3A **Hanover AB**

AI and Machine Learning III

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
4200905: Inverse Design Strategies for Textured Surfaces: Achieving Targeted Friction Laws
Li Fu, Julien Scheibert, Laboratoire de Tribologie et Dynamique des Systèmes, Ecully, France

The optimization of frictional interfaces is essential for various applications, such as robotic hands where precise control over friction laws is paramount. While linear friction laws are commonly observed in natural surfaces, achieving that in artificial surfaces with a limited number of asperities remains complex. This study introduces a systematic strategy for the inverse design of textured surfaces aimed at achieving linear friction laws, building upon a discrete Greenwood-Williamson model, which initially resulted in an asymptotic friction law without a guaranteed intercept at zero [1]. Central to our approach is the employment of a genetic algorithm (GA) to optimize the heights of individual asperities, treating each asperity as an independent genetic unit. Our findings indicate that the optimal textured surface can be represented as a combination of a truncated exponential and a demi-triangle distribution, effectively targeting the desired linear friction behavior.

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 FeF2 and FeF3 clusters. Our findings reveal that the formation of FeF2-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
Nikolay 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
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.

3B Hanover C

Commercial Marketing Forum III

Session Chair: TBD

8:00 - 8:20 am - **Available**
8:20 - 8:40 am - **Nouryon**
8:40 - 9:00 am - **Evonik Oil Additives USA, Inc.**
9:00 - 9:20 am - **The Lubrizol Corporation**
9:20 - 9:40 am - **Nyco America**
9:40 - 10:00 am - **Biosynthetic Technologies**

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

10:40 - 11:00 am - **Pilot Chemical Company**
11:00 - 11:20 am - **Munzing**
11:20 - 11:40 am - **BASF Corporation**
11:40 am – 12:00 pm - Available

3C Hanover D

Condition Monitoring I

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

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
4203371: The Detection of Oil-Soluble Color Bodies vs. MPC Varnish Potential Measurements
Matthew Hobbs, EPT, Calgary, Alberta, Canada

Recently, s-MPC test methods have been presented as alternatives to the standard D7843 MPC test. Although several s-MPC procedures exist, they all omit solvents. Advocates claim that these tests detect soluble varnish that is otherwise washed away during D7843 testing.
Our investigation confirmed that solvent use leads to a loss of oil-soluble “color bodies,” however, these cannot be considered "varnish" based on their solubility in saturated solvent. There is, therefore, little correlation between the s-MPC and D7843 methods.
Finally, tests performed, both with and without solvent, suggested that dilution is responsible for the detection of “color bodies” that are more likely to promote varnishing. This occurs because the solvent is less polar than base oil and it, therefore, allows true soluble varnish to be detected following its precipitation. These results suggest that the standard D7843 MPC test remains the best available option for varnish monitoring in in-service oils.

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

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 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 later showed the practical capability of the method as a train-based sensor.

3D — Hanover E

Metalworking Fluids II

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 MCCP). Scope of Work : A comparative tribological study of 3 commercial 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 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 show, 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 categoric 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
Wilhelm Rehbein, Isabell Lange, LANXESS Deutschland GmbH, Mannheim, Germany; Kevin DiNicola, John Williams, Salvatore Rea, LANXESS Corporation, Naugatuck, CT

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, Indian Oil Corporation Ltd. R&D Center, Faridabad, Haryana, India

Water based synthetic cutting fluid is free of mineral oil, emulsifier, conventional EP & AW additives which provides 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 product in auto ancillary industries for ferrous machining ranging from mild steel, cast iron, hardened alloy steel, stainless steel.

11:40 am – 12:00 pm - Available

3E — Hanover F

Rolling Element Bearings III

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 analyzing 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 four 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, 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 Vitrimer 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.

3F Courtland

Sustainability in Motion II

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:40 am - **Invited Talk 1**

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**

3G Regency V

Materials Tribology III

Session Chair: Kylie Van Meter, Sandia National Laboratories, Albuquerque, NM
Session Vice Chair: Craig Barbour, Florida A&M University, Tallahassee, 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, 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 extreme 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 National Laboratory, 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 am - 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_2 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 $8x10^{-8}$ $mm^3/(N-m)$. 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_2B_2) 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} $mm^3/(N-m)$. This is an interesting behavior unlike other MXene (such as $Ti_3C_2T_x$) 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

Session Chair: Wai Mak, University of California, Los Angeles (UCLA), Inglewood, CA
Session Vice Chair: Pial 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_2-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, Marshal 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_2 has low vapor pressure, low operating temperatures, and long life making it an ideal space lubricant. MoS_2-coated 60NiTi has shown comparable tribological properties to MoS_2-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_2-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_2 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_2 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 frictional surfaces is usually done by hand work. This work consists of mechanical shearing of the MoS2 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 MoS2 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_2 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_2 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_2 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, The 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-10-8 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 10-7 torr, 5 m/s speed, and ambient operation. Initial tests with space-compatible greases and solid lubricants like MoS2 and Ag show stable, repeatable results, demonstrating the system's potential to enhance lubricated contacts in space applications.

11:00 - 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 Miliate, 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 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_2 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 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.

3I — Regency VII

Electric Vehicles III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 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 one that can handle high-power density electrical drivetrains that effectively protects and cools inverter, e-motor and gearbox system. This means a combination of advanced hardware cooling approaches and an advanced fluid to prevent overheating. The benefit of 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 am - 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 CO2 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, 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_2 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_2 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 CO2 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
4242868: Structure-Property of Functionalized Sulfur-Containing Antiwear Additives for Application in Electric Driveline Fluids
Jessica Tanuwidjaja, Travis Holbrook, Luke Stribling, Devin Wall, Michelle Curtis, Timi Singa, Chevron Oronite, LLC, Richmond, CA

Durability requirements of an Electric Driveline Fluid (EDF) are challenging due in part to the demanding needs particular to an Electric Drive Unit: Performances at high speeds and low viscosities, low susceptibility to copper corrosion, and long effective lifespans. In this presentation, tribological, corrosion, and oxidation properties of functionalized sulfur-containing antiwear additives will be discussed. This knowledge enables better component design to address the multifaceted requirements of an EDF.

11:00 - 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 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 crucial element in the evolution of electric mobility.

3J The Learning Center

Rheology I

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 two 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°C) and hot (150°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 - 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 1GPa, 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 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 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 are 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°C to -40°C. Next, the apparent viscosity and yield behavior is determined in a 1-minute flow test at varied temperatures. 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 be used as 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.

3K — Dunwoody

STLE JAST Early Tribology Symposium I

Presentations Pending.

4A — Hanover AB

AI and Machine Learning IV

Session Chair: Max Marian, Pontificia Universidad Católica De Chile, Santiago, Chile
Session Vice Chair: Shuangbiao Liu, Northwestern University, Evanston, IL

2:00 - 2:40 pm - **Invited Speaker**

2:40 - 3:00 pm
4188321: A Contemporary Review and Optimization-based 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

Session Chair: TBD

2:00 - 2:20 pm - The Lubrizol Corporation
2:20 - 2:40 pm - Cargill, Inc.
2:40 - 3:00 pm - The Lubrizol Corporation

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

4:00 - 4:20 pm - **BASF Corporation**
4:20 - 4:40 pm - **BASF Corporation**
4:40 - 5:00 pm - **Available**

4C Hanover D

Condition Monitoring II

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
Thomas Kirkby, Tom Reddyhoff, 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 - **Condition Monitoring Business Meeting**

4D — Hanover E

Metalworking Fluids III

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
Co-Presenters: Andrew Yoder, Taylor Lagler, The Lubrizol Corp, Wickliffe, OH
Co-Author: 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 overbased 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 wear, 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

Rolling Element Bearings IV

Session Chair: Thomas Russell, Exponent, Natick, MA
Session Vice Chair: Ujjawal Arya, Purdue University, West Lafayette, IN

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 NDm 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 tests of bearings were conducted with ZrO_2 nanoparticles dispersed lubricant. The ZrO_2 nanoparticles dispersed lubricant showed an extension of fatigue life compared

to the lubricant without ZrO_2 nanoparticles. The surface analysis of the ball after the fatigue test showed that a ZrO_2 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_2 layer formed under rolling conditions suppressed surface damage and crack propagation.

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

4:00 - 5:00 pm – **Rolling Element Bearings Business Meeting**

4F Courtland

Sustainability in Motion III

Session Chair: TBD
Session Vice Chair: TBD

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 was (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 CO2 emissions. A detailed LCA comparison will be discussed, comparing classical esterification methods with this innovative process technology.

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

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

4:00 – 4:20 pm – Available

4:20 – 4:40 pm – Available

4:40 – 5:00 pm – Available

4G Regency V

Materials Tribology IV - Tribute to Yip Wah Chung Special Session

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

Invited Presentations Pending

4H Regency VI

Aerospace II

Session Chair: Daniel Miliate, 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 C., 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 J/mm^3 to 100 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°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
Kasimuthumaniyan Subramanian, Moses Adaan Nyiak, Ahmed Tiamiyu, Philip Egberts, 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 $Al_{25}Co_{25}Cr_{25}Fe_{25}$ and doped $Al_{24.6}Co_{24.6}Cr_{24.6}Fe_{24.6}Zr_{1.5}$, each approximately 8 µm 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 colling 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, Pial 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
Katerina Papanikolaou, Angelos Koutsomichalis, Emmanouil Georgiou, Hellenic Air-Force Academy, Athens, Greece; Lais Lopes, Dirk Drees, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; 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.

4I — Regency VII

Electric Vehicles IV

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
4200889: Ester Performance in EV Drivetrains
Simon Morton, Sasol, Lake Charles, LA

Esters can play a key role in improving performance in EV Drivetrains. These chemistries can maximize lubricity performance of base fluids while offering excellent copper corrosion and elastomer compatibility, high dielectric strength, and heat capacity along with favorable environmental characteristics. These attributes help to improve high mechanical and chemical stability over a wide operating range of speeds and temperatures experienced within the EV Drivetrains. This study aims to demonstrate the functional benefits certain esters can bring to EV lubrication.

4:20 - 4:40 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.

4:40 - 5:00 pm
4200262: Low Conductivity Electric Vehicles Coolants for Battery Thermal Management System
Simmi Datta, Naresh Gutta, Neelam Agarwal, Subinoy Paul, Indian Oil Corporation Ltd. R&D Center, Faridabad, Haryana, India, Kavita Rai, A. Arora, Mukul Maheshwari, Indian Oil Corporation Ltd., Delhi, India

Battery thermal management system plays a vital role in controlling the battery thermal behavior by retaining the operating temperature at optimum range (15 to 35°C). Liquid cooling is a more efficient & most promising coolant system which delivers best performance to maintain battery pack in uniform a temperature range due to its high heat capacity & higher heat transfer coefficient. Since the coolant flows in battery pack carrying electric power, the key performance parameter that differentiates 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

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, The 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 – 5:00 pm - Available

4K — Dunwoody

STLE JAST Early Tribology Symposium II

Presentations Pending.

Bonus Program — Centennial Ballroom

Career Pathways Panel Discussion

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.