rapid pump-down in ~1 hour. The design targets operations up to 600°C, vacuum levels in the mid-10<sup>-8</sup> torr range, and sliding speeds of 3450 rpm (up to 54 m/s with 12-inch disks). Future upgrades include a cryogenic stage and a low-speed, high-torque, unidirectional/oscillatory drive. The instrument measures coefficient of friction and temperature under varied conditions (e.g., load, speed, temperature, purge gases). To date, it has achieved 10<sup>-7</sup> torr, 5 m/s speed, and ambient operation. Initial tests with space-compatible greases and solid lubricants like MoS<sub>2</sub> and Ag show stable, repeatable results, demonstrating the system's potential to enhance lubricated contacts in space applications.

**11:00 am - 11:20 am**

**4205306: Friction and Wear Life of Aerospace Dry Film Lubricants in Point and Line Contacts**

Samuel Leventini, Michelle Padilla, Abrar Faiyad, Daniel Miliute, Ashlie Martini, University of California Merced, Merced, CA

Dry film lubricants (DFLs) are frequently selected for aerospace tribological applications where conventional lubricants, such as grease and oil, aren't ideal to use under extreme conditions. To quantify and understand friction coefficient and wear behaviors, researchers have made numerous comparisons between DFLs through ball-on-disc benchmark testing. However, those tests may not reflect every contact that occurs during the operation of machinery in aerospace. In this study, we complemented ball-on-disc testing with block-on-ring configuration to test the tribological properties of DFLs that are being considered for aerospace use. After testing, results were analyzed in the context of various theories that have been proposed in the literature.

**11:20 - 11:40 am**

**4205346: Impact of Substrate Adhesion on MoS<sub>2</sub> Lubrication**

Wai Mak, Andrew Clough, The Aerospace Corporation, El Segundo, CA

In the lubrication of moving mechanical assemblies for space, dry film lubricants and coatings act as alternatives to liquid lubricants when temperature extremes preclude effective lubrication by oils. Although solid lubricants have been used in space systems since the 1950s, there has been limited research on how solid lubricants' adhesive properties affect tribological performance of the contacting surfaces for relevant space mechanisms. In this study, we examine the interfacial properties that affect solid lubricant performance by examining solid lubricants that have applicability to space applications. Friction and mechanical properties of materials were tested in vacuum at varying temperatures utilizing pin-on-disk and scratch testing methodology. The results will inform future materials selection and designs of moving mechanical assemblies for space applications.

**11:40 am - 12:00 pm**

**4205326: Wear Liner Composites for Aerospace Wear and Friction Applications**

Hau-Nan Lee, Lucas Amspacher, Justine Paul, Natalie Kadlubowski, Timothy Harper, Richard Fiedler, DuPont, Wilmington, DE

Wear liners are self-lubricating materials used in a wide range of aerospace applications. These liners reduce friction in components like fan blades and thrust reversers, effectively eliminating metal-to-metal contact wear and increasing component lifespan. To lower the friction, traditional wear liners often utilize PTFE which is continually coming under regulatory pressure. This presentation introduces a new safe-and-sustainable-by-design wear liner developed by DuPont™ Vespel®, which does not use PTFE as an ingredient. A proprietary solid lubricant added to a polymer matrix provides the critical wear and friction performance. Our tribological evaluations, conducted under pin-on-plate configuration, demonstrate that the new material achieves equivalent or improved performance compared to existing PTFE-containing options. By advancing wear liner technology, we are addressing regulatory challenges while promoting component longevity and safety in critical aerospace applications.

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Regency VII

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**Electric Vehicles III**

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**Session Chair:** TBD

**Session Vice Chair:** TBD

**8:00 am - 8:40 am**

**4205093: All-In-One e-Fluid Technology to Cool Inverter, e-Motor and Provide EV Gear Lubrication**

Michael Gahagan, Lubrizol, Derby, Derbyshire, United Kingdom

An e-fluid technology is described as handling high-power density electrical drivetrains that effectively protects and cools inverters, e-motor, and gearbox system. This means a combination of advanced hardware cooling approaches and an advanced fluid to prevent overheating. The benefit in this approach compared with the use of multiple coolants requiring different cooling & lubrication circuits with associated equipment is that it is more conducive towards high power densities. This summarizes consortium work by FlandersMake, Dana, Diabatix and Lubrizol and we present a thermal-hydraulic model and assembly of an electrical drivetrain which is cooled by a

single oil cooling & lubrication circuit using modelling environments and physical testing in actual hardware. These models were verified and the thermal response of the electrical drivetrains under varying load conditions and using different cooling approaches was investigated with the e-fluid.

**8:40 - 9:00 am**

**4200888: Dedicated e-Fluids for Improving Energy Efficiency**

Hitesh Thaker, Anusha Srinivas, Infineum USA L.P., Linden, NJ; Shaochi Ma, Infineum International Ltd., Shanghai, China

As part of their commitment to reducing CO<sub>2</sub> emissions, many OEMs are increasingly incorporating higher levels of electrification in vehicle designs, focusing on more compact and higher voltage systems. Additionally, they are transitioning to lower viscosity fluids to enhance electrified powertrain efficiency while ensuring hardware protection. This shift has driven the development of a new generation of e-fluids that deliver both efficiency gains and durability, along with material compatibility. Comprehensive electric drive unit efficiency testing, which combines drive cycle analysis with full operation range mapping (steady state testing), provides deeper insights into the impact of lubricants compared to standardized test procedures like WLTP. This paper discusses the highlights and the significant roles that both base oils and additives play in achieving optimal performance.

**9:00 - 9:20 am**

**4203235: Creating EV Fluids for Extending Driving Range.**

Jason Carter, SK Enmove, Clarkston, MI; Eunjin Jeong, SK Innovation, Daejeon, Republic of Korea

Every electric vehicle system on the market has its own unique set of demands. Driving range is a key performance indicator for any EV vehicle. We will demonstrate how custom EV additives and baseoil combinations can lead to overall vehicle performance and improve driving range. Data and example fluids from in-house blending and testing of mock finished EV fluids will be provided.

**9:20 - 9:40 am**

**4188548: Efficiency Measurements of Fluids for E Axle Application**

Torsten Murr, Shell Global Solutions Deutschland, Hamburg, Hamburg, Germany

With the automotive world looking now already into the 2nd & 3rd generation of E Fluids, lubricant manufacturers are designing fluids that can best protect highly integrated electric powertrains with a clear target to further help to improve the efficiency to support extended ranges of BEV s. Low viscosity solutions are not always been the only solutions. The new fluid solutions need to provide lower CO<sub>2</sub> intensive products to decarbonize the lubricant formulation. In order to balance the technical properties and requirements with available and more sustainable components and base oils, Shell has generated studies to assess key aspects of those next generation formulations for transmission fluids. The study aims to generate and assess data for understanding performance aspects like efficiency and the potential to formulate low viscous fluid solutions, oxidation stability, material compatibility and CO<sub>2</sub> footprint.

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

**4204268: Eco-Design and Validation of EV fluids**

Flavio Sarti, TotalEnergies, Solaize, France

In alignment with the European Union's Fit for 55 initiatives and the transition to electric mobility, the eco-friendly design of lubricants can significantly reduce emissions. This work addresses CO<sub>2</sub> reduction across multiple levels: from the careful selection of additives and base oil components to the energy mix of manufacturing plants, the control of friction and mechanical losses in electric vehicles (EVs), and the potential downsizing of battery packs. This research demonstrates a

practical case where a completely eco-designed fluid has been tested and validated through tribological, drive units durability, and EV fleet tests.

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

**10:40 - 11:00 am - Open Slot**

**11:00 am - 11:20 am**

**4190253: High Speed Aeration Test Development and Findings for e-Fluids**

Masahiro Ishikawa, Infineum USA, Linden, NJ

In automotive electrification, motors and gear boxes operate at extremely high speeds, as compared to ICE for which the foaming test methods ASTM D892 and D6082 had been previously developed. At higher speeds of >20,000 rpm, aeration increases and a lubricant's ability to release air becomes even more critical for proper lubrication. The need for high-speed aeration performance is compounded further when formulating low viscosity e-fluids for greater efficiency. Infineum have developed the High-Speed Aeration Test (HSAT), using a homogenizing aggregator that generates extremely high speeds under shear (up to 27,000 rpm). A correlation study between the HSAT and ASTM D892 and D6082, standard foaming tests, show no sign of correlation. HSAT has properly differentiated e-fluid viscosity while ASTM tests D892 and D6082 could not. This paper addresses the further findings from HSAT studies such as mineral vs synthetic base oil, additive effects, thermal aging effects, and others.

**11:20 - 11:40 am**

**4203368: Copper Corrosion Inhibition in e-Transmission Fluids – A Mechanistic Insight**

Loan Vo, Dairene Uy, Oluwaseyi Ogunsola, Sarah Matthews, Shell Global Solutions (US) Inc., Houston, TX

Copper corrosion is a critical concern for e-transmission fluids, as exposure of the copper windings of e-motor to fluids can compromise vehicle reliability and safety. Laboratory tests frequently show that fluids with sulfur-containing additives tend to exhibit poorer performance with respect to copper corrosion but the mechanism of corrosion has not been well established. It was hypothesized that the corrosive molecules such as hydrogen sulfide, a potential degradation product of sulfur-containing additives, may contribute to this corrosion issue. This paper presents a test method developed to detect degraded gaseous byproducts in lubricants, aimed at better understanding the underlying corrosion mechanisms. The test method has been correlated with other standard copper corrosion test methods. Additionally, solid analysis on corroded deposits provides further evidence and insights into the species that may contribute to copper corrosion in electric vehicles.

**11:40 am - 12:00 pm**

**4200367: Low Aeration/Traction Lubricant Solutions for High-Speed Electric Drivetrain**

Philip Ma, Donna Mosher, Chad Steele, BASF, Florham Park, NJ

The advancement of electric drivetrains has intensified the need for specialized lubricants that optimize performance while ensuring efficiency and longevity. This study investigates the formulation of low high-speed-aeration, low traction lubricants tailored for electric drivetrain systems. These innovative fluids are designed to minimize air entrainment while reducing frictional losses, which is critical for maximizing energy efficiency and ensuring smooth operation. Our experimental results reveal that low high-speed-aeration, low traction lubricants significantly improve heat management, and efficiency, leading to enhanced performance of electric drivetrain. This research underscores the potential of low high-speed-aeration, low traction lubricants as a



## Rheology I

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**Session Chair:** TBD

**Session Vice Chair:** TBD

**8:00 - 8:40 am**

**4200674: Rheology Can Help Tribology**

Laurent Rougeau, Mikaël Petit, INS, Genay, France

Rheology, in the service of tribology, can help understand phenomena or to discriminate lubricants for specific applications. Two examples will be discussed, one for space applications, the other for automotive. The need for new lubricants for space assemblies led two years ago to the synthesis of 2 new lubricants (gelled oils) with very similar behavior in ball bearings. The use of rheological analysis made it possible to choose the most suitable solution in terms of cold (until  $-150^{\circ}\text{C}$ ) and hot ( $150^{\circ}\text{C}$ ) conditions and long-term behavior. For automotive, cold start conditions can be strongly linked to the quality of the engine oil, particularly when soot begins to accumulate (before changing the oil). Rheology helped to understand the low shear thickening effect (related to engine start-up) and to evaluate dispersants efficiency (reduction of this thickening effect) leading to a more effective engine oil. Various test assemblies (including rheo-tribology) and protocols will be discussed.

**8:40 am - 9:00 am**

**4205745: Rheological Test Methods for Driveline and EV Fluids**

Carlos Sanchez, Southwest Regional Research Institute, San Antonio, TX

Lubricants in electric vehicles tend to behave differently in the presence of an electric field. There are many rheological test methods used for engine and drivetrain applications that are relevant to EV systems. Rheology can be used to evaluate all lubricants for visco-elastic behavior, loss modulus, and viscosity, and to name a few. Previous studies at SwRI have demonstrated that an electric field affects the viscosity of new and used driveline fluids in different ways. Using a similar approach, other lubricant properties were investigated while subjected to an electric field. This work will discuss different rheological test methods used for evaluating greases and driveline fluids.

**9:00 - 9:20 am**

**4206132: Extracting Temporary Shear Thinning Curve of Lubricant from MTM Traction Test Data**

Pinzhi Liu, Silabrata Pahari, Jie Lu, Weixue Tian, ExxonMobil Technology and Engineering Company, Annandale, NJ

Fluid temporary shear thinning at the contact zone of non-conformal contact contributes to the measured traction coefficient. Traction coefficient can be calculated with computational EHL knowing the high-pressure viscosity relationship and the shear thinning characterization of the lubricant. However, direct measurement of high-pressure shear-dependent viscosity is challenging, especially for pressures higher than 1 GPa, which are highly relevant in actual applications. In this paper, we'll use PAO4 as an example to back-calculate the shear thinning curve from MTM traction test data. We'll assess and compare the applicability of Carreau and Eyring stress shear thinning models, which are two commonly used models for temporary shear thinning. The acquired high-

pressure shear curve can then be used as input for modeling of other non-conformal contact applications and geometries.

**9:20 - 9:40 am**

**4203405: Automated Measurement of Mid-Shear Viscosity in Full Shear Curve Mapping Using the Tapered Bearing Simulator (TBS)**

Loan Vo, Tianshi Fang, Oluwaseyi Ogunsola, Shell Global Solutions, Houston, TX

Understanding rheological characteristics of a fluid is essential for fluid development, especially for optimizing lubrication performance and fuel efficiency. The impact of temperature and shear rate on fluid viscosities requires multiple viscometers to capture the complete shear profile, ranging from  $10$  to  $10^7 \text{ s}^{-1}$ . Mapping of viscosity across this broad range of shear rates is essential to characterize the viscosity changes across multiple operating conditions and explore how the resulting profile can influence energy efficiency. The mid-shear rate range of  $10^4$  to  $10^6 \text{ s}^{-1}$  is particularly important, as it is where fluids often exhibit the most significant viscosity changes. In this study, a method using TBS was developed to measure viscosities of fluids over this critical mid-shear rate range. The data collected was incorporated into a full shear viscosity curve, providing valuable insights on the influence of temperature, shear rate, and chemical compositions on fluid viscosity.

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

**4192489: Tribological and Rheological Insights into the Lubrication Potential of Eco-Friendly Thixotropic Silica Gels**

Arun Kumar, Vivek Kumar, Yogesh Joshi, Manjesh Singh, Indian Institute of Technology, Kanpur, India,

Toxicity from conventional oil and grease lubricants can be mitigated by introducing water-based lubricants with improved rheological properties. We present a thixotropic colloidal gel of silica nanoparticles formed in the presence of NaCl. Our experiments demonstrate that the tribological performance of the formulated gel can be optimized by tuning its rheological properties. We achieved an optimal combination of super-low friction and negligible wear using a thixotropic and chemically robust gel formed through van der Waals interaction between the flocs which provides self-repairing properties and continuous tribo-film formation. These attributes enable the gel to maintain and regain its structure during periods of inactivity, while also forming a thin film with sufficiently low viscosity to slip into the interfacial contact zone and continuously replenish it with lubricant.

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

**10:40 - 11:00 am**

**4177179: Low Temperature Mechanical Properties of Lubricating Greases Using Rheology and Comparison to Current Industrial Techniques**

Jacob Bonta, Valvoline Global Operations, Lexington, KY

In this study the low temperature mechanical properties of greases is evaluated using a parallel plate rheometer with an environmental testing chamber (ETC) and compared to current industrial techniques. Lubricating greases (LGs) are found in nearly all mechanical devices and are employed in diverse environmental conditions. Understanding the mechanical properties of these materials under low temperature usage is vital to their design and current techniques suffer poor repeatability. Here LGs of varied thickener and base oil chemistries are considered. First, small amplitude oscillatory (SAOS) testing under low strain is used to monitor the evolution of the viscoelastic moduli during a temperature sweep from  $25^\circ\text{C}$  to  $-40^\circ\text{C}$ . Next, the apparent viscosity and yield behavior is determined in a 1-minute flow test at varied temperature. Finally, each LG is

examined using the traditional ASTM D1748 and DIN 51805 methods to compare measured behaviors.

**11:00 - 11:20 am**

**4205648: Rheology as a Tool for In-Service Grease Analysis and Compatibility Testing**

Richard Janosky, Dylan Kletzing, Richard Wurzbach, MRG Labs, York, PA

Rheology has broad applicability to the field of grease analysis. Though it has seen notable historical use and research, growth of the technology within the grease analysis field has been hampered by the lack of a standardized methodology. Currently, a published ASTM method, utilizing a stress rheometer, is imminent. The potential impact of this method is vast, with specific applicability in areas such as new grease quality control testing and grease compatibility testing. While publication of this method serves as a significant milestone for grease analysis, it is imperative that concerns for in-service grease analysis also be addressed. This research will aim to evaluate the applicability of the imminent ASTM method for compatibility testing, and for in-service grease analysis, and compare with those that have been historically used for this testing, laying out specific concerns for in-service samples.

**11:20 - 11:40 am**

**4205659: Establishing Grease Rheology Testing Triggers From Screened In-Service Grease Analysis**

Dylan Kletzing, Richard Janosky, Richard Wurzbach, MRG Labs, York, PA

Screening In-service grease analysis is an often overlooked and underutilized tool to maintain an important asset, the grease. Grease screening is performed by a lab to identify outlier samples for full analysis and onsite as a QC check. Currently grease consistency could use a way to correlate in-service evaluation with advanced testing. Die extrusion testing will be evaluated for correlation with rheology testing to develop the method to identify samples that should be tested via rheology if possible.

**11:40 am - 12:00 pm**

**4283048: The Story of Asphalt – From Rheology to Tribology**

Kartik Pondicherry, Paul Staudinger, Julius Heinrich, Anton Paar GmbH, Graz, Austria; Runhua Zhang, University of Wisconsin, Madison, WI

Asphalt is a mixture of bitumen and aggregate materials such as gravel or crushed stone, and more than 90% of the roads in the world are paved using asphalt mixtures. While rheological characteristics of bitumen play an important role in the performance and lifetime of the roads, the tribological interaction between the aggregate and the bitumen can influence the laying process (mixing and compaction) itself. This process is very energy-intensive and the high process temperatures lead to generation of undesirable fumes and also cause thermal ageing of the asphalt. To counter this, certain additives are added to the asphalt which could potentially reduce the mixing and compaction temperature. The current work offers a short overview of bitumen rheology along with case studies showing the performance enhancing effect of additives on the tribology of the asphalt mixture.

**STLE JAST Early Tribology Symposium I**

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**Session Chair:** Kyle Schulze, Auburn University, Auburn, AL

**8:00 - 8:40 am** – Open Slot

**8:40 - 9:00 am**

**4241586: The Effect of Graphite Domain Direction on the Friction Coefficient of Ta-CN<sub>x</sub> Coating Measured by Polarized Raman and SERS Analysis**

Takayuki Tokoroyama, Noritsugu Umehara, Nagoya University, Nagoya, Aichi, Japan

Polarized surface-enhanced Raman scattering was applied to low- and high- friction surfaces of tetrahedral amorphous carbon nitride (ta-CN<sub>x</sub>) to reveal the presence of the graphite structure and investigate the angular dependence of the graphite domains that formed on the topmost surface. The measured D peak intensity differed along the incident electric field toward the sliding direction, from parallel to perpendicular and armchair edges may be present. The results for the low- friction surface indicated that graphite domains exist on the ta-CN<sub>x</sub> disk and transfer layer on the counter material (Si<sub>3</sub>N<sub>4</sub>) ball in directions different from the sliding friction, which suggests an incommensurate configuration.

**9:00 - 9:20 am**

**4303617: Accelerating the Discovery of Tribological Materials using High-Throughput Workflows**

Tomas Babuska, Justin Hall, Thomas Diebold, Michael Dugger, John Curry, Sandia National Laboratories, Albuquerque, NM

The requirements, performance, & reliability of tribological materials are difficult to characterize & predict due to system properties being highly stochastic. Many contacts have time dependent properties due to external influences, requiring extensive testing time. This limits the development of process-structure-property-performance relationships without high-throughput techniques. We explore the benefits/limitations of high throughput & automated testing methods & discuss the need to enhance all aspects of the tribological research process from sample preparation to testing & analysis. The pros & cons of serialized vs. parallelized testing, contributions of test duration, & required human interaction are all explored for large material systems. An exemplar binary nanocrystalline metal coating system (Pt-Au), showing ~2688 tests performed in multiple environments across 448 unique compositions is highlighted. SNL is managed & operated by NTESS under DOE NNSA contract DE-NA0003525.

**9:20 - 9:40 am**

**4242215: Nanorheology and Nanostructure of Lubricious Soft-Boundary Films**

Shintaro Itoh, Nagoya University, Nagoya, Aichi, Japan

Polymer films formed on solid surfaces have been reported to exhibit high lubricity in boundary lubrication. For lubrication design using polymer films, it is essential to clarify the mechanical properties and molecular conformations of the films. In our previous research, we successfully quantified the mechanical properties (shear viscoelasticity) of nanometer-thick polymer films by applying the fiber wobbling method (FWM), a nanorheology measurement method we developed. Furthermore, we are working to elucidate the lubrication mechanism by analyzing the interface nanostructure of the polymer films using neutron reflectometry. In this presentation, we report representative and recent results.

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

**4303200: From Haptics to Lubricant Additives: the fundamental questions that drive innovation in Tribology**

Sitangshu Chatterjee, Afton Chemical Corporation, Richmond, VA

Haptics (derived from the Greek word 'haptikos') pertains to the sense of touch, and the use of haptic devices is ubiquitous in consumer electronics - phones, laptops, cars, gaming consoles etc. Lubricant additives enhance the performance of base oils and are critical for prolonging the working life of automobiles and industrial equipment. What does innovation in these seemingly unrelated domains have in common?

In this talk, I will shed some light on the things that helped me transition from studying haptic devices as a graduate researcher, to supporting an organization's lubricant additive R&D efforts as an industry professional. Taking examples from my early career, I will talk about the role of taking a first-principles approach and the importance of asking fundamental questions in solving complex problems.

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

**10:40 - 11:00 am**

**4241783: Rubber Friction Control Focusing on Local Stick-Slip Induced by Stiffness Inhomogeneity**

Satoru Maegawa, Fumihito Itoigawa, Nagoya Institute of Technology, Aichi Nagoya City, Japan

Hysteresis friction arises when a viscoelastic material like rubber slides on a rough hard surface, due to deformation resistance from surface asperities. This friction is correlated with  $\tan\delta$ , the ratio of storage modulus to loss modulus, indicating whether elastic or viscous properties dominate. Typically, increasing  $\tan\delta$  enhances hysteresis friction, making  $\tan\delta$  control key for friction design. This study proposes a novel approach focusing on structural design of viscoelastic materials. Rubber specimens with nonuniform stiffness in the sliding direction are examined. When an asperity slides on rubber with alternating soft and hard regions, lateral deformation increases as asperities engage the hard regions, generating local stick-slip. This local stick-slip enhances friction via hysteresis loss. Experimental and simulation results are presented, along with a friction prediction model incorporating lateral deformation behavior.

**11:00 - 11:20 am**

**4272074: Cavitation Dynamics at the GEL-Water Interface**

Alexander McGhee, University of Arizona, Tucson, AZ; Jin Yang, Zixiang Tong, University of Texas, Austin, TX; Christian Franck, University of Wisconsin, Madison, WI

Cavitation at liquid-solid interfaces critically influences engineering and medical applications, yet subsurface effects remain poorly understood. Here, we employ laser-induced inertial cavitation (LIC) along with Spatiotemporally Adaptive Quadtree mesh Digital Image Correlation (STAQ-DIC) and Embedded Speckle Pattern (ESP) techniques for high-fidelity, full-field measurements of deformation, velocity, and strain within soft materials. By varying LIC nucleation standoff distances, gel stiffnesses, and cavitation energy, we develop a predictive model for maximum damage. Our findings reveal how nucleation distance profoundly affects spatiotemporal deformation, wave propagation, and mechanical strain within gels. These insights advance our understanding of soft tissue responses to cavitation, guiding improved therapeutic strategies and engineering designs that harness cavitation's benefits while reducing harmful effects.

**11:20 am - 12:00 pm**

**4231698: Achieving Superlubricity Through the Synergistic Effects of DLC Coatings and Organic Acids**

Motoyuki Murashima, Tohoku University, Sendai, Miyagi, Japan

This study explores the achievement of superlubricity through the combination of diamond-like carbon (DLC) coatings and organic acid lubricants. Friction tests revealed that specific solutions, such as lactic acid and serine at optimal concentrations, can reduce the friction coefficient to below 0.01. Molecular dynamics simulations using the ReaxFF potential demonstrated the strong adsorption of lactic acid molecules on DLC surfaces, highlighting their role in forming stable, low-friction interfaces. Additionally, dielectric barrier discharge (DBD) treatment was utilized to modify the DLC surface, generating carboxyl- and hydroxyl-rich layers crucial for maintaining superlubricity. The development of intermittent DBD application further enhanced the durability of the low-friction state. These findings underscore the synergistic effects of DLC coatings and organic acid lubricants in achieving and sustaining superlubricity under atmospheric conditions.

4A

Hanover AB

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**AI and Machine Learning IV**

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**Session Chair:** Max Marian, Leibniz University Hannover, Hannover, Germany

**Session Vice Chair:** Shuangbiao Liu, Northwestern University, Evanston, IL

**2:00 - 2:40 pm**

**4279249: How Industry and Academia Collaborate in the Digitalization of Materials in Germany and the EU**

Peter Gumbsch, Karlsruher Institut für Technologie KIT, Karlsruhe, Baden-Württemberg, Germany

The digital transformation will expedite materials development, component assessment, and lifetime predictions. A cornerstone is the collaborative creation of a materials knowledge base grounded in aligned knowledge graphs, coupled with a distributed FAIR data research platform. This talk aims to sketch out how an ontology-based federated materials data infrastructure can capture the hierarchical dependencies between processes, microstructure, properties, and behavior of advanced materials, and how this is prototypically implemented with academia and industry in Germany. Lessons learned will be reported, outlining strategies for participation at various levels. This includes a sample framework for scalable generation of FAIR data. It also gives a showcase FAIR data package for a pin-on-disk tribological experiment, which demonstrates a collection of scalable techniques that extend the reliability and reusability of experimental tribological data beyond typical publication practices.

**2:40 - 3:00 pm**

**4188321: A Contemporary Review and Data-Driven Evaluation of Archard-Type Wear Laws**

Brian Delaney, Q. Jane Wang, Wei Chen, Yip-Wah Chung, Northwestern University, Evanston, IL; Ryan Evans, The Timken Company, Canton, OH

This review evaluates recent sliding wear experiments to determine whether Archard's Wear Law and its variants still hold theoretical value. In this analysis, modified Archard models (incorporating variable exponents for load, sliding speed, and material hardness) were optimized for 39 independent studies out of 74 reviewed papers. A Gaussian mixture model clustered the optimized exponents into two groups: one centered around the original Archard model, and the other reflecting alternative optimized exponents. The review found that 79% of the papers referencing a

wear model employed an Archard variant. Analysis showed that models using material hardness as the primary factor influencing wear volume struggled to make accurate predictions. Although the Archard-type model maintains its theoretical relevance in relating wear volume to applied load and sliding speed, its dependence on a constant wear coefficient and material hardness falls short in describing wear phenomena comprehensively.

### **3:00 - 4:00 pm – Exhibitor Appreciation Break**

#### **4:00 - 4:20 pm**

##### **4192490: Estimation of Friction Force from In-Situ and Top-View SEM Images of Polyacetal Friction Interfaces and Generation of Low-Friction SEM Images Using Deep Learning**

Hiroshi Kinoshita, Serina Tanaka, Naohiro Matsumoto, University of Hyogo, Himeji, Japan; Yoshiyuki Sugai, University of Hyogo & Daicel Corporation, Himeji, Japan

We have pioneered the development of a device that enables direct in-situ, top-view observations of friction interfaces using scanning electron microscopy (SEM) with a microtribometer and electron-transmitting membranes. This device allows the acquisition of SEM images capturing the formation of transfer films, wear debris, rolled debris, and free layers on polyacetal (POM) resin friction interfaces. However, the relationship between these phenomena and friction forces remains unclear. Friction forces were estimated from the SEM images using deep learning, and the key feature points influencing the deep learning decisions were identified through class activation mapping (CAM). Furthermore, low-friction SEM images of POM friction interfaces, corresponding to friction forces below the minimum values observed in friction tests, were generated using generative AI.

#### **4:20 - 5:00 pm - AI and Machine Learning Business Meeting**

4B

Hanover C

### **Commercial Marketing Forum IV**

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**Session Chair:** TBD

#### **2:00 - 2:20 pm**

##### **4301599: Lubrizol: A Versatile Rust Preventive for Long-Term Outdoor Corrosion Protection**

Amelia Hadler, Maria Shepherd, Robert Dura, Lubrizol Corporation, Wickliffe, OH

Heavy-duty rust preventives are vital for long-term corrosion protection in applications such as automotive underbody coatings and outdoor metal frameworks. Existing products tend to use aging technology limiting formulating options, obscuring metal surfaces, and exhibiting poor UV stability. This talk introduces Lubrizol's Alox® MT9335, a novel polymer-based coating that forms a clear, dry film with excellent corrosion protection and UV stability. Designed for versatility, its clear color broadens application scope, while its concentrated composition offers expanded formulating flexibility.

#### **2:20 - 2:40 pm**

##### **4301470: Cargill: Priolube™ bio-based synthetic ester thickeners**

Scott Davis, Nick Weldon, Cargill, York, North Yorkshire, United Kingdom

There is an increasing demand for lubricants to be more efficient, last longer while reducing oil sump capacity in both the industrial and automotive sectors. Synthetic base oils and additives are

utilized to meet these demands. There is also a desire to increase the bio-based content of lubricants. Competing aims of performance and higher bio-based content can conflict, as commonly used synthetic base oils are predominately petroleum-based polyalphaolefins (PAOs). One way to address these competing demands is to formulate with ester-based shear-stable thickeners. Such lubricants can provide outstanding friction reduction, improved formulation efficiency and the biobased content of formulations can be increased. This can be achieved over a wide viscosity range.

Here we will present new Priolube™ bio-based synthetic ester thickeners which allow the formulator to create high viscosity but also high efficiency formulations with low wear while increasing the bio-based content.

**2:40 - 3:00 pm**

**4301761: Lubrizol: Zinc Free Hydraulic - Enabling the Future of Hydraulic Fluids**

Jared Cornett, The Lubrizol Corporation, Wickliffe, OH

The need for environmentally conscious, zinc-free hydraulic fluids are gaining momentum in marine/offshore, construction, forestry, and mining industries. High-performing, OEM approved, zinc-free hydraulic fluids not only ensure a more sustainable solution but also pave the way for the future of hydraulic fluids by setting new standards in oil drain intervals, equipment durability, and sludge control. In this talk, we will discuss how Lubrizol enables the hydraulic fluids of tomorrow with our new, top tier, zinc-free hydraulic additive: Lubrizol® AH933ZF.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 4:40 pm**

**4301897: BASF Corporation: Emgard® Transportation Lubricants - Lubricant Solutions for a Sustainable Future**

Michael Barry, Arjun Goyal, Donna Mosher, Philip Ma, BASF Corp., Florham Park, NJ

BASF's Fuel and Lubricant Solutions is a leader for sustainable high-performance drivetrain lubricants in selected transportation markets.

With our leading progressive technologies for EMGARD® transmission and axle lubricants, we establish industry standards for high performance and sustainable lubricants through joint customer developments providing maximum value to all.

This session will highlight those advancements in our BASF portfolio while highlighting areas of efficiency, carbon reduction, e-mobility and enabling a sustainable future.

**4:40 - 5:00 pm**

**4304002: ExxonMobil: Advanced PAO Technology Enabling High-performance Passenger Vehicle (PV) Fluid Solutions**

Raymond McDonald, ExxonMobil, Emmaus, PA

Evolving regulations and consumer trends will continue to drive the automotive industry to reduce CO<sub>2</sub> emissions. This in turn will drive new ICE designs and operation, as well as adoption of alternate powertrain vehicles such as BEVs, HEVs and PHEVs. Next-generation PV hardware designs are likely to require high performance, low viscosity fluids. New engine oil specifications and EV hardware designs for integrated electric drive units will challenge formulators to deliver low viscosity fluids that balance traditional lubrication with volatility and efficiency. Therefore, base oil selection will be a critical consideration when developing these fluids. This presentation summarizes recent evaluations documenting benefits in efficiency, and other performance areas, made possible via an advanced low-viscosity/low-volatility PAO technology platform. The results demonstrate that this novel technology can enable development of next-generation fluids and



## Condition Monitoring II

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**Session Chair:** Jacob Bonta, Valvoline Global Operations, Lexington, KY

**Session Vice Chair:** Matthew Hobbs, EPT, Calgary, Alberta, Canada

**2:00 - 2:40 pm**

**4200473: Reliability Starts Here: Best Practices for Fluid Analysis**

Josh Gaschler, POLARIS Laboratories®, Indianapolis, IN

A world-class lubrication program involves several key elements, including proper sampling techniques, appropriate frequencies, safe storage and handling, and effective contamination control. Oil contamination is a leading cause of component wear and equipment failure, making it essential to use only clean lubricants in operations. Cleanliness-control centers play a vital role in ensuring that lubricants are stored and transferred in a contamination-free environment. Participating in routine sampling with an oil analysis program is a critical step when it comes to increasing equipment reliability. Furthermore, extracting clean, accurate oil samples is key to receiving accurate data and maintenance recommendations back from the lab; simply put, it's a case of "garbage in, garbage out." In this presentation, we will discuss best practices for fluid analysis and the foundational principles necessary for a successful lubrication program.

**2:40 - 3:00 pm**

**4205664: Achieving ISO 17025 Accreditation for Inservice Grease Analysis Programs**

Jonathan Wright, Dylan Kletzing, Richard Wurzbach, MRG Labs, York, PA

In the field of tribology, grease analysis has historically represented a small fraction of samples tested, with the majority being oil samples. More recently numerous industries have realized the benefits of in-service grease analysis, resulting in significant cost-savings, decreased downtime, optimized lubrication intervals, and a greater focus on proactive maintenance. With such large industry decisions riding on the results of grease analysis, it is important for laboratories to maintain rigorous quality programs to ensure the reliability of data. Achieving ISO 17025 accreditation for the Quality Program of a grease analysis lab provides such documentation. This paper will reveal a proven approach for laboratories to achieve ISO 17025 for in-service grease analysis per ASTM D7918, and demonstrate how end users of grease analysis services can rely on this accreditation to for confidence in the value of analysis on samples that they submit.

**3:00 - 4:00 pm – Exhibitor Appreciation Break**

**4:00 - 4:20 pm**

**4204935: Condition Monitoring Method for Oxidation of Biodegradable Hydraulic Oils**

Tomomi Honda, University of Fukui, Fukui, Japan

Recently, it is required to use biodegradable oil from the viewpoint of global environmental problems. On construction machines, online sensing systems have been developed, and some construction machines are beginning to use fluid property sensors. However, there are few reports on the degradation diagnosis of biodegradable hydraulic fluid using fluid property sensors. In this study, we aimed to improve the diagnostic accuracy by investigating their relationships with the parameters of the color analysis sensor and the fluid property sensor. We made oxidized

biodegradable oils using the RPVOT without water and catalyst and measured color parameters, physical properties, and TAN using these sensors. As a result, it was suggested that using a combination of color analysis and fluid property sensor, we can detect the early stage of oxidation and indirectly know the value of TAN from the dielectric constant.

**4:20 - 4:40 pm**

**4205126: Electrical Impedance Spectroscopy for Lubricant Condition Monitoring**

Tom Reddyhoff, Thomas Kirkby, Imperial College London, London, United Kingdom

Monitoring the condition of lubricants is crucial in maintaining the efficiency and longevity of mechanical transmissions across various sectors such as transportation, power generation, and industrial equipment. Electrical impedance spectroscopy (EIS), a powerful tool to determine electrochemical properties, is underutilized in lubricant monitoring. This study uses both in situ and ex situ approaches to examine lubricants. Ex situ bulk properties were analyzed using a novel EIS probe, while in situ properties were investigated using a lubricated ball-on-disc contact in a mini-traction machine (MTM) tribometer. Lubricants were tested to investigate the effect on resistance, capacitance, and tribological behavior, correlating with friction and wear data. Anti-wear film thickness was also investigated by comparing in-situ EIS data with MTM-SLIM data with results showing a good correlation. This paves the way for EIS to be utilized in both lab-based and online testing of engine oils.

**4:40 - 5:00 pm**

**4302474: Identification of Lubricant Types Using Near-infrared Spectroscopy and Machine Learning**

Kyoko Kojima, Hitachi, Ltd., Tokyo, Japan

Near-infrared spectroscopy is difficult to interpret spectral data and applying machine learning, but the equipment is inexpensive, suitable for transmittance measurement, and easy to use. Until now, the physical properties of lubricants and the moisture content in lubricants have been predicted from the near-infrared absorption spectra with data preprocessing and applying regression algorithms. In this presentation, a new technology that processes near-infrared absorption spectral data with a classification algorithm to identify commercially available lubricant products will be introduced. Also, it was demonstrated that it is possible to distinguish the oil type even if the oil is used for the same product. The technology is expected to be used for fuel quality assessment and counterfeit oil detection.

**5:00 - 5:30 pm - Condition Monitoring Business Meeting**

**4D**

**Hanover E**

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**Metalworking Fluids III**

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**Session Chair:** Stefanie Velez, MUNZING CHEMIE GmbH, Bloomfield, NJ

**Session Vice Chair:** Stephanie Cole, Munzing North America, LP, Bloomfield, NJ

**2:00 - 2:40 pm**

**4186275: A Statistical Approach to Studying Additive Interplay for Chlorinated Paraffin Replacement in Cutting Oils**

Andrew Yoder, Taylor Lagler, Johnnie Thomlison, The Lubrizol Corp, Wickliffe, OH

Through a controlled statistical approach across three experimental phases, an extensive study utilizing a Tap and Torque instrument was conducted to understand the additive effects of various esters, sulfur carriers, and over based calcium sulfonate. A chlorinated paraffin and a commercially available chlorine alternative were used as controls. An optimal type and balance of these components were identified as crucial for good performance in the first two phases. In the third phase, we explored the effect of additive package concentrations on performance and some surprising results emerged. In all phases, we observed that the tool life had a significant impact on torque even after extensive testing. Variability was also attributable to the bar and/or tap itself. Overall, our findings highlight the complex interplay of additive components and tool conditions in determining performance, underscoring the need for careful consideration of formulation and experimental variables.

**2:40 - 3:00 pm**

**4194864: Study of Tribology Properties and MWF Chemistries in Titanium Drilling**

Yixing Philip Zhao, Quaker Houghton Company, Conshohocken, PA; Reza Riahi, University of Windsor, Windsor, Ontario, Canada

Titanium is used in aerospace, biomedical devices, defense, etc. due to its light weight, high strength, and good corrosion resistance. However, it is difficult to machine titanium alloys, due to difficulty machinability and low thermal conductivity. Water based metalworking fluids can reduce friction, low tool wear, provide good surface finish.

The effects of three different types of MWFs on some key tribological properties were investigated in CNC drilling on titanium in different load and feed rate conditions. The torque, tool wears, surface morphologies, and drilling force profiles were analyzed. The results showed the coolants with different chemistries can provide lubrications more specifically for EP, boundary, and mixed regimes due to different lubricity additives, emulsion technologies and cooling properties. These results may give us good tools to formulate and engineer advanced water base MWF for machining not only titanium but also steels and aluminums.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 5:00 pm - Metalworking Committee Meeting**

4E

Hanover F

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**Rolling Element Bearings IV**

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**Session Chair:** Thomas Russell, Exponent, Natick, MA

**Session Vice Chair:** Daulton Isaac, AFRI Turbine Engine Division, Wright Patterson Air Force Base, OH

**2:00 - 2:40 pm**

**4202633: Measurement of Bearing Frictional Torque with a New High-Speed Test Rig**

Joseph Shore, Amir Kadiric, Imperial College London, London, United Kingdom; Pawel Rycerz, Guillermo Morales-Espejel, SKF Research and Technology Development, Houten, Netherlands

Rolling bearings employed in aerospace, machine tool spindles and electric vehicles applications are subjected to ever increasing speeds, reaching N<sub>m</sub> values exceeding 2 mln. There is therefore growing interest in understanding bearing frictional performance under such conditions. However, common bearing friction models have not been tested at these high speeds and there is a lack of relevant experimental friction data. To address this, a new custom bearing test setup, the High-

Speed Bearing Rig (HSBR), has been developed to measure friction torque at speeds up to 45000rpm (>2 mln Ndm). The novel arrangement implemented in the HSBR allows for measurement of friction torque in a single bearing, in contrast to previous similar attempts employing two pre-loaded test bearings. This paper will describe the HSBR and its use to investigate the frictional performance of a super-precision hybrid ACBB under oil mist lubrication, focusing on the influences of axial load, speed, and oil supply.

**2:40 - 3:00 pm**

**4203594: Effect of Nanoparticles on the Rolling Bearing Life in oil lubrication**

Yoji Sunagawa, Idemitsu Kosan Co., Ltd., Ichihara, Japan

Rolling contact fatigue test of bearings were conducted with ZrO<sub>2</sub> nanoparticles dispersed lubricant. The ZrO<sub>2</sub> nanoparticles dispersed lubricant showed an extension of fatigue life compared to the lubricant without ZrO<sub>2</sub> nanoparticles. The surface analysis of the ball after the fatigue test showed that a ZrO<sub>2</sub> layer formed. Residual stress measurement on the disc surface after the fatigue test resulted in increased compressive residual stress. It was concluded that the ZrO<sub>2</sub> layer formed under rolling conditions suppressed surface damage and crack propagation.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 5:00 pm - REB Business Meeting**

4F

Courtland

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**Sustainability in Motion III**

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**Session Chair:** Shubhamita Basu, Perstorp Polyols, Inc., Toledo, OH

**2:00 - 2:20 pm**

**4175352: Carbon Emission Reductions Utilizing Renewable Energy for Chemical Production of Estolide Base Oils**

Matt Kriech, Biosynthetic Technologies, Indianapolis, IN

With concepts like sustainability and environmental performance gaining momentum in the lubricant industry, many companies are finally seeking ways to incorporate such characteristics into their product lines. While such terms seem simple at first glance, their subjective nature can make them difficult to understand and implement. One tool for navigating such concepts in a more objective way is the Life Cycle Assessment (LCA). In 2022 a cradle-to-gate LCA was conducted on the production of Estolide Base Oils. The findings suggested that the largest source of emission were (1) driven by fertilizer production for the growing of Castor crops used in the production of Estolides, and (2) the electricity used in the facility that was produced from coal. Utilizing this data 2.3 MW of renewable wind turbines and a 2.0 MW solar array were installed at the facility. The results and lessons learned from updating the 2022 LCA utilizing these new sources of renewable energy will be presented.

**2:20 - 2:40 pm**

**4201951: Novel and Innovative Process Technology to Reduce the Carbon Footprint of Lubricant Esters.**

Jef Van de Poel, Oleon NV, Ertvelde, Belgium

Sustainability has shifted from being a market differentiator to an expectation from customers. The lubricants industry is in need of a comprehensive portfolio of safe and sustainable solutions, contributing to the global transition towards a net-zero carbon economy. Enzymatic esterification is an innovative technology that utilizes enzymes, nature's own catalysts, in the production process. These enzymes offer numerous advantages, including natural origins, high specificity, and lower temperature and pressure requirements, ensuring safer production conditions. Additionally, they act as non-hazardous biocatalysts, minimize processing waste, and significantly reduce CO<sub>2</sub> emissions. A detailed LCA comparison will be discussed, comparing classical esterification methods with this innovative process technology.

**2:40 - 3:00 pm**

**4294844: Tribology & Sustainability: Integrating in Plant Production to Achieve ROI and Lowering Carbon Footprint**

Douglas Sackett, Dilmar Oil Co., Monticello, FL

Lubrication and Reliability have taken on a whole new meaning with new corporate responsibility to achieve "net zero" or "carbon neutrality" by 2035-50 and how as Tribologist or Reliability/Lubrication Engineers do we look at all the avenues that we can utilize to achieve and document this goal. Working with the companies in the field to teach, train and assess this process to integrate the leading Tribology research and development and how to use it properly in the field. The UN explains the difference between sustainable development and sustainability as follows: "Sustainability is often thought of as a long-term goal while sustainable development refers to the many processes and pathways to achieve it".

We will look at new and old lubrication formulation, technology and how to implement Tribology knowledge into plant reliability strategy to lower your GHG or carbon footprint while assessing and calculating how to achieve the highest ROI.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4G**

Regency V

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**Materials Tribology IV - Tribute to Yip Wah Chung Special Session**

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**Session Chair:** Q. Jane Wang, Northwestern University, Evanston, IL

**2:00 - 2:20 pm**

**4296553: Tribochemical Activation of Diels-Alder Cycloaddition Reactions**

Ashlie Martini, Sourabh Kumar, Donglin Yang, University of California Merced, Merced, CA; William Oprisu, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Adam Braunschweig, CUNY, New York, NY

Shear and normal stress in a tribological interface can activate chemical reactions, a phenomenon that can be leveraged for mechanochemical synthesis. Here, we focus on the use of tribological conditions to activate [4+2] Diels Alder cycloaddition reactions. Experiments are performed using a mini traction machine as a liquid anvil cell to generate high stress within a polyalphaolefin base oil that is transmitted to the reactants to activate the reaction. Rates of the Diels-Alder reactions are quantified with proton NMR. Classical molecular dynamics simulations, modified to capture the cycloaddition reactions of interest under conditions matched to the experiments as closely as possible. The simulations enable the effects of heat, normal stress, and shear stress to be differentiated and show how force is transmitted from the base fluid to the reactants, thus providing new insights into tribochemical activation mechanisms more broadly.

**2:20 - 2:40 pm**

**4297023: Sliding At the Nexus of Surface Science and Tribology**

Seong Kim, Pennsylvania State University, University Park, PA

Many principles of surface science are deeply rooted in tribological phenomena. One such process is the adsorption and reaction of molecular species from the environment (either from the gas phase or a liquid lubricant), which influence friction and wear between two solid surfaces moving at different relative speeds. The adsorption of water molecules in humid air can alter the tribological response of solid materials, while the adsorption of organic molecules from a gaseous environment can lead to unexpected yet highly effective lubrication. If these molecules are reactive, they can modify the surface chemistry of solids undergoing frictional shear. Additionally, friction itself can induce chemical reactions of adsorbed molecules that would not otherwise occur. This talk will highlight several examples where surface science plays a critical role in advancing tribological understanding.

**2:40 - 3:00 pm**

**4297010: The Promise of Carbon-based Materials in Friction and Wear Control**

Ali Erdemir, Texas A&M University, College Station, TX

Carbon-based materials have been at the forefront of intense scientific research due to their diverse chemical and structural forms, some providing exceptional friction and wear properties. Natural graphite and diamond have existed for many millennia, but myriad others have been synthesized in laboratories. In particular, using advanced physical and chemical vapor deposition methods, researchers have developed synthetic diamond and diamond-like carbon films exhibiting superlubricity and extreme resistance to wear. In this talk, I will elaborate on the tribology of these and other forms of carbon, including the ones resulting from tribocatalysis and contact electrification. I will also discuss the potential of such carbon forms in a range of industrial applications. Overall, new discoveries in carbons are leading the way for further reducing friction and wear in real mechanical systems and, hence, potentially contributing to a green and sustainable future.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 4:20 pm**

**4291547: Stress-Dependent Activation Volumes and Viscosity: From Shear Thinning to Glass Formation**

Wilfred Tysoe, Nicholas Hopper, University of Wisconsin-Milwaukee, Milwaukee, WI; Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL

While theories for both sliding friction and metal deformation by dislocation motion rely on atomic-scale models, there are no molecular-scale models for fluid viscosity. We thus propose a molecular ensemble that enables the transport of molecules in a fluid by allowing a central molecule to exchange with one of its nearest neighbors. The model is analyzed using strategies developed for tribochemical reactions. The results depend on an activation volume for the exchange process, which itself decreases with increasing normal and shear stresses. The decrease in volume of the reacting ensemble with increasing pressure causes it to reach a point at which there is no longer space for molecules to exchange without the size of the molecular ensemble increasing. This size increase finally causes the formation of a glassy material. Finally, this change in activation volume with shear stress or strain rate leads to a formula for shear thinning that is in excellent agreement with experiment.

**4:20 - 4:40 pm**

**4298990: Wear of Diamond**

Hong Liang, Texas A & M University, College Station, TX

In engineering applications, diamond materials are far from lasting forever. This presentation will discuss the wear and wear mechanisms of diamond in general and the tribochemical interaction and phase transformation in detail. Under various contact conditions, we will investigate the effects of temperature and environments on diamonds in terms of microstructure, phase transformation, oxidation, and others that might affect their stability.

**4:40 - 5:00 pm**

**4272762: Material Tribology and Tribochemistry for Steels**

Zaid Al Hassan, Xinqi Chen, Shuangbiao Liu, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Nikhil Murthy, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Wear presents a significant challenge in high-performance engineering, where steel components are subjected to extreme pressure, elevated temperatures, and continuous sliding contact. While traditional coatings synthesized with Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD) offer wear resistance, they can be costly, difficult to scale, and hard to regenerate. This research investigates in-situ formation of self-replenishing carbon-based tribofilms from lubricant additives. Cyclopropanecarboxylic acid (CPCa) undergoes tribopolymerization under stress and heat, forming durable wear-resistant films on steel. Raman spectroscopy confirms their stability, showing graphitic or diamond-like carbon features. The catalytic properties of steel, particularly chromium and nickel, promote tribopolymerization. These findings suggest a scalable and sustainable approach to enhancing wear resistance in steel, offering a promising alternative to traditional coatings.

**4H**

**Regency VI**

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**Aerospace II**

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**Session Chair:** Daniel Miliute, University of California - Merced, Merced, CA

**Session Vice Chair:** Adam DeLong, Florida State University, Tallahassee, FL

**2:00 - 2:40 pm**

**4185032: Development of L-PBF Fabricated Bi-Metallic IN718 and L605 Superalloys for Mitigating High-Temperature Fretting Wear in Aerospace Components**

Sathisha CH, GE Aerospace Research, Bengaluru, KA, India; Kesavan D, Arivu Y, Indian Institute Of Technology Palakkad, Palakkad, KL, India

The aerospace industry needs components that improve jet engine performance and durability against fretting wear. Multi-material components are increasingly popular, as they combine advantageous properties. Laser Powder Bed Fusion (L-PBF) effectively produces these advanced components, enabling intricate geometries and the integration of multiple alloys in a single process. This study explores the application of L-PBF to produce bi-metallic superalloys, specifically combining IN718 (nickel-based) and L605 (cobalt-based) alloys. By controlling the volumetric energy density ( $97 \text{ J/mm}^3$  to  $100 \text{ J/mm}^3$ ), researchers achieved an optimized alloy with a stable interlayer, forming strong metallurgical bonds essential for mechanical integrity. Fretting wear tests (1645 N load,  $650^\circ\text{C}$ ) revealed that the L605 bi-material system exhibited superior wear

resistance due to a protective cobalt-chromium glaze layer, while IN718 experienced greater wear due to the absence of such protection.

**2:40 - 3:00 pm**

**4203343: Indentation Deformation Behavior of Cold-Sprayed Nanocrystalline High-Entropy Alloys**

Philip Egberts, Kasimuthumaniyan Subramanian, Moses Adaan Nyiak, Ahmed Tihamiyu, University of Calgary, Calgary, Alberta, Canada

Metallic surfaces of structural components operating in harsh environments degrade prematurely. Hence, coatings are applied to preserve the underlying substrate. Herein, we investigate the nanomechanical elasto-plastic response of light weight, stable nanocrystalline high-entropy alloy (HEA) coatings deposited via cold-spray technique on a A36 steel substrate using nanoindentation technique and atomic force microscopy (AFM). Specifically, two types of these coatings were examined: undoped  $\text{Al}_{25}\text{Co}_{25}\text{Cr}_{25}\text{Fe}_{25}$  and doped  $\text{Al}_{24.6}\text{Co}_{24.6}\text{Cr}_{24.6}\text{Fe}_{24.6}\text{Zr}_{1.5}$ , each approximately 8  $\mu\text{m}$  thick. Despite being 25% lighter, the hardness of the coatings are almost 4 times higher than the steel substrate. Interestingly, HEA coatings subjected to heat treatment also showed notable improvement in hardness and elastic moduli. Altogether, we report the thermal stability of the HEA coatings developed and the role of elasto-plastic behavior on governing the hardness and moduli of the coatings and substrate.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 4:20 pm**

**4179855: Additive Manufacturing of Bearings for Aerospace Applications - Integration of Cooling Channels**

Andreas Rottmann, Adrian Popp, Schaeffler Aerospace Germany GmbH & Co. KG, Schweinfurt, Germany

Additive manufacturing (AM) of M50NiL with selective laser melting has been successfully tested to compare the material properties (e.g., tensile strength, rolling contact fatigue behavior) with conventional M50NiL. The next step was to test the printed material under more specific conditions with small angular contact ball bearings, which resulted in comparable endurance capabilities. A mainshaft bearing with ceramic balls and integrated cooling channels was designed to use the advantages of AM under real application conditions. The integrated cooling channels could be placed closer to the raceway which results in an improved heat removal up to factor of two compared to mainshaft bearings with cooling channels that are made in a conventional way. To further improve the use of powder-based materials and metal 3D-printing the cooling channels of the full-scale bearing have been successfully improved via electrolytic polishing. This generates a smoother and more flow-optimized channel.

**4:20 - 4:40 pm**

**4199832: Exploring Tribological Behavior of Aluminum Alloy for Space Application Fabricated via Multimodal Metal Additive Manufacturing Processes**

Sougata Roy, Pail Das, Iowa State University, Ames, IA; Annette Gray, Matthew Mazurkivich, William Scott, Marshall Space Flight Center NASA, Huntsville, AL

Friction-induced energy dissipation poses a significant obstacle in space applications, especially during extended missions where energy losses accumulate and become substantial due to the limitations of lubrication in space. The Al6061 aluminum alloy stands out as a promising material for spacecraft component manufacturing due to its corrosion resistance, impressive strength-to-weight ratio, and its inherent insensitivity to the harsh conditions of the extraterrestrial environment. In this effort, we conducted a detailed investigation on the additive manufacturability



and tribological behavior of Al6061 alloy in ambient and vacuum atmospheric conditions at 20C temperature. We specifically examined two distinct additive manufacturing techniques: large scale Wire Arc Additive Manufacturing and meso-scale Laser-Powder blown Direct Energy Deposition. Additionally, in-depth characterization of worn our regions was conducted to explore the primary wear mechanisms in different conditions.

**4:40 - 5:00 pm**

**4194351: Tribological Performance of a Ni Based 3D Metal Printed Aeronautical Alloy**

Dirk Drees, Lais Lopes, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Katerina Papanikolaou, Angelos Koutsomichalis, Emmanouil Georgiou, Hellenic Air-Force Academy, Athens, Greece; Athanasios Tzanis, Electronics Depot-R&T Centre, Athens, Greece; Panagiotis Skarvelis, Hellenic Aerospace Industry S.A., Schimatari, Greece

3D metal printing has significantly advanced, becoming a revolutionary technology in aerospace by enabling the layer-by-layer creation of complex structures. This allows for customized parts from advanced alloys with superior mechanical and electrochemical properties, which were previously expensive or difficult to manufacture using traditional methods. However, additive manufacturing still has high setup costs and complexity. This study explores the potential of using conventional welding methods, such as Tungsten Inert Gas (TIG) welding, to produce simplified components from 718 Inconel alloy. A comparison of friction and wear performance with other commonly used aerospace materials will be made to assess this alternative method's applicability in the aeronautical field.

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**Electric Vehicles IV**

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**Session Chair:** TBD

**Session Vice Chair:** TBD

**2:00 - 2:40 pm**

**4203979: Estimating Power Losses in Electric Vehicle Drive Units: A Combined 1D Analytical and 3D CFD Approach**

Abdul Motin, Rivian Automotive, Plymouth, MI

This study presents a sophisticated methodology for accurately estimating the power losses in electric vehicle drive units (e-DU). By integrating one-dimensional (1D) analytical models with three-dimensional (3D) computational fluid dynamics (CFD), we focus on quantifying power losses primarily related to mechanical contact friction and oil drag in key components, including gears, bearings, and seals. Given the growing demand for electric vehicles (EVs), understanding power losses is indispensable for enhancing the overall efficiency and range of these vehicles. Our research examines various analytical models, validates them against experimental data, and analyzes the influence of drive torque and oil properties on power losses. The findings reveal a strong correlation between gear contact losses and experimental results, underlining the effectiveness of our combined methodological approach.

**2:40 - 3:00 pm**

**4201425: Enhancing Efficiency in Electric Drive Units (EDUs) through Lubricant Optimization**

Matthew Hauschild, Dmitriy Shakhvorostov, Evonik Oil Additives, Horsham, PA

In this study, we explore the impact of lubricant composition and physical properties on the overall efficiency of wet coil Electric Drive Units (EDUs) under both Worldwide Harmonized Light Vehicles Test Procedure (WLTP) and stationary conditions. Our study focuses on variations in kinematic viscosity (ranging from 3 to 6 cSt), viscosity index (ranging from 130 to 350), and base oil type (mineral and synthetic). Additionally, we explore the impact of viscosity index improvers with linear and comb structures.

Our results demonstrate that by increasing the lubricant viscosity index similar efficiency gains can be achieved without compromising durability which is consideration growing in importance for future EDU units.

**3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 4:20 pm**

**4199751: Reconstructing the Internal Shape and Interfaces in a Lithium-Ion Battery using Ultrasound**

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

Lithium-ion batteries provide the power source for most EVs. Determining their health non-invasively is challenging. A new method to determine the battery internal structure using ultrasound is presented. As a cell charges electrodes absorb lithium, changing modulus and hence, ultrasonic reflection. However, there are many internal layers, and the reflection is complex. A reflection model in a layered body is built and compared to data measured from battery samples. A genetic algorithm is used to vary model inputs (number, thickness, and properties of layers) until the prediction matches measurement. In this way, the internal structure of the battery is reconstructed. Predictions are compared with CT scans of the battery. When no prior-data is given to the model the prediction is close. With prior-data (such as the layer number or properties) an almost exact prediction is made. The method has potential for detecting defects in batteries or as a sensor for battery health.

**4:20 - 4:40 pm**

**4200262: Low Conductivity Electric Vehicles Coolants for Battery Thermal Management System**

Simmi Datta, Naresh Gutta, Neelam Agarwal, Subinoy Paul, IOCL R&D Center, Faridabad, Haryana, India; Kavita Rai, A Arora, Mukul Maheshwari, Indian Oil Corporation Ltd., Delhi, India

Battery thermal management system plays vital role in controlling the battery thermal behavior by retaining the operating temperature at optimum range (15 to 35°C). Liquid cooling is more efficient & most promising coolant system which delivers best performance to maintain battery pack in uniform atemperature range due to its high heat capacity & higher heat transfer coefficient. Since the coolant flow in battery pack carrying electric power, the key performance parameter that differentiate the coolants for electric vehicles from coolants for ICE is the low electrical conductivity requirements for electric vehicle coolants. This paper discusses the development of low conductivity EV coolants for EV buses, passenger vehicles & bombardier metro rail engines for indirect liquid cooling system. Developed coolant found to have excellent chemical & thermal stability, corrosion protection and compatibility with material of cooling assemblies of battery pack.

## Rheology II

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**Session Chair:** TBD

**Session Vice Chair:** TBD

**2:00 - 2:40 pm**

**4174786: Quantitative EHL-Eighteen Years In**

Scott Bair, Georgia Institute of Technology, Atlanta, GA; Wassim Habchi, Lebanese American University, Byblos, Lebanon

Eighteen years have passed since the first full elastohydrodynamic lubrication simulation employed the real pressure and shear dependence of viscosity measured in viscometers to accurately predict both film thickness and friction. This presentation will enumerate the advances in understanding brought on by the application of high-pressure rheology to the EHL problem. The central film thickness often depends on the shear-thinning at low pressure and time-temperature-pressure superposition demands that the same shear dependence be active at the high pressure where friction is generated. In this article some of the revelations resulting from quantitative EHL are reviewed. For example, it has been discovered that the minimum film thickness in point contacts depends upon the viscosity at the highest pressures of the contact. Quantitative EHL provides quantitative predictions of contact behavior.

**2:40 - 3:00 pm**

**4199299: Evaluating Slippage Characteristics in Nanogaps by Lubricant Flow Measurement Using Fluorescent Particle Tracking**

Hidetaka Ozeki, Naoki Azuma, Kenji Fukuzawa, Shintaro Itoh, Hedong Zhang, Yuxi Song, Nagoya University, Nagoya, Japan

In lubrication in a nanometer-sized gap, it has been found that large slippage occurs at the interface between the lubricant and the solid surfaces. The slippage causes the flow profile in the nanogap which is quite different from that in the microgap and changes the lubrication properties such as the vertical and frictional forces. Therefore, the method to evaluate the properties of the slippages in nanogaps is required. In this study, we propose a method to evaluate the properties of the slippages in nanogaps based on the flow velocity measurements of squeeze flow. The flow velocity was measured by particle image velocimetry (PIV) using the fluorescent particles whose sizes were nanometer-order, and the slippage velocities were calculated by analyzing the obtained velocity values. We evaluated the dependency of the properties of slippages on the sizes of nanogaps and found that shear stress was the important factor to determine the slippages.

**3:00 - 4:00 pm – Exhibitor Appreciation Break**

**4:00 - 4:20 pm**

**4202690: Characterization and Analysis of Polyol Ester Oil of Operating and Failed Scroll Compressors**

Hannah Liggett, Juan Bosch Giner, Christopher DellaCorte, University of Akron, Akron, OH

Though the popular R410A refrigerant gas is compatible with Polyol Ester Oil (POE) because of its solubility, the effects of its interaction have not been studied to its failure point. Limited literature has been addressed regarding the long-term effects of their interaction over 10 years of service. This study analyzes two field compressors, revealing that the failed scroll compressor's oil was dirtier compared to the operating compressor. This proposed work aims to characterize the oil's

properties from both scroll compressors. Oil characterization and tribological tests, along with assessing oil contamination will be conducted. The results will be compared to fresh oil samples to observe changes in tribological and rheological properties between the three POE samples. This analysis could provide insights into the projected changes in POE oil properties when paired with new refrigerant gases, as the use of R410A refrigerant gas is expected to decline over the next 15 years.

**4:20 - 4:40 pm**

**4199436: Study on the Effects of Antifoam Additives on Film Drainage and Bubble Dynamics in Oil-Based Systems**

Paul-Anael Pogu, Tom Reddyhoff, Imperial College London, London, United Kingdom; Eliane Gendreau, Robert Mainwaring, Hayley Bunce, Shell, London, United Kingdom

Foam stability in oil-based systems is a critical factor influencing performance in lubrication and tribology applications. While antifoaming agents are commonly used to mitigate foam formation, their precise effects on the dynamics of bubbles in oil remain less understood.

This study investigates the impact of antifoam additives on the drainage and thinning behavior of single bubbles rising through oil systems. A mechanical syringe pump was used to reliably produce bubbles in a liquid pool which were then tracked using high speed imaging. Once at the surface, both fluorescence and interferometry techniques were employed to observe the bubble film, measuring drainage rates, film thinning, anti-foam bridge formation, and tracking bubble rupture time. The efficiencies of different rupturing mechanisms were compared across a variety of antifoams and liquid systems, providing a greater insight into the selection of additives and the formulation of lubricants for specialized applications.

**4:40 pm - 5:00 pm**

**4308234: Running in Procedures for Grease-lubricated Bearings: Impact on Grease Ageing**

Gabriel Calderon Salmeron, Sergei Glavatskih, KTH Royal Institute of Technology, Stockholm, Sweden; Johan Leckner, Axel Christiernsson Int. AB, Nol, Sweden

Grease ageing impacts the frictional performance and service life of rolling bearings. Most of the grease ageing occurs within the first hours of operation, during the churning phase when the lubricant redistributes within the bearing. The ageing extent in this phase is influenced by the operational conditions, such as rotational speed. This raises the question of whether different running-in procedures (speed profiles) can reduce the level of grease ageing.

This work studies the effects of two distinct running-in procedures on two widely used greases: lithium complex and polyurea. Ageing is assessed through changes in the grease's rheological properties, with samples collected from both the bearing shoulders and raceway regions. The findings indicate that the choice of running-in procedure should be tailored to the thickener type to minimize grease degradation. These insights suggest a way to optimize running-in procedures in industrial applications based on grease formulation.

**STLE JAST Early Tribology Symposium II**

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**Session Chair:** Kyle Schulze, Auburn University, Auburn, AL

**2:00 - 2:20 pm**

**4236493: Quantification of Strain Distribution in Rubber Bulk During Friction Using Synchrotron**

Toshiaki Nishi, Sintaro Kurano, Ryosuke Ueda, Xiaoyu Liang, Wataru Yashiro, Takeshi Yamaguchi, Tohoku University, Sendai, Miyagi, Japan

Slip resistance for vehicle tires and shoes is important for preventing traffic and slip-and-fall accidents. In both cases, rubber treads are mounted to ensure the required slip resistance. Due to the low elastic modulus of rubber, the generation of friction force is accompanied with large strain. Regardless of adhesion, hysteresis, and plowing terms, it would be meaningful to understand and design the strain distribution of rubber bulk during friction. Although the strain distribution in rubber has been eagerly investigated based on numerical simulation, it is difficult to experimentally quantify it. The purpose in this study is to experimentally clarify the strain distribution in rubber bulk during friction against one resin sphere by using X-ray. The experiment was conducted in a synchrotron radiation facility (SPring-8) to ensure high intensity of X-ray. In result, the quantification of strain distribution in rubber bulk was experimentally completed.

**2:20 - 2:40 pm**

**4273153: Insights into the Fundamental Mechanisms of Ultralow Wear PTFE Composites**

Kylie Van Meter, Sandia National Laboratories, Albuquerque, NM; Brandon Krick, Florida State University, Tallahassee, FL

Polytetrafluoroethylene (PTFE) is a thermoplastic polymer known for its chemical inertness, vacuum compatibility, high-temperature stability, and low coefficient of friction ( $<0.1$ ). However, unfilled PTFE suffers from high wear rates ( $\sim 10^{-4}$  mm<sup>3</sup>/Nm) and is prone to creep, limiting its use in engineered components. Incorporating filler materials into PTFE to create composites can enhance wear resistance by 10 to 100 times, with reductions of up to 10,000 times with the right fillers. These “ultralow wear” composites experience minimal height loss of less than  $\sim 30$   $\mu$ m over 50 km of sliding. This talk will explore the fundamental mechanisms behind the significant improvement in wear resistance of PTFE composites, including 1) crack propagation prevention, 2) mechanochemical changes at the sliding interface, and 3) modifications of the sliding interface through filler accumulation and tribofilm reinforcement.

**2:40 - 3:00 pm**

**4233118: Laser Micro Texturing for Enhancing the Friction Between Metal Surfaces**

Yosuke Tsukiyama, Niigata University, Niigata, Japan

The laser micro texturing is widely used to enhance the mechanical properties and tribological properties. Although it is well-known that the shallow dimple patterns significantly improve the lubrication properties, the effect of micro protrusions on the friction has not been studied much yet. Our objective is to clarify the effect of micro protrusions formed on the metal surfaces on the high friction. In this study, the micro protrusions are made by nano second and Q-switched laser pulses. The laser is pulsed and scanned over the metals such as steel, Titanium and Aluminum alloy surfaces at specific intervals to form an array of micro protrusions. The friction between the laser processed surface against a counter surface showed more than two times as high as friction of as-polished ones. The effect of the laser irradiation on the apparent hardness of the protrusions

was considered as either heat effect and/or shape effect.

### **3:00 - 4:00 pm - Exhibitor Appreciation Break**

**4:00 - 4:40 pm**

#### **4276243: Active Matter and Tribology: The Conundrum of Establishing Mechanical Models to Complex Systems**

Kyle Schulze, Emily Guo, Auburn University, Auburn, AL; Thomas Angelini, Steven Chisolm, University of Florida, Gainesville, FL

The need to understand our biology as a material is clear: health is directly related to the environment and our body's response to external stimuli. However, for engineers living systems add an interesting wrinkle to our analytical tools, namely that they are composed of agents that consume energy and are not in thermal equilibrium. The cells within our bodies behave not unlike schools of fish or flocks of birds, they can all signal each other and move collectively or independently. Understanding how these motions are affected by the degree and rate of compressive loading (the most common condition a cell experiences) and in turn affect the mechanical performance of the tissue as a whole will hopefully lead to new health interventions. Here we explore the effects of rate and degree of pressure applied to cell monolayers in situ and resulting effects on mechanical performance.

**Bonus1**

Courtland

### **Bonus Program: Career Pathways Panel Discussion**

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**5:15 – 6:15 pm**

Join STLE for a panel discussion that delves into the diverse career paths of professionals who have successfully transitioned between industry and academia. Our distinguished panelists, each with a unique journey, will share their personal experiences, challenges, and achievements as they navigated these significant career shifts. This event aims to provide attendees with a deeper understanding of the motivation behind such transitions, the skills and mindset required, and the impact these changes have had on their professional and personal lives. Whether you're considering a move from industry to academia or vice versa or simply interested in learning more about the dynamic career landscapes, this panel will offer valuable perspectives and practical advice to guide you on your own career path.