MINNEAPOLIS

78th STLE ANNUAL MEETING & EXHIBITION | **MAY 19-23, 2024**

Preliminary Program

As of March 27, 2024

2024 STLE Annual Meeting Program At A Glance

Preliminary as of March 27, 2024

All sessions and events will take place in the Minneapolis Convention Center unless otherwise noted.

Saturday, May 18, 2024

12:00 pm – 6:00 pm – Onsite Registration (Convention Center Foyer)

Sunday, May 19, 2024

6:30 am – 6:00 pm – Onsite Registration (Convention Center Foyer)

Education Course Speakers Breakfast
7:00 am – 7:45 am – Seasons

Education Courses – 8:00 am – 5:00 pm
(registration required)

Advanced Lubrication 301: Advanced Additives – 200 C
Basic Lubrication 103 – 104 A
Bearings (in partnership with ABMA) – 200 A
Electric Vehicles 101 – 200 I
Grease 101 (in partnership with NLGI) – 200 DE
Machine Learning and Artificial Intelligence in Tribology **(New!)** (**Half-day course: 1:00 pm – 5:00 pm)** – 200 B
Metalworking Fluids 105: Introduction of Metal Forming Fluids – 200 H

Course Breaks – Foyer

4:30 pm – 5:45 pm STLE Section Leadership Training **(Invitation Only)** – 200 J

Student and New Member Networking Reception – **6:00 pm – 7:30 pm (Ticked Event/Invitation Only) –** Seasons

Monday, May 20, 2024

6:30 am – 6:00 pm – Onsite Registration (Convention Center Foyer)

Speakers Breakfast
7:00 am – 7:45 am – Seasons

Technical Sessions – 8:00 am – 10:00 am
1A – Tribochemistry I – 101 B
1B – Tribotesting I – 101 C
1C – Contact Mechanics I – 101 D
1D – Synthetic Lubricants and Hydraulics I – 101 E
1F – Nanotribology I – 101 G
1G – Surface Engineering I – 101 H
1I – Commercial Marketing Forum I – 101 J
1J – Electric Vehicles I – 200 DE

10:00 am – 10:30 am – **Networking/Refreshment Break** – Grand Ballroom Foyer

Opening General Session - 10:30 am – 12:00 pm – Grand Ballroom

Keynote Address:
"Tribology in the New Space Economy"
Brian Dykas, PhD, PE, Senior Materials and Process Engineer, Blue Origin

12:00 pm – 1:40 pm Lunch (on your own)

12:00 pm – 5:00 pm – **Commercial Exhibits and Student Posters** – Exhibit Hall B

Technical Sessions - 1:40 pm – 5:00 pm
2A – Tribochemistry II – 101 B
2B – Tribotesting II – 101 C
2C – Contact Mechanics II – 101 D
2D – Grease I – 101 E
2F – Nanotribology II – 101 G
2G – Surface Engineering II – 101 H
2I – Commercial Marketing Forum II – 101 J
2J – Electric Vehicles II – 200 DE

3:00 pm – 4:00 pm – **Exhibitor Appreciation Break** – Exhibit Hall B

5:00 pm – 6:00 pm – STLE Sustainability Forum – Seasons

6:00 pm – 7:30 pm – Networking Reception – Hilton Minneapolis

Tuesday, May 21, 2024

6:30 am – 6:00 pm – Onsite Registration (Convention Center Foyer)

Speakers Breakfast
7:00 am – 7:45 am – Seasons

9:30 am – 5:30 pm – **Commercial Exhibits and Student Posters** – Exhibit Hall B

Technical Sessions – 8:00 am – 12:00 pm
3A – Materials Tribology I: Tribute to Michael Dugger – 101 B
3B – Tribotesting III – 101 C
3C – Lubrication Fundamentals I: Additives – 101 D
3D – Grease II – 101 E
3E – Biotribology I – 101 F
3F – Nanotribology III – 101 G
3I – Commercial Marketing Forum III – 101 J
3J – Electric Vehicles III – 200 DE

10:00 am – 10:40 am – **Networking/Refreshment Break** – Exhibit Hall B

12:00 pm – 2:00 pm – **President's Luncheon/STLE Business Meeting –** Grand Ballroom

Technical Sessions – 2:00 pm – 5:00 pm
4A – Materials Tribology II: Tribute to Michael Dugger – 101 B
4C – Lubrication Fundamentals II: Marine Lubrication – 101 D
4D – Grease III – 101 E
4E – Biotribology II – 101 F
4F – Seals I – 101 G
4I – Commercial Marketing Forum IV – 101 J
4J – Electric Vehicles IV – 200 DE

3:00 pm – 4:00 pm – **Exhibitor Appreciation Break –** Exhibit Hall B

5:00 pm – 6:00pm – Women in Tribology Panel (Open to all attendees) – Seasons

Wednesday, May 22, 2024

6:30 am – 6:00 pm – Onsite Registration (Convention Center Foyer)

Speakers Breakfast
7:00 am – 7:45 am – Seasons

9:30 am – 12:00 pm – **Commercial Exhibits and Student Posters** – Exhibit Hall B

Education Courses – 8:00 am – 5:00 pm
(registration required)

Advanced Lubrication 302: Advanced Lubrication Regimes – 200 F
Auto/Diesel, Gasoline, Hydrogen and Ammonia **(New!)** – 200 J
Metalworking Fluids 240: Metalworking Fluid Formulation Concepts – 200 H
Sustainability: Biolubricants and Biofuels – 200 G
Synthetics: Basics & Applications – 200 I

Technical Sessions – 8:00 am – 12:00 pm
5A – Materials Tribology III – 101 B
5B – Condition Monitoring I – 101 C
5C – Lubrication Fundamentals III: Sustainable Lubrication – 101 D
5D – Gears I – 101 E
5E – Tribology of Biomaterials I – 101 F
5F – Sustainable Power Generation I – 101 G
5G – Fluid Film Bearings I – 101 H
5I – Commercial Marketing Forum V – 101 J
5J – Electric Vehicles V – 200 DE

10:00 am – 10:40 am – **Networking/Refreshment Break** – Exhibit Hall B

12:00 pm – 1:40 pm Lunch (on your own)

Technical Sessions - 1:40 pm – 5:00 pm
6A – Materials Tribology IV – 101 B
6B – Condition Monitoring II – 101 C
6C – Lubrication Fundamentals IV: Oil Degradation – 101 D
6D – Rolling Element Bearings I – 101 E
6E – Environmentally Friendly Fluids I – 101 F
6F – Sustainable Power Generation II – 101 G
6G – Tribochemistry III – 101 H
6J – Electric Vehicles VI – 200 DE

3:00 – 3:40 pm – **Networking/Refreshment Break** – Convention Center Foyer

5:00 pm – 6:00pm – **Worldwide Surface Topography Challenge** – 101 G

Thursday, May 23, 2024

6:30 am – 12:00 pm – Onsite Registration (Convention Center Foyer)

Speakers Breakfast
7:00 am – 7:45 am – Seasons

Education Course – 8:00 am – 5:00 pm
(registration required)

Electric Vehicles 202 **(New!)** – 200 FG

Technical Sessions – 8:00 am – 12:00 pm
7A – Materials Tribology V – 101 B
7B – Condition Monitoring III – 101 C
7C – Metalworking Fluids I – 101 D
7D – Rolling Element Bearings II – 101 E
7E – Environmentally Friendly Fluids II – 101 F
7F – AI and Machine Learning I – 101 G
7J – Electric Vehicles VII – 200 DE
7K – Wear I – 200 B
7L – Nonferrous Metals I – 200 A

10:00 am – 10:40 am – **Networking/Refreshment Break** – Foyer

12:00 pm – 1:40 pm Lunch (on your own)

Technical Sessions - 1:40 pm - 5:00 pm
8A – Materials Tribology VI – 101 B
8C – Metalworking Fluids II – 101 D
8D – Rolling Element Bearings III – 101 E
8E – Environmentally Friendly Fluids III – 101 F
8F – AI and Machine Learning II – 101 G
8K – Wear II – 200 B

3:00 pm – 3:20 am – **Networking/Refreshment Break** – Foyer

Session 1A 101 B

Tribochemistry I

Session Chair: Cinta Lorenzo Martin, Argonne National Laboratory, Argonne, IL

8:00 am - 8:40 am
4002101: The Activation Volume in Tribochemistry: What it Means and How to Calculate It
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

The activation volume gauges the effect of stresses on chemical reaction rates but is only a volume because the conjugate variable of a stress has the units of volume. It can be calculated using the Stearn-Eyring postulate; that it is a product of an activation length, comprising a vector from the initial- and transition-states, and the area over which the stress acts. The activation volume depends both on the direction of the applied force and the nature of the reaction. We discuss how the activation volume can be obtained by calculating the effect of an applied stress on the initial- and transition-state structures and show that the calculated results are in good agreement with the available experimental data. The compliances of these states, obtained from quantum calculations, can also be used to show that the applied stress only modestly influences the activation volume under the experimental conditions that can easily be obtained in the laboratory.

8:40 am - 9:00 am
3987831: Contact Mechanics Correction of Activation Volume in Mechanochemistry
Cangyu Qu, Lu Fang, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Activation volume is the key variable in mechanochemistry describing the effect of stress on reaction rate. However, its physical interpretation remains uncertain and significant discrepancies exist in recent tribology experiments. Here, we analyze the contact mechanics of the standard stress-assisted thermal activation model and find that, in some cases, a large correction is needed. We consider the force-dependent contact area and the nonuniform stress distribution, which were previously overlooked, leading to a correction function. For validation, we study the formation of antiwear tribofilms from zinc dialkyldithiophosphates (ZDDP). Combining colloidal-probe and regular AFM, we show that these and prior literature results, which are widely scattered if treated with the standard model, are in excellent agreement with our corrected model. This provides an accurate method for determining activation volumes and provides insights for interpretating them for elucidating tribochemistry.

9:00 am - 9:20 am
4000886: Molecular Dynamics Study of MAC Lubricants for Aerospace Applications
Daniel Miliate, Ashlie Martini, University of California, Merced, Merced, CA; Andrew Clough, Peter Frantz, Stephen. Didziulis, The Aerospace Corporation, El Segundo, CA

The development of multiply alkylated cyclopentane (MAC) lubricants has been instrumental in addressing challenges in space tribology. However, it is unclear how and why these lubricants ultimately fail, making predictions of performance and service lifetime difficult. Previous work suggested consumption of the MAC lubricants is due in part to lubricant degradation and subsequent volatility in the space environment. The objective of this study was to use molecular dynamics simulations to understand the mechanisms of degradation and volatility of MAC lubricants. Simulations with reactive and non-reactive potentials were used to model 1,3,4-tri-(2-octyldodecyl) cyclopentane under various

conditions to understand lubricant properties and reaction pathways. The findings here contribute to a better understanding of MAC lubricant consumption in aerospace applications.

9:20 am - 9:40 am
4003869: The Effects of -H and -OH Termination on Adhesion of Si-Si Nanocontacts Examined Using Molecular Dynamics and Density Functional Theory
James Schall, North Carolina Agricultural and Technical State University, Greensboro, NC; Brian Morrow, Judith Harrison, US Naval Academy, Annapolis, MD; Robert Carpick, University of Pennsylvania, Philadelphia, PA

Contact between silicon asperities and substrates terminated with -H and -OH functional groups is simulated using reactive molecular dynamics. Adhesion is low at full adsorbate coverages. As the coverage reduces, adhesion increases by factors of ~5 and ~6 for -H and -OH terminated surfaces, respectively, due to the formation of covalent bonds. In contrast, replacing -H groups with -OH groups while maintaining full coverage leads to negligible increases in adhesion indicating that marked increases in adhesion require unsaturated sites. Density functional theory calculations were performed to investigate the energetics of Si (111) surfaces terminated by -H or -OH groups. Both DFT and MD calculations predict the correct trends for the bond strengths: Si-O > Si-H > Si-Si. This work supports the contention of prior experimental observations that strong increases in adhesion after sliding Si-Si nanoasperities over each other is due to removal of passivating species on the Si surfaces.

9:40 am - 10:00 am
4006387: The Role of Shear Stress in ZDDP Tribofilm Formation at the Single Asperity Level
Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

ZDDPs form reaction film exerting antiwear properties by preventing metal/metal contacts. Zhang et al. reported that shear stress accelerated tribofilm formation using MTM-SLIM. However, while the tribofilm formation was generated by single asperity contacts, this aspect has not been extensively studied. The purpose of this study is to examine the effects of shear stress on ZDDP tribofilm formation at the single asperity level. To explore the effect of shear stress at a single asperity, we employed in-situ AFM techniques and assessed compression/shear stresses using FEM. Our results showed that tribofilm growth was prominent under high compression stress. Based on the correlations between compression/shear stresses and tribofilm thickness, only compression stress showed a significant relation with tribofilm thickness during initial sliding cycles. In our presentation, we will report the effects of shear stress on the tribofilm growth, extending our focus on longer sliding durations.

10:00 am - 10:30 am – Break

Session 1B — 101 C

Tribotesting I

Session Chair: George Plint, Phoenix Tribology Ltd., Kingsclere, Newbury, United Kingdom
Session Vice Chair: Kenneth Budinski, Bud Labs, Rochester, NY

8:00 am - 8:40 am
3988407: Development of Within-Cycle Variable Slide-Roll Ratio Test Geometries
George Plint, James Morley, Phoenix Tribology Ltd., Kingsclere, Newbury, United Kingdom

Wear occurs in conjunction with dissipation of frictional energy, generated by the combination of load and sliding speed. Most tribometers provide variable loading, but few offer within-cycle dynamic

loading. Other than reciprocating tribometers, most tribometers provide control of sliding or sliding-rolling velocity, but not within-cycle, dynamically varying, velocity. Various contacts (primarily gears and cams) are subject to both dynamically varying load and slide-roll ratio. We know that in a reciprocating tribometer, with sufficient stroke length, wear rate and mechanism vary with stroke position, hence local sliding velocity. This type of test can go some way towards modelling adhesive wear and scuffing in gears and cams but cannot be used for modelling wear and failure mechanisms associated with contacts subject to within-cycle, continuously variable, slide-roll ratios. This paper reviews the development and use of a number of novel variable slide-roll ratio test geometries.

8:40 am - 9:00 am
3988827: Development of a High-Stress Abrasion Test for Engineering Materials
Kenneth Budinski, Bud Labs, Rochester, NY

The ASTM B611 high-stress (produces crushing of abrasive particles) abrasion test for cemented carbides has been the gold standard for comparing the abrasion resistance of cemented carbides. However, this test does not work on steels and other materials because of adhesive interaction between the test specimen and the test's steel wheel. This project was initiated to explore the feasibility of using a dry particle crushing test rig to replace the ASTM B611 test. Test were conducted to determine the test repeatability and the applicability of the test to cemented carbides, hard steel (type D2 at 60 HRC), and a zirconia/alumina ceramic. It was determined that the test had good repeatability and produced material abrasion resistance rankings that were consistent with industry observations. It is concluded that this test can be a direct replacement for the ASTM B611 test with applicability to all of the candidate materials that may be considered for high-stress abrasion applications.

9:00 am - 9:20 am
3989113: Effect of Nitrogen-Rich Atmosphere on Fuel Lubricity Standards using HFRR, BOCLE, and SLBOCLE
Caleb Matzke, Briana Segal, Nikhil Murthy, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Fuel lubricity has a large impact on system wear in mixed and boundary lubrication regimes found in high pressure fuel pumps, however lubricity standards do not simulate fuel pump environments or reproduce observed pump damage. ASTM D5001 Ball-on-Cylinder Lubricity Evaluator (BOCLE) is used for evaluating lubricity of aviation turbine fuels, while ASTM D6079 High-Frequency Reciprocating Rig (HFRR) is used for diesel fuels. Scuffing Load BOCLE (SLBOCLE) measures scuffing failure in severe conditions in diesel fuels. All are conducted in air rather than the low-oxygen environment found in fuel pumps. We compared the three standards in both air and nitrogen gas environment for a wide range of fuels. We also observed differences in wear and fuel ranking due to the presence/absence of oxygen on fuel lubricity measurements for all fuels. We compare the three testing methods and discuss the differences between them using microscopy and spectroscopy of the wear scars produced from each method.

9:20 am - 9:40 am
3991105: Viscosity Measurement In-Situ Under Pressure Using Ultrasound
Rob Dwyer-Joyce, Gladys Peretti, The Leonardo Centre for Tribology, The University of Sheffield, Sheffield, United Kingdom; Nathalie Bouscharain, Fabrice Ville, University of Lyon, INSA Lyon, Villeurbanne, France; Nicole Dörr, Markus Varga, AC2T research GmbH, Wiener Neustadt, Austria

Machines in industry transmit motions under various speeds and loads, leading to high temperatures, shear rates, and pressures in contacts. Lubricant viscosity is crucial to separate surfaces in contact and ensure good efficiency. Viscosity depends on the operating conditions; its monitoring can thus prevent failures. Conventional viscometers cannot operate in contacts and cannot easily replicate high pressure. Ultrasound is an in-situ and non-destructive technique that has been used for predictive maintenance

and to measure wear or film-thickness. Recently, adding a matching layer improved the sensitivity of shear waves to liquids and thus led to new opportunities to measure lubricant viscosity using ultrasound. A high-pressure cell is instrumented with ultrasonic equipment. Several fluids are pressurized from ambient pressure up to 500 MPa. Ultrasound signals are acquired as well as temperature and pressure recordings. The impact of pressure on the ultrasound measurement is assessed.

9:40 am - 10:00 am
3998051: Experimental Analysis of Pasting of Brushed DC Motors
Roman Dzhafarov, Daniel Braun, Stephan Diez, BMW AG, München, Germany

Modern automobiles are equipped with many components in which DC motors are used. A possible failure mechanism in case of brushed DC motors can be so-called pasting. While operating the DC motor some carbon brush debris accumulates in the commutator's insulating air gaps. It clogs the slots with conductive carbon paste resulting in a loss of insulation resistance between the commutator segments. This phenomenon affects the motors efficiency and finally triggers the failure of the electric motor. The significant influencing parameters of this process are humidity, load regimes and the composition of the carbon brushes. The aim of this work is to derive the scientific understanding of the physical and contact mechanical phenomena behind the process of pasting as well as to show the interactions between the commutator, carbon and the used lubricants by different environmental conditions.

10:00 am - 10:30 am – **Break**

Session 1C — 101 D

Contact Mechanics I

Session Chair: Daniel Mulvihill, University of Glasgow, Glasgow, Scotland, United Kingdom

8:00 am - 8:40 am
4004711: A Semi-Analytical Transient Model of Elastohydrodynamic Mixed Lubrication Bearings under Electrical Loads
Robert Jackson, Jack Janik, Auburn University, Auburn, AL; Sudip Saha, University of North Dakota, Grand Forks, ND

In electric vehicles stray currents can occur due to leakages from the inverter transferring power from the batteries to the motor. These stray currents will seek to cross the fluid film in the rolling element bearings and gears. To cross the insulating lubricant film in the bearings. In so doing, an arc may form and damage the metal bearing surfaces. The current work presents a semi-analytical model of this using closed-form EHL models and modifying them for mixed lubrication and electrical contact. This is done by including a solid rough surface asperity contact model and a flow factor modified lubrication model. Transient effects are also included to consider changes in speed and other parameters during operation. The result is a model that is able to approximately predict the probability of surface damage and electrical properties of the bearings. The predictions are compared to testing and the damaged regions are in qualitative agreement.

8:40 am - 9:00 am
4012275: Contact Electrification-Induced Electroadhesive Axisymmetric Contact Model
Yang Xu, Hefei University of Technology, Hefei, China

Contact electrification (CE) is a universal phenomenon that occurs at the contact interface where tribo-charges transfer from one surface to another. These CE-driven charges can have a significant impact on the adhesive contact. However, these electrostatic charges are commonly ignored in the adhesive test. In the present work, a theoretical model is developed to study the CE-induced electroadhesive axisymmetric contact between a dielectric elastic parabolic surface and a dielectric rigid flat. Systems of non-linear equations are derived when two surfaces are in contact and separation phases, respectively. The results of the analytical model are validated by the recently developed full self-consistent numerical model. The effect of CE on the normal traction, interfacial gap, hysteresis loop and dissipated energy are quantitatively explored. The depth-dependent adhesive test is revisited using the analytical model to show that CE may also be a key factor for depth-dependent hysteresis.

9:00 am - 9:20 am
4004997: Thermoelastic Contact Simulation with Reciprocating Motion and Worn Surfaces
Shuangbiao Liu, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Frictional heating results in temperature rise and thermoelastic deformation of contacting materials. The heat flux is the product of friction coefficient, pressure, and velocity, which can be constant or varying. Steady-state problems or transient cases with constant velocity have been studied extensively, but transient problems with time-dependent heat flux, such as that subjected to a reciprocating motion, have not previously been explored. Furthermore, worn surfaces involving roughness change and wear debris are inevitable; the latter phenomena have profound impact on temperature transients and local deformation and may provide deeper insights into asperity contact evolution. This work consists of numerical simulations of interfacial thermal field and thermoelastic contact with measured worn surfaces to reveal surface evolution under the reciprocating motion. The results provide better understanding of results derived from laboratory tests and actual tribological systems.

9:20 am - 9:40 am
3987354: Inside Sliding Contact: Relationships Between Third Body Formation and Contact Waves
Mathieu Renouf, Alfredo Taboada, Université de Montpellier, Montpellier, France; Francesco Massi, Sapienza University, Rome, Italy

The analysis of sliding contacts is complex because they are the site of many phenomena (elastic accommodation, dissipation, degradation) involving many different physical effects (mechanical, thermal, physico-chemical). Through numerical simulation at the interface scale, based on discrete element simulations, we focus on the dynamic behavior of dry contacts and more particularly on the initiation of shear. We analyze the generation and evolution of the third body and its impact on the contact waves evolving in the structure.

9:40 am - 10:00 am
4006032: An Investigation of Hertz Theory as Applied to Spinning, Bouncing Balls
Jeffrey Streator, Prairie View A&M University, Prairie View, TX

Hertzian contact theory, which has been around for more than a century, is predicated on quasi-static deformation mechanics. This aspect of Hertzian theory is worthy of note given that Hertzian contact theory, in particular, and (quasi-static) elasticity theory, in general, are routinely applied to bodies that are far from static. The question, arises, therefore, as to the degree of applicability of Hertzian theory to short-lived contacts. For the current work, the validity of Hertzian contact theory for contacts of short duration is investigated. Polished steel balls are dropped from varying heights above polished steel slabs at various spin rates. The spin behavior of the balls before, during, and after the impact is recorded. A mathematical model based on Hertzian contact theory is developed. Predictions of the model are compared to experimental results.

10:00 am - 10:30 am – Break

Session 1D — 101 E

Synthetic Lubricants and Hydraulics I

Session Chair: Ryan Fenton, BASF Corporation, Tarrytown, NY
Session Vice Chair: Paul Norris, Afton Chemical Ltd., UK, Bracknell, United Kingdom

8:00 am - 8:40 am
4000842: Hydraulic Fluid Performance Demonstrations According to ASTM D7721 – Energy Savings Validated with Shear-Stable, High-VI Technology
Ricardo Gomes, Frank-Olaf Maehling, Thilo Krapfl, Evonik Oil Additives, Darmstadt, Germany

The fluid power industry sees an increasing need for reliable energy-efficient solutions. The efficiency of hydraulic fluids can be quantitatively compared according to the ASTM D7721 practice that defines minimum technical requirements for conducting tests with two or more hydraulic fluids, whereby in particular the last revision of year 2022 also refers to real world investigations. Hydraulic applications in the mobile and stationary applications (i.e., excavators and injection molding machines), are described in more detail. Our publication discusses test procedures and results on such equipment with monograde and shear stable high VI hydraulic fluids. The selection of a high VI hydraulic fluid with proper viscosity and shear stability is critical to obtain optimum system response and guarantee high long-term performance. The experiments confirm that shear stable polyalkylmethacrylates are the most suitable VI improvers to formulate energy-efficient hydraulic fluids.

8:40 am - 9:00 am
4002669: Zn-Free Strategies to Meet Bosch Rexroth Hydraulic Performance
Joshua Dickstein, Ryan Konrad, The Lubrizol Corporation, Wickliffe, OH

In addition to transmitting power, hydraulic fluids are responsible for lubricating hydraulic pumps, motors, and other system components. One of the many performance demands on the fluid includes protecting pumps against excessive wear. The market is demanding improved performance from hydraulic fluids and the high pressure/speed Bosch Rexroth RFT-APU-CL pump/motor test is considered a benchmark for high performance hydraulic fluids. Antiwear protection is usually accomplished through addition of zinc dialkyl dithiophosphates (ZDDP) which form protective sacrificial layers in tribological contacts. Fluids lacking ZDDP antiwear components are often unable to provide sufficient tribological protection of the brass parts to meet the Bosch Rexroth pump test requirements. However, there is a growing demand for zinc-free fluids that can deliver the same level of performance. This paper will describe efforts to overcome these performance challenges with zinc-free hydraulic additive formulating.

9:00 am - 9:20 am
3983883: Performance of Novel & Sustainable Synthetic Ester Base Oils with Hybrid Functionality
Martin Greaves, Jeff Dimaio, Ben Bergmann, Zach Hunt, VBASE Oil Company, Pendleton, SC

Secondary Polyol Ester™ base oils are a new family of API Group V synthetic base oil. The versatility of this platform chemistry allows for the possibility of creating a very diverse range of novel hybrid base fluids and performance additives. It is possible to control many functional and environmental performance properties that are critical to lubricant performance by carefully choosing the synthetic precursors. The performance of a range of new biodegradable base oils across the ISO-32 to 460

viscosity range will be illustrated. Their impressive hydrolytic, shear and oxidation stability will be discussed. Concepts for using them as deposit control additives and friction modifiers in alternative base oils will also be highlighted.

9:20 am - 9:40 am
3991059: Technical and Scientific Perspective from Using Polyglycol on a Composition of Compressor Lubricants
Eduardo Lima, Dow Chemical Brazil, São Paulo, Brazil

Perspective from relevant dimensions attributed to polyglycol as a high-performance and differentiated synthetic base lubricant technology applied to compressor systems, exploring from the polyglycol synthesis process to the technical attributes.

9:40 am - 10:00 am
3998770: Energy Efficient Compressor Lubricants for Low-GWP Refrigerant Systems
Justin Kontra, Frank-Olaf Maehling, Evonik Oil Additives, Horsham, PA; Xin Ding, Eckhard Groll, Davide Ziviani, Purdue University, West Lafayette, IN

Approaches to improve the efficiency of positive displacement compressors have focused mostly on design and refrigerant choice, while the development of high viscosity index (VI) lubricants to boost performance remains underutilized. Ideal lubricants protect surfaces, enhance sealing at compression interfaces, improve efficiency, and are compatible with low-GWP refrigerants. To measure the impact of high VI lubricants in these systems – formulations containing shear stable poly (alkyl methacrylates) were evaluated. These lubricants combine high VI, compatibility with several classes of refrigerant, and robust thermal/oxidative and hydrolytic stability. On a hot gas bypass test stand, steady state data points were measured using transcritical CO_2 compressors. The fluids containing poly (alkyl methacrylates) and VI of up to 200 demonstrated strong performance over a wide range of operating conditions and viscosity grades, while maintaining high oil stability in the CO_2 environment.

10:00 am - 10:30 am - **Break**

10:30 am - 11:30 am - **Synthetic Lubricants & Hydraulics Business Meeting**

Session 1F — 101 G

Nanotribology I

Session Chair: Lang Chen, ExxonMobil, Annandale, NJ
Session Vice Chair: Pranjal Nautiyal, Oklahoma State University, Stillwater, OK

8:00 am - 8:40 am
3997970: Invited Talk: Revealing the Structure-Property Relationships of Amorphous Carbon Tribofilms on Platinum-gGld Nanocrystalline Alloys
Frank DelRio, Tomas Babuska, David Adams, Ping Lu, John Curry, Brad Boyce, Sandia National Laboratories, Albuquerque, NM; Filippo Mangolini, Camille Edwards, The University of Texas at Austin, Austin, TX; Jason Killgore, National Institute of Standards and Technology, Boulder, CO

Platinum-gold (Pt-Au) nanocrystalline alloys have exhibited coefficients of friction as low as 0.01 and specific wear rates of about 10^{-9} mm^3 N^{-1} m^{-1}, largely due to the formation of carbon-based tribofilms. In this work, we examine the tribofilm structure-property relations via high-throughput and high-resolution measurements as a function of Pt-Au composition. As the Au solute content increased,

average grain size decreased and grain boundary (GB) segregation increased, which translated to a decrease in modulus via a rule-of-mixtures approximation and an increase in hardness from GB stabilization. Moreover, steady state-friction and wear decreased with Au content; low Au-content films showed substrate wear, while high Au-content films showed stable tribofilm growth. Finally, the tribofilm bonding configuration and viscoelastic properties were found to be consistent with hydrogenated amorphous carbon films. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

8:40 am - 9:00 am
4006170: Atomistic Simulations of Chemomechanics at Electrified Interfaces
Aravind Krishnamoorthy, Texas A&M University, College Station, TX

Designing more efficient mechanical energy transmission across electric powertrains requires a deeper understanding of molecular mechanisms of reactivity and chemomechanics at electrified interfaces. We perform density functional theory calculations and reactive molecular dynamics simulations to understand the surface reactivity and evolution of tribolayers at in electrified and non-electrified contact. Specifically, atomistic simulations of polyalphaolefin (PAO) lubricants in contact with naturally-oxidized steel surfaces describe the decomposition of lubricant molecules leading to the formation of amorphous, non-protective FeC-rich tribolayers, which degrade upon mechanical loading. The formation of Fe-C bonds is enhanced by higher temperatures, presence of electric fields and reducing agents in PAO. Insights from these simulations can provide design rules for realizing more protective tribolayers that are stable under extreme conditions of friction, temperature and electrification.

9:00 am - 9:20 am
4001738: Chemical Absorption-Induced Hysteretic Friction Behavior of Supported Atomically Thin Nanofilm
Philip Egberts, Chaochen Xu, University of Calgary, Calgary, Alberta, Canada

The hysteretic friction behavior of supported atomically thin nanofilms with chemical absorption was studied using atomic force microscopy (AFM) experiments. Samples of graphene, h-BN, and MoS_2 exfoliated onto silicon wafers and chemical reagents such as ethanol and acetone were evaporated in the vicinity of the nanofilms. It was found that the surface friction of nanofilms was increased with the with absorption of the reagents. A correlation between the hydrophobicity of the evaporated solvent and the measured friction was observed, indicating the essential role of the chemical absorption in the 2D nanofilm/substrate in tuning the friction behaviors of supported 2D materials.

9:20 am - 10:00 am
4079115: Bridging Atomistic and Continuum Scales Simulations for the Modelling of Mechanochemical Interactions and Tribofilm Growth
Daniele Dini, Stavros Ntioudis, James Ewen, Imperial College London, London, United Kingdom; C. Turner, University of Alabama, Tuscaloosa, AL

Generally, the investigation of thin films over experimentally-relevant timescales (i.e., seconds, minutes, hours) becomes infeasible through standard low-level methods (e.g., ReaxFF/NEMD or DFT) and typically demands the use of a multiscale modeling framework. We have therefore recently developed a numerically efficient and easy-to-implement off-lattice kMC framework. The proposed hybrid off-lattice kMC/MD framework relies on predefined transition events, therefore relaxing the limitations associated with on-the-fly methods and unlocks the possibility for off-lattice kMC simulations on amorphous systems involving different elementary events (e.g. reactions, adsorption/desorption, diffusion) over experimental timescales (i.e., seconds, minutes, hours). The method is tested to study thermal decomposition (and film growth) of TCP molecules on FE surfaces. This study represents a crucial step towards the virtual screening of lubricant additives to optimize tribological performance.

10:00 am - 10:30 am - **Break**

Session 1G 101 H

Surface Engineering I

Session Chair: Ali Beheshti, George Mason University, Sterling, VA
Session Vice Chair: Piash Bhowmik, University of North Dakota, Grand Forks, ND

Session Starts at 8:40 am

8:40 am - 9:00 am
4003937: Exploring the Tribological Behavior of Additively Manufactured Al-6061 Alloy for Space Applications
Pial Das, Sougata Roy, Iowa State University, Ames, IA; Matthew Mazurkivich, William Scott, Sara Rengifo, Marshall Space Flight Center NASA, Huntsville, AL

The use of additive manufacturing of Al6061 alloy provides additional freedom to fabricate custom parts with intricate geometries. Interestingly, the tribological performance of additively manufactured Al6061 components has remained relatively unexplored till date. In this study, we carried out a comprehensive investigation into the additive manufacturability and tribological performance of Al6061 alloy. Wire Arc Additive Manufacturing (WAAM) and Laser-Powered Direct Energy Deposition (LP-DED), two prominent metal AM routes were leveraged to fabricate test samples. Furthermore, TiC reinforced Al metal matrix composites (MMC) were developed with varied reinforcement percentages. Post fabrication, detailed microstructural characterization and tribological behavior in vacuum was conducted with detailed analyses of dominant wear mechanisms. This is the first time, an exhaustive discussion focusing DED and WAAM printed Al parts for space applications are presented in this study.

9:00 am - 9:20 am
4005694: Exploration of Spectrum Data from Non-Destructive Surface Roughness Measurement Techniques of Additively Manufactured Ti-6Al-4V
Robert Jackson, Loren Baugh, Samsul Arfin Mahmood, Kyle Schulze, Auburn University, Auburn, AL

Additive manufacturing is becoming an increasingly popular alternative for manufacturing high quality parts across a wide range of applications. A critical property that directly affects the fatigue life of an additively manufactured part is surface roughness. Understanding effective methods for characterizing surfaces and obtaining critical surface features that are responsible for catastrophic failures of the additively manufactured parts is critical to understanding their performance. Comparing different surface measurement techniques provides insight into the benefits and shortcomings of different working principles when representing a surface with scan data. It is important to identify what data is significant with respect to understanding specimen behavior, and an exploration of the spectrum of the scan data can be used to extrapolate additional potentially useful data even generating new data representing an area from a single surface profile.

9:20 am - 9:40 am
4043072: Physics-Informed Machine Learning to Improve Manufactured Surfaces
Tevis Jacobs, Lars Pastewka, Surface Design Solutions, Pittsburgh, PA

Surface topography controls the performance and reliability of surfaces in applications from automotive and aerospace to medical devices and consumer electronics. Yet too often our strategies to find the optimal surface finish rely on trial-and-error testing. While great strides have been made in the theory

and simulation of roughness-dependent surface performance, it remains difficult to translate this into the design and control for manufacturing. Recently, significant advances have been made in the science-guided optimization of surface topography. First we will review the physical models that predict performance relevant to real-world manufacturing scenarios. Then we will present recent advances in the use of physics-informed machine learning to improve surfaces. The use of AI eliminates the dependence on traditional roughness parameters and enables the direct modification of key performance indicators such as production efficiency, product lifetime, and product performance.

9:40 am - 10:00 am
4004324: Ultrasonic Nanocrystal Surface Modification: State-of-the-Art and Tribological Properties
Auezhan Amanov, Tampere University, Tampere, Finland

This paper provides a broad and comprehensive review of the most recent progress in the fundamental understanding of nanostructured surface layer materials produced by the ultrasonic nanocrystal surface modification (UNSM) technique on the tribological properties of materials. In this study, we demonstrate a detailed description of the literature on the subject and highlight challenges to producing nanostructured surface layer materials to improve the tribological properties of various materials, including additive manufacturing materials. This UNSM technology is widely used in industry due to its remarkable strengthening effect, low cost, and good adaptation. Recently, a portable UNSM technique was developed to be used directly in the field. This study focuses on the rigorous research and development of the current state-of-the-art UNSM technique with recent experimental results and potential tribology-related industrial applications.

10:00 am - 10:30 am - **Break**

Session 1I — 101 J

Commercial Marketing Forum I

8:20 am - 8:40 am
4084435: BYK Additives for Industrial Lubricants and Greases
Maximilian Boehmer, BYK-Chemie GmbH, Wesel, North Rhine-Westphalia, Germany

In the world of industrial lubricants, the effective management of foam, the improvement of grease viscosity and the stabilization of solid particles are key challenges. BYK proves to be a reliable supplier, offering a range of additive solutions for the lubricant sector. At the forefront of our offering are silicone and silicone-free defoamers that have been carefully developed to meet the requirements of all API classes. These defoamers are an indispensable tool to reduce foaming and ensure optimal performance in various applications. In parallel, BYK presents organoclays tailored to elevate the viscosity and stability of lubricating greases. Moreover, our dispersing additives stabilize solid particles such as graphite, MoS_2, PTFE, and an array of other fillers within lubricating oils. From perfect particle dispersion to anti-sedimentation and maintaining viscosity under high loads, our solutions are precisely tailored to the diverse challenges encountered in the lubricants market.

8:40 am - 9:00 am
4093494: Chevron Phillips Chemical Company: Synfluid® PAO as a More Sustainable Solution
Ken Hope, Tom Malinski, Chevron Phillips Chemical Company, The Woodlands, TX

The sustainability needs of the world are driving enhanced focus on how products are made and used. To meet these needs, there are many new and developing applications where Synfluid® PAO can aid in energy and emissions reduction. These are typically based upon the physical property requirements of

developing applications centered around the frictional properties and longevity of the fluid. This presentation will demonstrate the impact of PAO usage on energy reduction in the transportation and industrial sectors, which highlights the benefit side of the sustainability equation.

9:00 am - 9:20 am
4090696: DL Chemicals: Engineered Ethylene Propylene Copolymer System with High Performance Capability: Beyond Conventional OCP (Olefin copolymers)
Hoon Kim, DL Chemical Co. Ltd., Daejeon, Republic of Korea

Viscosity index is an empirical parameter indicating the resistance to viscosity change of a fluid with temperature variation. High VI is favorable as it means less thinning at high temperature. High VI can be achieved by addition of polymeric VM (viscosity modifiers). Although higher Mw is preferred for high TE (Thickening Efficiency) and high VI, higher Mw materials are more prone to the degradation under shear and are less shear stable. Because shear force tends to concentrate in the middle of the chain and so, the longer polymer chain is easier to break down. Shear stability is measured by viscosity loss after shearing. Along this line, DL Chemical has developed a series of engineered OCPs with high HTHS viscosity and excellent shear stability based on its unique metallocene catalyst technology that can control the key properties of the OCP system. In this presentation, we will introduce our latest OCP product along with its performances in terms of HTHS viscosity and shear stability.

9:20 am - 9:40 am
4091450: Colonial Chemical: Enabling the New-generation Metalworking Fluid Formulation
Steven Tang, Colonial Chemical Inc., South Pittsburg, TN

Many factors are shaping the new-generation metalworking fluids formulation. This presentation will examine those key factors and explore how to enable the performance expected for the next-generation metalworking fluids from additive perspectives.

9:40 am - 10:00 am
4093241: LANXESS: Hybase® GFX500: The Development of a Novel Incidental Food Contact Calcium Sulfonate
Ross Dworet, Lanxess Corporation, Shelton, CT; Wayne Mackwood, Jeremy Brideau, Lanxess Canada Co./Cie, Toronto, Ontario, Canada

LANXESS Application Technology performed a deep-dive study on what makes an ideal H1 CSC grease resulting in a next gen Overbased Calcium Sulfonate (OBCS), Hybase® GFX500, and platform. CSC Greases see wider adoption in the market including H1 versions requiring a high quality and performance OBCS. With 60+ years of OBCS and 20+ years in H1 CSC greases learning, LANXESS reexamined H1 grease formulations focused on emerging regulatory trends. The outcome, Hybase GFX500, a new performance OBCS, was developed to meet incidental food contact approval suitable to produce a high performance H1 finished grease. Compared to standard CSC grease, a grease thickened with Hybase GFX500 shows equal or better core performance combined with improved low temperature properties and improved oxidation life. LANXESS will demonstrate how it has leveraged its history in OBCS tech to develop the next-gen H1 OBCS offering superior performance while addressing evolving regulatory and performance challenges.

10:00 am - 10:00 am – **Break**

Session 1J 200 DE

Electric Vehicles I

Session Chair: Cole Frazier, Southwest Research Institute, San Antonio, TX

Session starts at 8:40 am

8:40 am - 9:00 am
4003758: Testing Approaches for Developing and Validating EV Fluids
Flavio Sarti, TotalEnergies, Solaize, France

As new electric powertrain technologies continue to evolve, new and promising prospects for multi-functional EV fluids are emerging, which raises the question of how to develop and validate them. This work shows how TotalEnergies implements a novel testing approach that integrates traditional laboratory standards with in-house methods based on vehicle fleet tests and entire system rigs (2EM & 3EM configurations). This approach aims to shorten the testing time and improve the reliability of the results, by introducing a new and more representative level.

9:00 am - 9:20 am
4004847: Oil Immersed Energized Copper Circuit Board Test Understanding
Hitesh Thaker, Scott Campbell, Infineum USA L.P., Linden, NJ

The development of new generation hybrid and electric vehicles with oil-cooled motors has created the need of dedicated fluids with improved efficiency and material compatibility. Copper compatibility especially in an energized e-motor environment is gaining a lot of attention in the automotive industry. An energized copper corrosion test (ECT) has been developed to study the impact of e-fluids on energized copper surfaces. The test is still evolving with variation different parameters including temperature, time, copper board setup and stacking. Understanding the impact of these parameters is key to developing new test methods and screen e-fluid candidates with better copper compatibility.

9:20 am - 9:40 am
4005529: Shaft Voltage Causes Bearing and Lubricant Degradation
Simon Hausner, Flucon, Barbis, Germany

Induction or capacitive charge, especially in electric machines operated at high frequencies, causes potential differences in the bearings, which can lead to spontaneous discharge through the otherwise insulating bearing lubricant. These electrical breakdowns damage the surfaces of the rolling elements and the bearing shells, creating pitting, fluting patterns, and reducing the lifetime of electric drives. The bearing lubricants must act as a countermeasure to these effects. Lubricants must be developed to provide sufficient isolation in the EHD contact or make discharge impossible through increased electrical conductivity. Utilizing an isolated assembly to measure the electrical impedance of a loaded thrust bearing and evaluate lubricants' ability to conduct discharge currents depending on operating conditions, various lubricants and film thicknesses were tested; this generated, detected, and evaluated breakdowns in tribological films, correlating them with bearing damage and life.

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

10:00 am - 10:30 am - **Break**

Tribochemistry II

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

1:40 pm - 2:20 pm
3988134: Analytical Tribology With a High Resolution 6 Axes Tribometer
Julien Fontaine, Antoine Normant, Galipaud Jules, Frédéric Dubreuil, CNRS/Ecole Centrale de Lyon, Ecully Cedex, France

In order to better understand tribological phenomena, a traditional approach consists in performing some surface analysis inside and outside the wear tracks. These analyses are frequently structural or chemical, sometimes mechanical. In this work, we use a high-resolution environment-controlled tribometer, based on a six axes force sensor, to probe existing wear tracks on hydrogenated amorphous carbon (a-C:H) films. This original approach helps understanding the respective role of surface modifications on the a-C:H coated flat or on the facing steel pin on the achievement of superlow friction. These experiments are combined with more traditional analytical means, like in situ XAES or AES analyses or ex situ SEM or AFM observations. The growth of a carbon-rich tribofilm on the steel counterpart appears necessary but not sufficient to reach superlow friction. Changes on the topography and chemistry of the a-C:H film seems also paramount.

2:20 pm - 2:40 pm
4005299: Microscale Tribochemistry of Diamond-Like Carbon Coatings
Brian Borovsky, Maureen Bowen, Ana Colliton, Hind Flaih, Eskil Irgens, Lucas Kramarczuk, Griffin Rauber, Zachary Van Fossan, Jordan Vickers, St. Olaf College, Northfield, MN; Seokhoon Jang, Seong Kim, Pennsylvania State University, State College, PA; Zhenbin Gong, Junyan Zhang, Lanzhou Institute of Chemical Physics, Lanzhou, China

We present results from a study of sliding friction on hydrogenated diamond-like carbon (H-DLC). We load a stainless-steel microsphere onto a H-DLC surface coated onto quartz crystal microbalance (QCM). By resonating the QCM, we generate a reciprocating shear motion at the interface with track lengths of 1 to 100 nm and a frequency of 5 MHz. The QCM performs friction measurements with the normal load fixed at values between 5 µN and 1 mN. These measurements can be sustained even when a secondary lateral motion is superimposed using a piezo stage, with a track length of 20 µm and frequency of 40 Hz. Our results show that adding microscale sliding causes a substantial reduction in friction detected by the QCM, after which a transfer film is observed on the tip. We associate this with the “running-in” behavior of H-DLC and its shear plane chemistry. We explore relationships between the sliding distance, contact size, and the tribochemistry of the transition to low friction sliding.

2:40 pm - 3:00 pm
4003327: Selective Coating on Metal Surfaces with Friction-Assisted Electrodeposition
Yang Song, ChenXu Liu, Yonggang Meng, Tsinghua University, Beijing, China

Nanocrystalline FeCoNi alloys were selectively deposited on a specified zone of a GCr15 bearing steel surface from the nonaqueous electrolyte with a novel friction-assisted electrodeposition (FAED) process. The results revealed that the friction load and deposition time played a significant role in controlling the surface morphology and thickness of the deposits. A uniform element distribution on the cross-section of the deposited film was observed. Moreover, the as-deposited layer shows a matching mechanical property to GCr15 substrate including hardness and complex modulus. This work demonstrates that

friction can provide fresh surface for crystal nucleation and eliminate “tip effect” for grain refine, meanwhile, the energy input from friction effectively promotes the reduction reaction. The monitoring of friction coefficient during FAED process can be used to estimate the stage of deposition layer growth.

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

4:00 pm - 4:20 pm
4001225: Friction and Wear Behavior of Gaseous and Volatile Fuels Using a Sealed Tribometer
Janet Wong, Jie Zhang, Hugh Spikes, Imperial College London, London, United Kingdom

The quest to reduce CO_2 emissions is leading to a transition from liquid hydrocarbon fuels such as gasoline and diesel to low carbon gaseous fuels such as methane, hydrogen and ammonia, as well increased use of gasoline/ethanol blends. In practical terms it is quite difficult to measure the tribological properties of these fuels; for gases because of containment issues and, for gasoline/ethanol blends, because they undergo selective evaporation and thus change composition during testing at elevated temperature. In this presentation we describe the use of a sealed tribometer, an HPR, to measure the friction and wear properties of both these classes of fuels. Based on the results obtained, the ability of these fuels to form tribofilms and their underlying mechanisms of action are discussed.

4:20 pm - 4:40 pm
3981340: Chemical Compatibility of Metal Oxide Nanoparticles and Lubricant Co-Additives
Imène Lahouij, Adam Nassif, Zhengyuan Peng, Frédéric Georgi, Pierre Montmitonnet, MINES Paris|PSL Research University, Sophia Antipolis, France

Nanoparticles (NPs) have been extensively studied for their potential use for lubrication due to their promising tribological properties. However, the interactions between NPs and the lubricant additive package can be complex, leading to either synergetic or antagonist effects. This can in turn influence the composition and robustness of the tribofilms. Here, we attempt to better understand how specific properties of metal oxide NPs, such as size, chemistry and density influence their compatibility with commercial additives. Various formulations were prepared using three commercially available additives and two different metal oxide NPs. Tribological experiments were conducted at boundary regime using pin-on-disc tribometer. The chemical composition of the tribofilms and their mechanical robustness were evaluated using respectively XPS and in situ SEM micro-mechanical testing setup. In the light of these results, the interaction mechanisms between NPs and additives are discussed.

4:40 pm - 5:00 pm
4025582: The Effect of Lubricant Contamination with Water on Friction Modifiers Tribofilm Properties
Ajay Pratap Singh Lodhi, Ardian Morina, University of Leeds, Leeds, United Kingdom

The appropriate use of chemical additives in lubricants can mitigate the impact of friction and wear in mechanical systems. Under severe conditions, these additives undergo tribochemical reactions, creating a low-friction tribofilm. However, presence of water in lubricant adversely affects the tribofilm’s growth and effectiveness. This study aims to: (I.) analyse the chemical composition of the tribofilm both with and without water in real-time, and (II.) study the effect of film growth on the dynamics of friction and wear. Several formulated oils containing organic (OFM) and inorganic (MoDTC) friction modifiers have been tested using a bespoke pin-on-disc tribometer integrated with Raman spectroscopy for real-time tribofilm analysis. SEM-EDS and FIB-TEM were also employed to obtain tribofilm chemical composition and thickness. The paper will discuss the effect of water contamination on tribofilm composition and its tribological performance relevant to the lubrication of hybrid engines.

Session 2B 101 C

Tribotesting II

Session Chair: Damien Yiyuan Khoo, Bruker Nano Inc., San Jose, CA
Session Vice Chair: Amani Byron, University of California, Merced, Merced, CA

1:40 pm - 2:20 pm
4002289: Recent Advances in Design and Development of Tribotesting for Electric Vehicle Lubricants
Damien Yiyuan Khoo, Melinda Bullaro, Bruker Nano Inc., San Jose, CA

The demand for new lubricants capable of withstanding the severe conditions in electric vehicle (EV) powertrains increases as the electric mobility gains its momentum. High starting torques, high speeds, and uncontrollable electrical currents passing through contact points create difficulties for EV lubricant testing. Conventional tribotesters are not developed for effective lubricant analysis in electrified environments. This study presents a modular benchtop tribometer equipped with a power source and a resistance data logger to evaluate the tribological performance of various EV lubricants under electrified conditions with varying sliding conditions. The findings suggest that the presence of electrical current at contact interfaces significantly affects friction, electrical contact resistance, and wear. Consequently, the electrified tribological testing methods explored in this study could potentially offer faster and more precise screening of electric/hybrid lubricants.

2:20 pm - 2:40 pm
3999049: Electrified Benchtop Tribology Grease Testing
Amani Byron, Ashlie Martini, University of California, Merced, Merced, CA; Tushar Khosla, Vishal Khosla, Rtec Instruments, San Jose, CA

Standard benchtop tests for grease tribology were modified to evaluate the effect of electric current on grease lubrication. Friction and wear performance with current were compared to results obtained using industry standards for commercially available electric motor greases. Then, test parameters were modified such that the benchtop conditions mimicked those in electric vehicle applications as closely as possible. Results were analyzed in terms of the effect of current on lubricant properties as well as the tribological interface itself.

2:40 pm - 3:00 pm
3999441: A Novel Approach for Tribological Evaluation of Textured Surfaces from Additive Manufacturing
Tobias Martin, Q. Jane Wang, Jian Cao, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Textured surfaces from laser powder bed fusion additive manufacturing (AM) possess unique tribological properties. Wear volume and steady-state friction are important characteristics; however, in boundary lubrication, material removal overlooks wear debris caught by surface texture and its effect on roughness parameters. Two measurements are proposed based on reciprocating ball-on-flat tribotests, affected and retained material, describing the amount of material participating in the contact and the portion of affected material remaining on the surface, as opposed to being removed. From this information emerge new avenues to understand how surfaces evolve. The results reveal, among other characteristics, that as-built AM surfaces readily retain wear debris, decreasing the wear track's maximum profile height and RMS slope. Though AM surfaces have more affected material than polished

surfaces, this retaining behavior, with appropriate texture orientations, results in similar wear volumes.

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

4:00 pm - 4:20 pm
4002066: Intelligent Lubrication: From Open-Loop to Closed-Loop
Min Yu, Imperial College London, London, United Kingdom

In most lubricated machines, a single fluid has to be “globally” used as a lubricant irrespective of the operational load, speed and temperature at multiple component contacts. However, lower viscosity of lubricant is desirable under high-speed and low-load operation condition, and vice versa, making the single-fluid lubrication performance inevitably compromised. To address these problems, the present work aims to design a closed-loop low-friction interface by actively controlling viscosity of lubricant with magnetorheological (MR) fluid at optimal values. Particularly, a lubricated piston-liner contact in a reciprocate rig is set up, a magnetic field is to actuate the fluid viscosity variation, the sliding frication and speed are taken into measurements feedback, and a PID controller is synthesized to minimize the interface friction. Experimental results show that the closed-loop lubrication system substantially reduces friction coefficients as compared to the open-loop one.

4:20 pm - 4:40 pm
4004486: Correlating Wear Performance with Lubricant Properties of Real Used Heavy-Duty Diesel Engine Oils
Thomas Kirkby, Tom Reddyhoff, Imperial College London, London, United Kingdom; Joshua Smith, Jacqueline Berryman, Mark Fowell, Infineum UK Ltd., Abingdon, United Kingdom; Claes Frennfelt, Patrick Holmes, Volvo Group Trucks Technology, Greensboro, NC

Soot levels in engine oils have increased due to longer service intervals and the drive to reduce emissions. This leads to problematic wear of components, especially in heavy-duty diesel engines. We have previously revealed the soot wear mechanism for a single soot-containing used engine oil. Here, we conducted rubbing tests on 11 used, soot-containing heavy-duty engine oil samples from engine dynamometer and real-world field trials. Regression analysis was used to correlate the wear volumes with 55 oil properties. This showed the single most important oil property in predicting wear volume to be Total Acid Number, TAN (low TAN --> high wear). Low wear also correlated with soot particle size/circularity, suggesting an abrasive mechanism, and pre-test calcium concentration. The reasons for these correlations and the resulting insights into heavy-duty engine wear mechanisms will be revealed in the presentation.

4:40 pm - 5:00 pm
4088646: Threaded Fastener Joints: Friction Control with Soft Coatings
Sergei Glavatskih, KTH Royal Institute of Tribology, Stockholm, Sweden

Threaded fasteners are a key technology in aerospace, automotive industry, power generation, rail transport, etc. To ensure an optimum friction range and protect the bolts against corrosion, coatings are used. New environmentally friendly coatings (mostly zinc-based) that replace chromium VI containing ones may give rise to a larger variation and uncertainty in friction. For environmental reasons and competitiveness, industry is also adopting new fastener tightening techniques. These trends have led to new behavior in the torque tightening curves of threaded fasteners, further complicating an already uncertain picture in the use of this ubiquitous component. Friction in the underhead contact dominates and, unfortunately, surface conditions in this contact are often overlooked. In this talk we show how a change in surface conditions (humidity, residues of cutting fluids, manufacturing method) may change friction behavior, affecting the clamp force and reliability of the joint.

5:00 pm - 6:00 pm - **Tribotesting Business Meeting**

Session 2C 101 D

Contact Mechanics II

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

Session starts at 2:20 pm

2:20 pm - 2:40 pm
3981100: A Multiscale Modeling System for Simulating a Radial Pump Plunger to Observe and Improve Tribological Performance
Henry Soewardiman, Shuangbiao Liu, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Nikhil Murthy, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

The plunger-bore interface of a high-pressure radial fuel pump is critical for the efficient delivery of high-pressure fuel. This interface has a clearance of at most a few microns and is easily subjected to misaligned plunger motion. This misalignment prompts scuffing under marginal lubrication conditions. Presented here is a multiscale modeling system of the pump, aiming to understand and quantify the behavior at the interface during a pumping cycle. This system couples the system-scale plunger motion and pumping mechanism with a comprehensive analysis of critical rubbing conditions, including the impact of surface roughness and solid-solid contact. The plunger performance is evaluated through the film thickness, pressure, and leakage. Surface design schemes are proposed, and their impact on the pump performance are evaluated to support a robust and efficient plunger-bore interface.

2:40 pm - 3:00 pm
4011644: Design Improvement of Clearing Plate in a Biomass Comminution System through Contact Analysis
Lianshan Lin, James Keiser, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; Chris McKiernan, David Lanning, Forest Concepts, Auburn, WA

The Crumbler rotary shear system was designed to achieve ideal feedstocks with small but equal sizes, which can improve flowability therefore to reduce costs and energy. Apart from improving the wear resistance of major components, accelerating the feedstock flow through the rotary shear machine plays an equivalent role in improving its efficiency and saving the cost simultaneously. This study focuses on optimizing the clearing plate in the Crumbler rotary shear system to enhance feedstock flowability and improve wear resistance. We employ analytical analysis and finite-element simulations to investigate the impact of surface curvature on contact pressure from wood particles. The optimized clearing plate is expected to extend its lifetime and enhance wood chips' flowability. Field tests with the newly designed clearing plates validate the advantages. The methodology and validation techniques offer valuable insights for addressing wear problems in similar static components.

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

4:00 pm - 4:20 pm
3991076: Exploring the Mechanics of Triboelectric Nanogenerators via In-Situ Experiments
Daniel Mulvihill, Charchit Kumar, Gaurav Khandelwal, Elias Bokedal, Nikolaj Gadegaard, University of Glasgow, Glasgow, United Kingdom

With the increasing use of sensors and self-powered devices, the need for sustainable and distributed power sources has become increasingly high. In this regard, a new energy harvesting technology, based on triboelectric nanogenerators (TENGs), is emerging. Lately, TENG research has grown considerably, but the fundamental governing mechanisms are still not fully understood. In this work, nominally flat rough surfaces were fabricated using micro-molding techniques. A bespoke test rig was developed, based on repeated contact-separation mode, to concurrently measure the electrical signal, contact force, and contact area. Tests were performed to investigate the contact area and load dependent electrical response. Automated image analysis macros were developed to process the contact interface images. The comprehensive electro-mechanical investigation results provide an improved understanding of triboelectrification in TENGs at a small scale and a correlation with localized contact areas.

4:20 pm - 4:40 pm
4015264: Influence of Poroelasticity and Unloading Rates in Enhancement of Gel Adhesion
Wonhyeok Lee, Melih Eriten, University of Wisconsin-Madison, Madison, WI

Hydrogels, polymeric networks swollen with water, exhibit time/rate-dependent adhesion due to their poroviscoleastic constitution. In this study, we conduct probe-tack experiments on gelatin and investigate the influence of water drainage and unloading rate on pull-off forces and work of adhesion. We also utilize in-situ contact imaging to monitor separation kinematics and interfacial crack speeds. At maximum drainage and unloading rates corresponding to subsonic interfacial crack speeds, we observe an order of magnitude enhancement in adhesion. Through relaxation tests, we identify a quick viscoelastic relaxation response followed by a slow poroelastic relaxation regime. We then explore the links between gels' relaxation response to the observed adhesion enhancement and discuss those findings with prior research on poroviscoelastic fracture and adhesion of various materials and existing models. The results could assist better design of bio-adhesives and tissue scaffold interfaces.

4:40 pm - 5:40 pm - **Contact Mechanics Business Meeting**

Session 2D — 101 E

Grease I

Session Chair: Cindy Liu, Dow Chemical Company, Midland, MI
Session Vice Chair: Lu Fang, Tesla, Redwood City, CA

1:40 pm - 2:20 pm
4005474: Recipes for Success: The Impact of Various Promoter Systems on Calcium Sulfonate Complex Grease Performance
Joseph Kaperick, Darryl Williams, Afton Chemical Corporation, Richmond, VA

The use of calcium sulfonate thickener systems has become increasingly popular due to recent market dynamics such as availability, pricing and labelling concerns of lithium-based soaps. While calcium sulfonate thickener systems offer enhanced performance, ingredients and recipes for making this class of thickener are varied and finding the optimal solution for a given application can be very complicated. In this study, various promoters were used to create greases from 300 TBN overbased calcium sulfonate detergent and the impact on finished grease performance was evaluated using a variety of different bench tests.

2:20 pm - 2:40 pm
3986417: An Improved Model to Describe Oil-Separation Properties of Lubricating Greases
Femke Hogenberk, Dirk Van Den Ende, Matthijn de Rooij, University of Twente, Enschede, Overijssel,

Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

The complex process where base oil is released from a lubricating grease to lubricate the contacts in a bearing (i.e., bleeding) is still not fully understood. For instance, its relation to the properties of the grease remains unclear. In this work, a model is presented to describe the process of bleeding on a porous medium. This model is based on several grease properties that are expected to be relevant to this process, e.g., the permeability and elasticity of the thickener matrix and the thickener-base oil affinity. Experiments were carried out to capture the flow of base oil from a grease sample into a piece of blotting paper. This was done for one type of grease with varying amounts of base oil. A comparison between experimental results and the presented model shows the ability of this model to describe the bleeding process.

2:40 pm - 3:00 pm
3981847: Tribology and Grease Lubricated Ball Bearings
Piet Lugt, Sathwik Chatra K R, Nicola De Laurentis, SKF Research and Technology Development, Houten, Netherlands

During the last decade great progress has been made in understanding the lubrication mechanisms in grease lubricated bearings. In this presentation we will give an overview of the model development in this area such as on the effect of churning on grease life, grease bleed and degradation, oxidation and the concept of “minimum” grease life.

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

4:00 pm - 4:20 pm
3983353: Controlling Micropitting on Wind Turbine Main Bearings
Marc Ingram, Thomas Baldwin, Ingram Tribology Ltd., Carmarthen, United Kingdom; Karl Petersen, Debottam Bose, Troels Moeller, Siemens Gamesa Renewable Energy A/S, Brande, Denmark

The main bearing of a wind turbine can sometimes exhibit a localized micropitting damage. Here we develop a test method to evaluate the ability of a grease to reduce micropitting, emulating the likely conditions at the wind turbine main bearing contact. We investigate the performance of the greases under three different conditions by varying the contact pressure and slide/roll ratios. We also investigate the effect of the greases on artificially generated dimples. These dimples emulate the occurrence of dents which can occur on bearings and act as initiation sites for further damage. We find that micropitting can occur around the edges of the dimples and greases can reduce this occurrence – helping grease manufacturers develop new products and wind turbine operators to select better performing products to increase reliability and wind turbine up-time.

4:20 pm - 4:40 pm
3980531: Fast Screening of Wear Regimes in a Four Ball Setup
Lais Lopes, Dirk Drees, Pedro Baião, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium

A fast-screening method is developed in four ball setup, to evaluate wear regimes more efficiently. Current ASTM methods require running multiple short tests over a range of loads. In this presentation, we show an alternative approach by an automated method. How to evaluate the results of this method, how parameters can be fine-tuned to suit ranges of products, and what new insights can be gained, are the results of this research. The level of correlation with other test methods is also examined. The method is initially focused on detecting the seizure regime, because once a lubricant enters this regime, all lubricating functionality is lost in a normal application. Some indications to extend the method to the catastrophic failure range, called weld load, are made, but the real discussion is whether this weld load has any practical value. This approach intends to provide the additives and lubricants industry a new method to continually check and improve quality and performance.

Nanotribology II

Session Chair: Pranjal Nautiyal, Oklahoma State University, Stillwater, OK
Session Vice Chair: Arnab Neogi, University of Illinois Chicago, Chicago, IL

1:40 pm - 2:20 pm
4005864: Invited Talk: Coatings That Manufacturing Themselves: Formation, Interface Transfer, and Performance of Tribosintered Metal Oxide Coatings
Robert Carpick, Parker LaMascus, Nwachukwu Ibekwe, Daniel Delghandi, Andrew Jackson, University of Pennsylvania, Philadelphia, PA; Pranjal Nautiyal, Oklahoma State University, Stillwater, OK; Gordon Lee, ExxonMobil, Annandale, NJ; Tobias Gellen, Robert Wiacek, Pixelligent LLC, Baltimore, MD

Metal oxides typically require temperatures above 1000°C to form solids. Metal oxide nanocrystals dispersed in lubricants can sinter at room temperature under tribological stress. The solid, surface-bound coatings formed prevent wear, scuffing, micropitting, and macropitting. We will discuss tribosintering mechanisms, reviewing its occurrence across many nanocrystals, substrates, co-additives, and tribological conditions. We will then discuss the coatings' durability when run in nanocrystal-free lubricants using a ball-on-disc tribometer with in situ film thickness measurement. Coatings made from multiple nanocrystals, including ZrO_2 and TiO_2, remain durable for 8 hours under boundary contact conditions that would otherwise cause scuffing. Further, when one surface is uncoated, transfer to the that surface occurs, which further increases the surface-protecting potential of these nanocrystals. We will discuss the mechanism of adhesive transfer and how it affects coating performance.

2:20 pm - 2:40 pm
4029106: Surface Oxide Layers Dictate Interfacial Adhesion of Cold-Sprayed Bulk Metallic Glass Single Particles
Frank DelRio, Michael Kracum, Ping Lu, Ian Winter, Michael Chandross, Thomas Hardin, Sandia National Laboratories, Albuquerque, NM

Cold spraying (CS) is a solid-state deposition process where microscale powder particles are accelerated at high speeds towards a substrate via expansion of a preheated gas through a diverging-converging nozzle. In this talk, we present an experimental and numerical study on the adhesion of CS bulk metallic glass (BMG) single particles on aluminum and steel substrates. On both substrates, it was found that the surfaces consisted of single particles and empty craters, with microstructural gradients across the particles. The coefficient of friction and adhesion energy were 0.24±0.02 and 35.4±3.3 MPa for the BMG-aluminum pair and 0.37±0.04 and 262.3±29.6 MPa for the BMG-steel pair, respectively. Molecular dynamics simulations showed that the change in adhesion was most likely due to differences in substrate oxide thickness and yield strength, but not due to variations in substrate density and mixing enthalpy. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

2:40 pm - 3:00 pm
4004615: Observing and Modeling the Wear Process of Heterogeneous Interface
Xin Tang, Tianbao Ma, Tsinghua University, Beijing, China

Understanding the wear process of heterogeneous interface between hard and soft phase is important to the fabrication of materials, such as improving the wear resistance of particle reinforced metal matrix composites and the accuracy of chemical mechanical polishing. However, the wear process can be hardly observed as the heterogeneous interfaces are usually buried under the surface. Here, we

proposed a nanowear test method by combining the focused ion beam to expose the heterogeneous interface, atomic force microscopy to simulate an single asperity, and scanning electron microscope to characterize the wear evolution and interfacial damage. Three typical wear forms have been observed, i.e., merely matrix wear, particle fracture and particle pull-out. We found the increasing interfacial friction force would induce particle wear mechanism transition to fracture or pull-out, depending on the particle edge angle, tip edge angle, and the force required to pull out the entire particle.

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

4:00 pm - 4:20 pm
4001677: Nanolubricants for Increasing the Lifetime of Machine Elements and Cutting Tools for Machining Processes
Laura Pena-Paras, Demófilo Maldonado-Cortés, Martha Rodríguez-Villalobos, University of Monterrey, Nuevo Leon, San Pedro, Mexico

Machining is a commonly used manufacturing method in the metal-mechanic industry. Different approaches for cleaner production have been used to reduce wear along with the energy consumption of the process and increase the quality of the workpiece. For example, nanoparticles have been explored as additives for lubricants for friction reducing and load bearing purposes. Laboratory studies performed have demonstrated significant enhancements in tribological properties of lubricants additized with nanoparticles. In this talk, recent studies by our group are presented showing the effect of adding nanoparticles into lubricants in the lifetime of machine elements and cutting tools for machining processes. Statistical methods were used to optimize the nanoparticle concentration in the lubricant. Results showed that the output parameters were significantly enhanced by adding nanoparticles to the lubricant, which can impact the efficiency of the manufacturing process and reduce costs.

4:20 pm - 4:40 pm
4002106: Analytical Friction Models for Molecular Adsorbates
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

Atomic-scale nanoscale friction models, based on ideas from Tomlinson and Prandtl, conventionally use simple periodic sliding potentials to model the velocity and temperature dependences of the friction force, for example, as measured in an atomic force microscope. However, this approach is not well suited to describing the friction of adsorbed molecular overlayers, for example, self-assembled monolayers (SAMs) and of more complex potential energy surfaces. This is addressed by developing analytical models for more complex systems. In the first approach, we use the ideas of Evans and Polanyi, which develops a thermodynamic theory to analyze stress-dependent reaction rates and also use a simple model interaction potential between the tip and the outer surface of the organic substrate to develop analytical models for molecular friction of self-assembled monolayers (SAMs) on surfaces, so-called friction modifiers.

4:40 pm - 5:00 pm
3998763: Molecular Dynamics Analysis of Polymer Friction in Heterogeneous Surface
Hitoshi Washizu, Kazuki Ito, Masaki Hayama, Yudai Ogawa, Tomohiro Kinjo, University of Hyogo, Kobe, Hyogo, Japan; Yuji Higuchi, Kyushu University, Fukuoka, Japan

Although friction and wear of polymer is interesting topic, less knowledge are obtained. This is because polymer have high structure, for example not only amorphous but crystal phase. In this talk we show recent analysis using molecular dynamics simulation to understand friction of polymers. Not only amorphous but crystal structure is prepared to understand the phenomena. Scanning the surface by metal ball, we can distinguish the friction and wear dynamics on each surface due to the sliding condition. Then hard particle such as carbon nanotubes are added to increase the surface strength. With

the addition of nanotubes, the friction coefficient decreased which is consistent with the experiment. We also investigate the friction dynamics with bulk properties such as viscoelastic modulus.

5:00 pm - 6:00 pm - **Nanotribology Business Meeting**

Session 2G — 101 H

Surface Engineering II

Session Chair: Wenbo Wang, Oak Ridge National Laboratory, Oak Ridge, TN

1:40 pm - 2:00 pm
4003750: Enabling High-Performance Surface of Biodegrade WE43 Magnesium Alloys via Laser Shock Peening
Wenbo Wang, Oak Ridge National Laboratory, Oak Ridge, TN; Wenjun Cai, Virginia Tech, Blacksburg, VA

Magnesium (Mg) alloys are promising candidates for use as degradable implant materials. However, the fast degradation of Mg alloys in physiological environments makes it challenging to ensure their structural integrity and adequate strength over the required time for complete tissue and bone healing. On the other hand, high surface friction and wear debris formation in load-bearing implants can produce an undesirable reaction. Hence, an effective method that optimizes the tribocorrosion resistance of Mg alloys is needed. In this study, the effects of nanosecond and femtosecond laser shock peening (LSP) techniques on the surface properties of WE43 Mg alloys under different treatment conditions and the resulting tribocorrosion behavior of WE43 Mg were investigated in simulated vivo physiological conditions. Materials characterization is combined with finite element simulations to reveal the beneficial effects of LSP.

2:00 pm - 2:20 pm
4002591: Application of LST on Cutting Inserts Used in CNC Machining of Aluminum Alloys to Increase Their Performance
Demófilo Maldonado-Cortés, Laura Pena-Paras, Renata Cruz Olace, Fabiola Alvarez del Bosque, Ana Paola Castillo Barraza, Universidad de Monterrey, San Pedro Garza Garc, Nuevo Leon, Mexico

In this investigation a method to increase wear performance of form drills used in CNC turning of aluminum alloys was studied. Two form drills were compared, one with LST and one without LST in order to find out if the application of laser surface texturing of these tools enhances their wear performance. The LST was applied as an array of micro-dimples with a 0.2 mm diameter, 100 µm of depth and a distance between each circle of 0.4mm. An increase of 80.11% of wear resistance was achieved.

2:20 pm - 2:40 pm
4004786: Understanding the Correlation Between Surface Topology and Lubrication Performances of Quasi-Random Nanostructure Surfaces by Using Deterministic Lubrication Models
Hongwei Zhang, Chicheng Ma, Chengjiao Yu, Hebei University of Technology, Tianjin, China; Shuangcheng Yu, Xingyi Metal Group, Haining, China

Surface topology has strong influences on the tribological performances of engineering surfaces such as contact, lubrication and adhesion. Researching mainly the effects of various periodic structures or randomly distributed surfaces. Quasi-random nanostructures (QRNS) surfaces, which were inspired by nature, have attracted interests in many research fields, because their possibilities to be self-assembled for scalable manufacturing. We numerically generated the QRNS by spectral density functions, and

utilized an EHL model to characterize the lubrication performances of the QRNS surfaces under point contact condition. The influences of applied load, velocity, and lubricant viscosity on the EHL performance of various rough surfaces were investigated. Further, validation of results using CFD modeling. It was concluded that QRNS surface showed the optimal EHL performance among all the surfaces studied which might due to its unique topology connectivity and lubricant retention capabilities.

2:40 pm - 3:00 pm
4001578: A Novel Approach to Lubrication: Interactions Between Gadolinium-Doped DLC Coatings and Phosphorus-Based Ionic Liquids
Takeru Omiya, Albano Cavaleiro, Fabio Ferreira, University of Coimbra, Coimbra, Portugal; Filippo Mangolini, The University of Texas at Austin, Austin, TX

Improved approaches for friction and wear management could lead to dramatic reductions in greenhouse gas emissions. Among the materials, diamond-like carbon (DLC) coatings for their wear resistance and phosphorus-containing ionic liquids (ILs) for their friction reduction properties have attracted considerable attention. In this study, DLC coatings deposited by high-power impulse magnetron sputtering were doped with the rare earth metal gadolinium (Gd-DLC) and their sliding lubricity was evaluated in the presence of three different phosphorus-containing ILs. The test results showed a significant reduction in wear rate of approximately 80% when two different ILs were used. In addition, post-test wear tracks were observed using advanced surface observation equipment such as XPS and ToF-SIMS, which revealed details of the interaction between the ILs and the Gd-DLC coating. This comprehensive study is expected to lead to further optimization of the lubrication system design.

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

4:00 pm - 4:20 pm
3987454: The Influence of Geometry and Test Conditions on Lifetime and Endurance of Solid Film Lubricants. Testing Strategy and Data Production Method Enabling AI?
Lais Lopes, Pedro Baião, Dirk Drees, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Nathan Pekoc, Everlube Products, Peachtree City, GA

Solid film lubricants are commonly evaluated with a few key standard methods, such as ASTM D2625, D2714, D2981, in a variety of pressures and motion profiles. Often these tests don't reveal a relationship between industrial operating conditions and the test method. In this work, selected solid film lubricants are subjected to different testing conditions, illustrating optimization of the formulation to operating conditions is possible, given enough know-how and experience both in formulation and in testing conditions. While some coatings are more suitable to high-speed unidirectional contact conditions, others can be more suitable for one-time fasteners, or for reciprocating test conditions. Further, the potential for a more efficient data production method is illustrated, opening the way for better statistics and data management, perhaps even AI analysis into structure-property relationships.

4:20 pm - 4:40 pm
4004606: Structure and Friction Performance of Sulfonitrocarburizing Layer Prepared by Plasma Nitrocarburizing and Low Temperature Ion Sulfurizing
Zhehao Zhang, Tsinghua University, Beijing, China

During plasma nitriding, a portion of the iron particles sputtered from the substrate combined with nitrogen to form iron nitride and cover the surface of the sample, giving the treated sample a gray appearance. In this work, ion sulfurization was intended to combine with plasma nitrocarburizing to form a sulfonitrocarburizing layer on 38CrMoAl. The samples treated with nitrogen, carbon, and sulfur at the same time showed violent COF fluctuations and poor wear resistance during the friction process. A dense and anti-friction sulfonitrocarburizing layer was prepared by plasma nitrocarburizing and then

low temperature ion sulfurizing. Through process optimization, the sulfurizing layer achieved a balance between the anti-friction effect and the binding force. The composite structure of FeS polycrystals, sulfur-containing nanocrystals, and a nitrocarburizing layer made the sulfonitrocarburizing layer show an excellent anti-friction effect and wear resistance.

4:40 pm - 5:00 pm
4075913: Preparation of Thin-Film Transistors by Surface Energy-Directed Assembly
Jingwei Zhang, Tsinghua University, Beijing, China

The application of current processes to fabricate metal oxide patterns is hindered by their high cost, low resolution, low pattern fidelity or low throughput. To overcome these problems, surface energy-directed assembly (SEDA) process with a high applicability and a high efficiency is developed.
Plasma treatment can generate a large number of hydroxyl groups on the surface of the substrate to form a hydrophilic surface, after photolithography, self-assembly monolayer (SAM) film was deposited on the patterned substrate using a chemical vapor deposition process to introduce hydrophobic groups. After removing the remaining photoresist, the photoresist protected hydrophilic pattern regions were exposed thereafter, realizing the fabrication of the functionalized substrate. Selective adsorption of metal oxide precursor solutions can be achieved using the substrates, metal oxide patterns is made after drying and post-treatment process. TFTs and even gate circuits can be prepared on this basis.

5:00 pm - 6:00 pm - **Surface Engineering Business Meeting**

Session 2I — 101 J

Commercial Marketing Forum II

1:40 pm - 2:00 pm
4084491: Optimol Instruments: Diversity of Tribological Testing with Optimol Instruments From Standard to Innovative Methods
Ameneh Schneider, Optimol Instruments, München, Germany

Optimol Instruments, headquartered in Munich, is an international leader in the manufacturing of tribological test systems. For more than 50 years, Optimol Instruments has been a trusted partner to customers with innovative technology, field-proven solutions, expert advice, and comprehensive services directly from Germany. As a technology leader with a strong practical orientation, we offer a wide range of fully developed lab scale test scenarios for tribological phenomena with high practical relevance. Comprehensive automation solutions offer advantages in terms of efficiency, cost-effectiveness, and quality assurance, giving our customers a significant advantage in the marketplace. In 2023 Optimol Instruments has invented the first H2-Tibocell for tribological testing under hydrogen atmosphere successfully. The presentation will show the audience various application examples from diverse sites of tribology - in everyday life to electrical vehicle, water-based coolants and much more.

2:00 pm - 2:20 pm
4088994: Functional Products: Everything You Need to Know About PPDs From Functional Products
Mike Woodfall, Functional Products, Macedonia, OH

Functional Products routinely works closely with customers to determine the best pour point depressant technology for their formulations. Every lubricant is unique, and with more novel base oils on the market, improving low temperature performance can be challenging. Whether you are formulating with mineral oils, synthetics, re-refined, or biobased base oils, come spend 20 minutes to gain an understanding of our products and the especially processes we use to improve low temperature

performance of specialty lubricants.

2:20 pm - 2:40 pm
4091111: The Lubrizol Corporation: Improved Microbial Control for Metalworking Fluids
Gabe Kirsch, The Lubrizol Corporation, Wickliffe, OH

While the need for effective biocontrol in metalworking fluids is well established, legacy fungicide chemistries are known to have certain shortcomings, such as insoluble salt formation and inferior fluid concentrate stability. The relatively high cost of registering improved fungicides has also limited the expansion of user options in this market space. As a solution to these concerns, Lubrizol has introduced CONTRAM™ MB7188, a highly concentrated, low dose fungicide based on BBIT (N-butyl-1,2-benzisothiazolin-3-one). Our talk will discuss features of this new product, including its benefits over incumbent technologies.

2:40 pm - 3:00 pm
4094102: Biosynthetic Technologies: Estolide Technology for Sustainable and High-Performance Lubricant Technology
Matthew Kriech, Biosynthetic Technologies, Indianapolis, IN

Biosynthetic® Technologies has developed a revolutionary new class of high-performance bio-based base-oils oils and additives for the lubricant and metalworking fluid markets. These novel sustainable additives use the patented Estolide technology and are biobased, biodegradable, non-bioaccumulative, and non-toxic. The Estolides provide exceptional performance with superior lubricity, film strength, biostability, hydrolytic stability, oxidation stability, and increased polarity on both ferrous and non-ferrous alloys. Estolides are synthetically produced natural feedstocks and have undergone a 3rd party audited life cycle assessment showing the benefits to carbon footprint reduction and sustainability. This 30-minute session will be a must for anybody looking to develop a sustainable, high-performance, metalworking fluids or lubricants.

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

4:00 pm - 4:20 pm
4088042: Advancion Corporation: Advancion — A New Name, A Fresh Approach, A Trusted Partner
Michael Lewis, Advancion Corporation, Buffalo Grove, IL

For over 80 years, Advancion has practiced the commercial process of propane nitration to manufacture unique additives used in a wide range of end markets. As market drivers have evolved in that time, so has our portfolio of functional additives supporting metalworking fluid applications. In addition to product portfolio expansion, Advancion's commitment to sustainabilty has also evolved as assessed by independent evaluators such as Ecovadis. The audience will learn how Advancion's purposeful development across market segments enables innovation, fuels quality improvement, and accelerates application knowledge in today's dynamic marketplace to refresh and remain relevant in modern metalworking formulations.

4:20 pm - 4:40 pm
4095966: Evonik: VISCOPLEX Products for Emulsion Retention in Engine Oils
Matthew Hauschild, Rhishikesh Gokhale, Evonik Oil Additives, Horsham, PA

Production and adoption of hybrid electric vehicles is increasing globally, in addition hydrogen powered engines are progressing towards production in key vehicle segments. Oils in these engines will experience increased amounts of water as the result of lower operating temperatures and from hydrogen as a fuel. As a result, emulsion properties of oils will become increasingly more critical to the performance and protection of the engines of hybrid vehicles. Evonik VISCOPELX products can provide a

solution to this growing market need.

4:40 pm - 5:00 pm
4094277: ExxonMobil: SpectraSyn™ Base Stocks: Elevating Group II Base Stocks to Meet High Performance Specifications
Manish Patel, ExxonMobil Chemical Company, Spring, TX

The automotive industry is facing challenges to meet increasingly higher performance demands. New low viscosity, low volatility (LVLV) base oil technology is required to address next generation engine oil formulation specifications such as API and ACEA or specific OEM requirements. While all Spectrasyn™ base stocks can improve performance, the LVLV PAO technology platform of SpectraSyn™ MaX 3.5 is unique in synergistically boosting the low temperature and low viscosity performance of group II and II+ base stocks. With this boost in performance, LVLV PAO increases formulation options for next generation lubricants. This presentation will demonstrate how SpectraSyn™ base stocks can elevate group II base stock performance to meet increasing specifications and expand base oil formulation options.

Session 2J — 200D E

Electric Vehicles II

Session Chair: Thomas Wellmann, FEV, Auburn Hills, MI
Session Vice Chair: Andrew Velasquez, Southwest Research Institute, San Antonio, TX

1:40 pm - 2:20 pm
4004397: Efficient Shear Stable Thickeners for the Heavy-Duty EV Market: Theory, Application, Proof
Alexei Kurchan, Cargill Inc, Plainsboro, NJ; Kevin Duncan, David Gillespie, Cargill, Snaith, East Yorkshire, United Kingdom

Transmission fluids for light duty EVs trend ever lower in viscosity, however the high torque operating environment of heavy-duty EV powertrains will present much more severe operating conditions. This will place different demands on the fluid and require the use of thicker lubricants to prevent wear and maintain adequate lubrication. High viscosity (HV) thickeners are an efficient way to formulate fluids that meet these requirements. In this paper, we will show how design of experiments methodology can be used for new product development to prioritize R&D work and target desired product properties. The model that was developed was then used throughout the NPD process to aid process development and increase understanding. The performance of the HV thickeners will be demonstrated in benchtop tribological testing and confirmed in industry standard efficiency rig testing. Connecting product development to rig testing enables high quality structure-performance conclusions to be drawn.

2:20 pm - 2:40 pm
4003572: The Energy Efficiency Improvement Effect of Low Viscosity Engine Oil with MoDTC in a Large Displacement Engine
Kenji Yamamoto, Ryo Hanamura, Koichi Takano, Shinji Iino, ADEKA Corporation, Tokyo, Japan

Recent studies on energy efficiency improvement with gasoline engine oil, achieved through viscosity reduction and the incorporation of effective friction modifiers (FM), have predominantly focused on 1.5 to 4-liter engines. While investigating the influence of viscosity and FMs in several engines with approximately 2-liter displacements, the authors have confirmed the impact of MoDTC-formulated low and ultra-low viscosity engine oils in enhancing energy efficiency. Conversely, it has also been observed that excessive viscosity reduction can lead to increased friction loss in certain engines. In this study, the

effects of viscosity reduction and MoDTC in a large engine with over 5 liters of displacement, typically operated with engine oils of relatively high viscosity, were examined. While a negative impact of excessive viscosity reduction has been clearly identified compared to previous engines, a significant improvement in energy efficiency due to MoDTC has also been observed.

2:40 pm - 3:00 pm
3976801: Lubricants Requirements for Electrified Heavy Duty Drive Trains
Torsten Murr, Shell Global Solutions Deutschland, Hamburg, Germany

With the ongoing drivetrain electrification in the on-highway area, OEMs and manufacturers need to develop efficient & integrated EDUs. Zero emission vehicles were released by various OEMs. Different e-motor concepts are introduced to the market. For dry e-motors, where the copper parts are separated from the gearset, conv. GL-4/5 technologies can be used. For wet e-motors, where e-motor and reduction gear share one oil circuit, dedicated fluid are required. This allows more efficient, compact and integrated e-motor solution with one fluid. Important is that e-axles won't be compatible with conv. axle fluid. The high content of sulfur containing AW & EP additives, which are required for GL-5/SAE J2360 performance levels, are not compatible with the copper parts of the electric motor and can cause corrosion or electrical shortcuts. The wear protection of the gearset has to be balanced carefully to ensure the compatibility with the electrical parts. This requires innovative fluid concepts.

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

4:00 pm - 4:20 pm
4004779: Thermal Conductivity Enhancement of EV Fluids by Carbon Nanotubes
Chanaka Kumara, Harshvardhan Singh, Wenbo Wang, Jun Qu, James Haynes, Hsin Wang, Oak Ridge National Laboratory, Oak Ridge, TN; Ning Ren, Jacob Bonta, Edward Murphy, Roger England, Valvoline Global Operations, Lexington, KY

Carbon nanotubes (CNTs) have excellent thermal conductivity (TC) but tend to aggregate and precipitate when mixed into oil due to their poor suspendability. We utilized organic surface modification techniques to improve CNTs suspendability in non-polar electric vehicle (EV) base oils. CNTs were able to successfully suspend in a EV base oil at room temperature and 100^{o}C using a combination of surface modification and dispersant. The CNT dimensional properties (length and diameter) and concentration appear to influence TC. Although the base oil TC is improved with increased CNT concentration, the oil viscosity also increases simultaneously, which will negatively impact the heat transfer efficiency. Surface-modified CNTs had less effect on the oil viscosity compared to the unmodified CNTs. By selecting the appropriate combination of CNTs and surface modification, we were able to improve the EV base oil TC by 8-12% after adding only 0.025 wt% of CNTs with little change to oil viscosity.

4:20 pm - 4:40 pm
4004696: Beyond the Battery: A Holistic View of Thermal Management Fluids in BEVs
Gareth Brown, Lubrizol Ltd., Hazelwood, Derbyshire, United Kingdom

The concept of direct immersion cooling for BEVs is gaining traction due to the significant advantages in battery performance and safety. However, battery cooling is just the start, a modern BEV requires thermal management beyond the battery. Thermal management of motors and inverters, as well as component integration is becoming ever more important. Today, BEV hardware designs vary significantly, and the role of thermal management fluids is unsettled. Certain solution providers are advocating for "universal" thermal management fluids, however the fluid performance requirements for BEV hardware vary significantly. At the other extreme, it is not feasible to have a dedicated fluid for each hardware component as the result is unnecessary complexity. This presentation will examine potential scenarios for balancing complexity with performance in delivery of BEV lubrication and thermal management, and how different solutions may arise depending upon system design and duty cycle

attributes.

Tuesday, May 21, 2024

Session 3A 101 B

Materials Tribology I: Tribute to Michael Dugger

Session Chair: John Curry, Sandia National Laboratories, Albuquerque, NM
Session Vice Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

8:00 am - 8:40 am
4024752: Tuning the Friction Evolution and Aging Behavior of PVD MoS_2 Films
Michael Dugger, Tomas Babuska, John Curry, Alexander Mings, Steven Larson, Sandia National Laboratories, Albuquerque, NM

The outstanding steady-state friction coefficient and wear behavior of physical vapor deposited (PVD) thin films of MoS_2 in inert atmospheres is well known. Steady-state friction coefficients below 0.01 and wear rates below 10^{-8} $mm^3/(N.m)$ have been achieved through doping with a variety of metals, ceramics, carbon, and other dichalcogenides. However, little attention has been given to film performance in low duty cycle applications or during startup after long periods of dormant storage. In these cases, the first few cycles of sliding are often all that matters for correct operation, and many films with low friction and wear at steady-state exhibit dismally high friction upon first operation or upon restart of a previously operated mechanism after a long period of storage. Fortunately, the start-up performance of PVD films can be tuned through modification of the near-surface structure without compromising steady-state performance. This presentation will highlight one such approach.

8:40 am - 9:20 am
4080358: Advances in Solid Lubrication for Space and Vacuum Applications
Christopher DellaCorte, The University of Akron, Akron, OH

Solid lubricant films have evolved to address the lubrication needs in space and vacuum applications. From simple monolithic, vapor deposited lead films to complex, multi-layer coating systems, the field of solid lubrication has advanced to meet ever more challenging lubrication requirements. This presentation will review advancements in thin metal film and multi-layer lamellar solid lubricants. Space experiments used to understand and improve the technology will be highlighted. Additionally, examples of their capabilities through vacuum bearing testing will show that long-term R&D has resulted in meaningful improvements in the technology enabling mission success here on earth as well as beyond.

9:20 am - 10:00 am
4071115: Mutual Interests in Metal Sulfide Solid Lubricants for Space and National Security Applications
Jeffrey Lince, Space Tribology Consulting, Inc., Culver City, CA

The space industry and Sandia National Laboratories (SNL) have historically had a mutual interest in metal sulfide-based solid lubricants like MoS_2. Friction and endurance degradation during extended storage is an ongoing concern, either prior to launch or to ensure the reliability of electromechanical devices critical to nuclear weapons. Studying aging is complicated by the difficulty of quantitatively accelerating oxidation. We will present results on the effect of aging in real-time of sputter-deposited MoS_2 based solid lubricants on their surface composition and tribology. We will also present results

from a study conducted with SNL motivated by our mutual interest in sliding electrical contacts involving optimization of the friction and electrical conductivity of sputtered Au/MoS_2 coatings. Finally, new results will be presented on a novel cost-effective method we recently developed for producing metal sulfide-based solid lubricant coatings for space and other applications.

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

10:40 am - 11:20 am
4071046: In-Situ Tribology of Solid Interfaces
Kathryn Wahl, US Naval Research Laboratory, Washington, DC

Tribology problems by nature involve the examination of contacts within "buried" interfaces. Rubbing surfaces may be separated by protective (or corrosive) fluids or solids and operate in environments ranging from vacuum to high pressure or temperature. Determining the mechanisms behind friction changes, wear or failure involves either separating the contacts or devising a way to determine what is happening in real time, while the tribocontact is loaded and active. These in-situ or in operando approaches increase the technical challenge to engineer the test apparatus and interpret the data, but also bring great rewards in providing insight into what physical and chemical processes are occurring during sliding and wear. In this presentation, we will describe and highlight the ways we have approached developing in-situ tribometry and tribology science along with the 'behind the scenes' connections and inspiration we took from others in the field.

11:20 am - 11:40 am
4024754: A MoS_2 Composite Mystery: Uncovering Hidden Performance Traits
Tomas Babuska, Michael Dugger, Steven Larson, Alexander Mings, John Curry, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) based coatings doped with materials such as Sb_2O_3, Au, Ti and Ni have been accepted as the industrial standard because of their touted environmental agnostic ultra-low friction ($\mu<0.05$) and wear behavior (10^{-7}–10^{-9} mm^3/Nm) in both humid and dry environments. Their performance in humid environments is due to the mitigating interactions of dopants with environmental species allowing MoS_2 to be expressed at the sliding interface. There exists an unreported phenomenon that can occur at high relative humidities where the friction coefficient of MoS_2/Sb_2O_3/Au becomes extremely high ($\mu\sim1$), yet the coating does not fail. This ultra-high friction behavior has never been shown in published literature yet has far reaching consequences for real-world applications. This work looks at the fundamental causes of ultra-high friction instabilities for MoS_2/Sb_2O_3/Au composites in humid environments. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

11:40 am - 12:00 pm
3999448: Effect of MoS_2 Coating Deposition Conditions on Water Sorption/Desorption via ToF-SIMS
Nicolas Molina Vergara, Filippo Mangolini, Andrei Dolocan, The University of Texas at Austin, Austin, TX; John Curry, Michael Dugger, Tomas Babuska, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) coatings find extensive use in applications demanding low friction response in inert or vacuum environments. Nonetheless, the reversible and irreversible water sorption within the coating during handling or periods of dormancy leads to a pronounced increase in friction with potential catastrophic reliability issues of sliding components. Despite the number of studies that quantitatively evaluated the water uptake in MoS_2, a quantification of the water diffusivity in MoS_2 and its dependency on the material microstructure is still lacking. To address this knowledge gap, we conducted ToF-SIMS depth-profile analysis after dosing MoS_2 films with a water isotopic tracer (D2O). The resulting depth profiles are then modelled using a classical Fickian diffusion model that allows for the quantification of the dependence of the diffusion coefficient on coating morphology. This work was funded by SNL, managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Session 3B 101 C

Tribotesting III

Session Chair: Kerry Cogen, Infineum USA LP, Linden, NJ
Session Vice Chair: Steven Twining, Elemental Scientific, Inc., Navasota, TX

8:00 am - 8:40 am
4004801: Application of the Four-Ball EP Test as an FZG (A10/16.6R/90) Scuffing Screening Test with Reference Fluid Assessment
Kerry Cogen, Yanzhao Wang, Jannat Ahmed, Infineum USA LP, Linden, NJ

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

8:40 am - 9:00 am
4005000: Complete Mixing of Dilute- Highly Viscous Samples- for ICP Analysis
Steven Twining, Elemental Scientific, Inc., Navasota, TX

Most new lubricant manufacturers measure elemental content using Inductively Coupled Plasma. More often than not, lubricant samples are diluted 1:10 with kerosene, xylene, or a similar solvent. This works for most samples having viscosities lower than 600 cSt. One of the challenges with ICP is that even if they sit for a short time, diluted samples containing more viscous oil tends to settle. This talk highlights a novel technique using a non-mechanical homogenization capability to fully mix samples ranging from 600 cSt to 4000 cSt that have been diluted 1:10 with solvent, to present fully homogenized samples to the ICP for analysis immediately after mixing. Both the ICP analytical technique and results from complete homogenization for all lubricant analysis sample types in this study will be highlighted. This includes sample preparation by weight, and automated sample introduction across the stated viscosity range for ICP analysis.

9:00 am - 9:20 am
4005068: Characterizing Tribofilms Formed on M50 and CR30 Bearing Steels
Daulton Isaac, Mathew Kirsch, Alexander Fletcher, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH; Justin Schuh, Elizabeth Craft, Ronald Zeszut, University of Dayton Research Institute, Dayton, OH

Bearing steels exhibit varying resistance to scuffing, and it is thought that this is influenced by a steel's ability to form a tribofilm to protect the underlying material in low specific film thickness conditions. Thus far, only a limited amount of work has been done to characterize the tribofilms formed on these steels. This work uses X-Ray Photoelectron Spectroscopy (XPS) and Scanning Electron Microscopy (SEM) to chemically and morphological characterize the tribofilms formed on various bearing steels tested in the same MIL-PRF-23699 lubricant. The growth characteristics and the composition of the film are seen to depend on the substrate on which it is generated.

9:20 am - 9:40 am
4005119: Enhancing the Spacer Layer Imaging Method by Error-Correcting Colorimetry
Alexander MacLaren, Imperial College London, London, United Kingdom; Parker LaMascus, Robert Carpick, University of Pennsylvania, Philadelphia, PA

The Spacer Layer Imaging Method (SLIM) is widely used to measure the thickness of additive and lubricant films, in lubricant development and testing, and for research on mechanochemistry and elastohydrodynamic lubrication. The measurement is extremely sensitive to experimental procedure and image analysis, in some cases reporting completely unphysical film thickness trends. The prevailing image analysis techniques make it challenging to interrogate these errors, which are routinely obscured by spatial averaging. This talk presents a robust suite of novel a priori and a posteriori method to improve the accuracy of the SLIM measurement. Several common 'silent errors', including aliasing to adjacent fringe orders, and color drift due to the optical properties of the system, are discussed, with examples. In combination, these methods allow reliable mapping of films up to 700 nm in thickness, representing a significant milestone for SLIM applied to elastohydrodynamic contact.

9:40 am - 10:00 am
4005128: Observation of Tribofilm Formation During Rolling Contact Fatigue Testing
Matthew Smeeth, PCS Instruments, London, United Kingdom; Marc Ingram, Ingram Tribology Ltd., Carmarthen, United Kingdom

The spacer layer image mapping technique has been a very useful tool in Tribology research for many years. It has been widely used on mixed sliding /rolling tribometers to view the Tribofilms being formed under relatively short (<3 hours) tests. With the need for greater longevity of machine components it would be beneficial to observe the behavior of these tribofilms over much longer and higher contact cycle tests. Carrying out these tests using a standard sliding rolling tribometer would mean very long tests, typically many days long. In this work the SLIM technique was modified to allow measurements to be made on the central roller from an MPR test rig. This rig simulates the line contact of gears and provides the high rates of contact cycles desired for rapid tribofilm longevity studies. This new technique was investigated using a range of fully formulated oils and simple blends.

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

10:40 am - 11:00 am
4005581: Analysis of Metals in Oils and Coolants with a Novel Nitrogen-Based Plasma Optical Emission Spectrometer
Mike Plantz, Eric Moen, Radom Corporation, Pewaukee, WI

Performing elemental tribology without argon and large ICP platforms is possible with the novel Radom MICAP-OES 1000 nitrogen plasma system. This microwave inductively coupled plasma instrument relies on a patented Cerawave™ ceramic disk which replaces the water-cooled coil and high-power RF generator required in traditional ICP systems. The use of nitrogen gas, a simultaneous spectrometer, and a water chiller-free design presents significant cost-of-operation savings over Ar-based ICP systems. Unique features of the system will be discussed, followed by analysis results and sample throughput performance for both engine oil and coolant samples.

11:00 am - 11:20 am
4014032: Fretting Testing: Challenges and Statistical Considerations
Melissa Mushrush, DuPont de Nemours Inc., Wilmington, DE

Wear and degradation of surfaces due to fretting leads to many issues across many industries, from automotive applications to electrical connections to osteosynthetic implant plates and screws. This work takes a closer look at the various test methods and equipment, as well as statistical considerations for the measurement of lubricant effectiveness against fretting damage.

11:20 am - 11:40 am
3998708: What if Removing the Third Body Layer From a Dry Contact?
Simone Ciprari, Sapienza University of Rome and Safran Landing Systems, Roma, Italy; Valentin Ripard, Safran Landing Systems, Villeurbanne, France; Aurélien Saulot, Univ. of Lyon, INSA Lyon, Villeurbanne, France; Francesco Massi, Sapienza University of Rome, Roma, Italy

An experimental approach to evaluate the role of third body in dry contacts is proposed. Ultrasonic cleaning technique is applied on a contact pair to remove the third body layer. The comparison of the frictional tests performed on the same first bodies, with and without the interface layer, evidenced a strong influence of the third body on the overall frictional behavior. Moreover, an external third body has been reintroduced on the cleaned samples to test its effect on the frictional response of the contact pair. A predominant role of the interface layer on the overall frictional behavior, rather than the one of the substrate, has been pointed out. The third body layer almost fully control the frictional response of the material. The developed procedure allows to test artificially produced third bodies, to investigate the role of different features (morphology, composition) on the overall frictional response of the system.

11:40 am - 12:00 pm
4004549: Tribological Investigations Under Varying Pressure Atmospheres
Felix Zak, Gregor Patzer, Optimol Instruments Prüftechnik GmBH, Munich, Bavaria, Germany; Ameneh Schneider, Optimol Instruments, München, Germany

This paper presents a novel tribotest option specifically designed to operate under various pressurized atmospheres. The development of this test option addresses the need to simulate real-world conditions encountered in numerous industrial applications where components and materials are subjected to mechanical friction and wear under specific gas environments. By exposing test samples to controlled gas atmospheres at different pressure levels (up to 100 bar), the tribotest option provides a valuable tool for evaluating the tribosystem for performance and durability of materials under different operating conditions. In some series of tests, the behavior of a common material pairing (100Cr6) with different lubricants under varying pressure environment in a nitrogen atmosphere has been investigated. The aim of the investigation is to verify the response of the tribosystem expressed by the variation of the Coefficient of Friction (COF) as a function of the ambient pressure.

Session 3C — 101 D

Lubrication Fundamentals I: Additives

Session Chair: Kuldeep Mistry, Chevron Lubricants, Richmond, CA
Session Vice Chair: Ramoun Mourhatch, Chevron Oronite, Richmond, CA

Session starts at 8:40 am

8:40 am - 9:00 am
4000333: Influence of Shear Stress and Pressure on the Mechanochemistry of ZDDP and ZDP
Hugh Spikes, Chuan Wang, Jie Zhang, Janet Wong, Imperial College, London, United Kingdom

Zinc dialkyldithiophosphates (ZDDPs) are crucial lubricant additives in almost all engine oils and in many hydraulic and industrial gear oils. They limit wear by reacting to form protective phosphate-based films on rubbing metal surfaces. Several previous studies have shown that the rate of this phosphate tribofilm formation increases exponentially with both temperature and shear stress, indicative of a mechanochemical reaction mechanism. Recently, it has also been suggested that the reaction rate decreases slightly with applied hydrostatic pressure. This presentation describes a study of the influence of both shear stress and pressure on tribofilm formation of ZDDPs and their sulphur-free analogues the zinc dialkylphosphates (ZDPs). The results are interpreted in terms the underlying molecular mechanism of ZDDP tribofilm formation.

9:00 am - 9:20 am
4004698: Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM
Kerry Cogen, Jannat Ahmed, Infineum USA LP, Linden, NJ; Matthew Flynn-Hepford, Arya Ahmadi, Mahshid Ahmadi, Olga Ovchinnikova, The University of Tennessee, Knoxville, TN

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

9:20 am - 9:40 am
4002804: Surface Competition of Lubricant Additives Impacting Antiwear Performance and Mitigation
Ashish Jha, Christophe Le Deore, Marco Mata Mendoza, Brendan Miller, Chevron Oronite, Richmond, CA

Wear control is one of the key performance areas for lubricant oils. Antiwear additives in the oil require unhindered access to metal surfaces to be able to form tribofilms and minimize wear. However, antiwear additives often compete with other additive components for these metal surfaces compromising their surface antiwear activity to varying extents. This presentation will show how such detrimental surface competitions can be overcome (minimized) through knowing the structure-activity correlations of specific additives posing such risks.

9:40 am - 10:00 am
3988349: New Polymeric Organic Friction Modifiers
Ezio Amerio, Alina Filin, John Dixon, Nouryon, Deventer, Netherlands

CO_2 emissions limits are getting stricter worldwide, increasing the demand for low viscosity lubricants. However, these lubricants are extremely thin at high temperatures, which poses a potential threat of boundary friction. Multifunctional polymeric organic friction modifiers provide a solution to this problem by reducing friction and wear, leading to improved energy efficiency and extended equipment lifetime. What differentiates these products from conventional organic FMs is that they contain multiple functional groups within a single oligomeric molecule. This allows them to adsorb onto the metal surface at various points, forming a specific film that significantly reduces the coefficient of friction across all lubrication regimes, even at very low treat rates, without negatively impacting traction properties. These FMs outperform metal-containing ones across a wide temperature range and demonstrate a highly advantageous synergistic effect when used in combination with MoDTC.

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

10:40 am - 11:00 am
4002795: Synergy of Additives Improving Engine Cleanliness Performance of Lubricant Oils
Allan Isenberg, Ashish Jha, Devin Wall, Matthieu Decuupere, Sandy Lemesle, Priyank Shah, Andrew Suen, Chevron Oronite, Richmond, CA

Modern internal combustion engines are designed by OEMs to be increasingly more fuel and power efficient. These design improvements, however, set a much higher performance standard for lubricating oils to maintain engine cleanliness. This presentation will showcase novel components and some synergies between these lubricant components providing ways to meet these stringent cleanliness requirements. Mechanistic insights underlying those synergies will be discussed.

11:00 am - 11:20 am
4004620: Impact of Alcohol Branching on Lubricant Performance
Andrew Satterfield, ExxonMobil Technology & Engineering, Clinton, NJ

Alkyl carbon chains derived from long-chain alcohols are ubiquitous in lubricants, whether as integral components of synthetic ester base stocks, or as side chains to improve the additive solubility, friction control, or wear protection of lubricant additives. Long-chain alcohols are derived either from natural sources or from various synthetic processes, each yielding a unique molecular structure. The unique structures of these long-chain alcohols can have a profound impact on lubricant performance. However, such differences in performance are not always well understood, particularly for commercially available alcohols that are complex mixtures. This presentation will review the characteristics of some commercially available long-chain alcohols, particularly the nature of their molecular branching. Test data for model lubricant components prepared from these alcohols will be presented, and the impact of alkyl chain structure on lubricant performance will be discussed.

11:20 am - 11:40 am
4001276: How Polymeric Additives Affect Lubricant Film Thickness
Janet Wong, Bastien Bolle, Imperial College London, London, United Kingdom; Mao Ueda, Shell Lubricants Japan, Kanagawa, Japan

Polymeric additives are frequently used as viscosity modifiers (VMs) in lubricants. They modulate the viscosity of a lubricant and hence impact on lubricant film thickness in a rubbing contact. Usually, higher viscosity lubricants give higher film lubricant. For VM-doped lubricants, however, this is not always the case. Literature has shown that they can generate films thicker or thinner than predictions. This may be due to induced changes in inlet conditions or lubrication flow. In this work, laser spectroscopy will be used in operando to examine the behavior of polymeric additives in lubricants. Specifically, the distribution of VMs in and around a contact and how that relates to film thickness will be explored.

11:40 am - 12:00 pm
3994940: PPD Selection Criteria for Evolving Market and Regulatory Trends
DurgaPrasad Chalasani, Evonik Oil Additives USA, Inc., Horsham, PA

Several market trends and increasingly stringent regulations are influencing PPD selection and treat rates. Some of these trends (a.) continued concern about low temperature performance of aged engine oils, (b.) the drive toward fuel efficiency and corresponding shift toward low viscosity engine oil grades, (c.) increasing interest in and use of re-refined base oils (RRBO's), and (d.) more stringent low temperature performance specifications in industrial applications, particularly Tractor Hydraulic Fluids- are demanding a renewed interest in studying PPD selection and performance. Polyalkyl Methacrylate chemistry based PPD's can adapt to a variety of lubricant formulations and can be tailored to meet the latest formulation requirements. This presentation will provide an overview of the PPD mechanism and

will demonstrate how proper PPD selection and fine tuning of treat rates for each of the above four trends allows formulations to meet stringent low temperature performance requirements.

Session 3D — 101 E

Grease II

Session Chair: Gareth Fish, The Lubrizol Corporation, Wickliffe, OH
Session Vice Chair: Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

8:00 am - 8:40 am
4001958: Dynamic Thixotropic Recovery of Lubricating Greases under Varied Recovery Conditions
Jacob Bonta, Valvoline Global Operations, Lexington, KY

In this study, the thixotropic recovery of lubricating greases under varied strain and temperature is examined using a parallel plate rheometer. Degradation and subsequent modulus recovery are properties associated with the grease microstructures when exposed to cycles of shear and rest. The conditions of the rest cycle have impacts on the rate and extent of recovery. Three grease thickeners are considered: lithium 12-hydroxystearate, fumed silica, and polyurea. Small amplitude oscillatory (SAOS) testing is first used to evaluate the moduli in an undisturbed state. A 1-hour shear program is applied to each material, after which the storage modulus is tracked over time in SAOS evaluation. Varied conditions of recovery are explored by varying the % strain and temperature applied during the recovery phase. The recovery profiles compare the differences microstructural recovery. These results show that rheological analysis may provide insights not observed in standard industrial testing.

8:40 am - 9:00 am
4004325: Characteristics of Hybrid Greases Blended with Nano Structure Urea Grease
Akihiro Shishikura, Idemitsu Kosan Co., Ltd., Ichihara, Chiba, Japan

The characteristics and performances of nano structure urea grease (INS-UG), which has thickener fibers down to nano-sized, have already been reported. On the other hand, by mixing separately manufactured greases with different types of thickeners, a hybrid grease that has the characteristics of each type can be manufactured. In this presentation, we mixed INS-UG to lithium and lithium complex greases and tried to add the characteristics of INS-UG, such as low fretting wear, to the performance of those greases. As a result, by adding 5 to 10 wt% of INS-UG to lithium and lithium complex greases, heat resistance (dropping point) was improved, and fretting wear was reduced by 1/3 to 1/5. In addition, the results of oiliness tests and rheology analysis showed that mixing INS-UG with different thickener type greases was effective in controlling friction and wear as well as the transport properties of the grease.

9:00 am - 9:20 am
4004129: Comparative Analysis of Lithium and Urea Thickener Morphology and Implication for Grease Performance
Cindy Liu, Matthew Thorseth, Lauren Huffman, Pete Rozowski, Dow Chemical Company, Midland, MI; Jocelyn Zhao, Shell, Shanghai, China; Edward Worthington, Shell, Hamburg, Germany

Lithium thickeners are the most widely used in grease, but they are challenged by raw material increased price, competitive supply, and EH&S concerns in recent years. Urea-based thickeners are one of the alternatives of lithium thickeners, especially for high temperature application. This study investigates morphology of lithium and urea thickeners, aiming to elucidate the microstructure characteristics in relation to their grease properties. Through advanced microscopic techniques, we will show the morphological attributes of lithium complex soap, in-situ formed diurea and preformed diurea thickeners as in the grease within the base oil matrices. We also analyze the thickeners by removal of

the oil phase similar to the previous literature and show the effect of sample preparation conditions on microstructure. We will highlight the commonalities and distinctions between these thickeners and discuss the interplay between the morphology and grease properties in rheology and tribology.

9:20 am - 9:40 am
4027391: A Novel Method for Assessing the Efficiency of Grease-lubricated Rolling Element Bearings
Gabriel Calderon Salmeron, Sergei Glavatskih, KTH Royal Institute of Tribology, Stockholm, Sweden; Johan Leckner, Axel Christiernsson Int. AB, Nol, Sweden

One component in achieving a more sustainable society is improved grease lubrication, which can potentially reduce global CO_2 emissions by up to one percent in the short-term perspective. However, achieving such a challenging goal demands a transformative shift in how grease lubricants are selected and formulated. Additionally, the current absence of methodologies to assess grease efficiency adds further complexity to this challenge. In this work, the authors present a new methodology for measuring grease efficiency in a bespoke high-speed bearing test rig. The friction torque response of different grease compositions is presented in experiments with long duration (up to one-month experiments). A wide range of operating speed conditions, covering from zero to very high speeds, was evaluated to tackle several challenges of emerging technologies, such as electric vehicles. A discussion of the impact of the energy-saving potential of different grease candidates is presented.

9:40 am - 10:00 am – Open Slot

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

10:40 am - 11:00 am
4003024: Sub-Zero Temperature Friction and Film Stability of Lubricating Greases
Debdutt Patro, Amar Sheelwant, Sravan Josyula, Anshuman Dube, Ducom, Bangalore, India

Sub-zero temperatures cause cold-induced stiffness, making grease impede and retard the motion of rolling elements in several applications. Existing standards ASTM D1478, ASTM D4693 provide guidelines to evaluate the starting and running torque but suffer from poor precision. In this work, we have developed a novel low-temperature module on the multi-capability pin/ball on disc tribometer with electrical contact resistance technique to simultaneously record friction and film stability at -50°C. Several greases were tested at different sub-zero temperatures both on the tribometer as well as the standard ASTM D1478 tester. The ball on disc tribometer tests show strong correlations between friction and % film thickness. Furthermore, long duration tests were used to evaluate and differentiate durability of low temperature greases. The results highlight the suitability of standard and non-standard test methods for analyzing the sub-zero temperature behavior of lubricating grease.

11:00 am - 11:20 am
4027387: On Grease Lubrication of Oscillating Rolling Bearings: Probing the Potential of Ionic Liquid Additives
Roman de la Presilla, Sergei Glavatskih, KTH Royal Institute of Tribology, Stockholm, Sweden; Johan Leckner, Axel Christiernsson Int. AB, Nol, Sweden

Oscillating rolling element bearings are found in a wide range of applications. From the large pitch bearings that allow wind turbine blades to be turned into and out of the wind, to the bearings found in pointing or gimbaling mechanisms used in space applications. When bearings are subjected to oscillating motions, they do not achieve full film lubrication. Instead, mixed or boundary lubrication prevails. A complex wear process ensues, compromising the life of the component and leading to excessive bearing torques. Current research indicates that no single grease formulation can prevent bearing wear in such conditions. A test rig has been developed to evaluate lubricating bearing grease performance in a wide range of oscillating frequencies and amplitudes. Results for greases loaded with ionic liquid additives are

presented and discussed. Grease formulation is shown to have a profound influence on the emergence and severity of the resulting surface damage.

Session 3E 101 F

Biotribology I

Session Chair: Meagan Elinski, Hope College, Holland, MI
Session Vice Chairs: Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile and Quentin Allen, Brigham Young University, Provo, UT

8:00 am - 8:40 am
4030037: The Science of Tribology in Medical Devices
Elizabeth Hippensteel, J&J MedTech, Warsaw, IN

The Science of Tribology plays a significant role in the development of various medical devices including artificial joints, cardiovascular devices, and contact lenses. Understanding wear behavior, friction, and lubrication regimes in these systems are essential to their functionality and optimization. Although wear mechanisms of modern materials are well understood, further investigation of tribological behavior under high demand and adverse conditions is needed. There is a push to standardize new methods to better rank new materials, challenge designs, and compare across labs globally. Advancement in computational modelling also plays a key role in predicting the tribological performance of new devices. Manufacturing processes and packaging are evolving for a more sustainable future so tribological challenges must be considered alongside this development. DePuy is committed to reducing its carbon footprint, with the lab in Leeds, UK achieving Platinum Certification from My Green Lab.

8:40 am - 9:00 am
3976511: Rendering Contact Mechanical Stimuli for Texture Tactile Perception
Francesco Massi, Livia Felicetti, Sapienza University, Rome, Italy; Eric Chatelet, INSA Lyon, Villeurbanne, France

In the past decades, notable efforts have been placed in the investigation and understanding of tactile perception. Nevertheless, while acoustic or visual stimuli are well mastered and simulated by screens or loudspeakers, it is still a challenge to simulate tactile stimuli, leading to the reproduction of tactile perception and discrimination. Recent works allowed to identify the friction-induced vibrations as one of the main signals at the origin of touch. Originated by the transient contact interaction between skin and surface textures, the key features of such vibrations have been related to the textures of the explored surfaces. In this work, the rendering of such mechanical stimuli by a vibrotactile device is presented. While the reproduced signals demonstrated to be effective in discriminating the different simulated textures, playing with the identified signal features allows to guide perception of virtual textures.

9:00 am - 9:20 am
4005538: Advancing Hemiarthroplasty: A Joint Motion-Simulating Biotribometer to Predict In Vivo Performance of Cartilage
Markus Wimmer, Amandine Impergre, Francesca De Vecchi, Rush University Medical Center, Chicago, IL; Olga Antipova, Argonne National Laboratory, Lemont, IL

Hemiarthroplasty involves replacement of one of the articular joint surfaces with an artificial bearing surface. It offers a clear benefit in patients with localized cartilage damage, preserving the healthy bone and cartilage in the joint to maximize future treatment options. And hemiarthroplasty is inherent in the replacement of individually diseased wrist or foot bones, which have multiple articulations with

neighboring bones. Currently, failure most often occurs by degeneration of the opposing articular surface. A critical challenge in advancing hemiarthroplasty performance is the ability to identify bearing surfaces that will maintain healthy cartilage. Here, we report about the performance of candidate biomaterials by wear testing them against bovine cartilage plugs in a joint motion-simulating biotribometer, using PG/GAG and hydroxyproline as measures of cartilage matrix degradation and live/dead assays as a measure of cell damage.

9:20 am - 9:40 am
4001963: 2D Material-Enhanced Metal Matrix Composites: A Study on Their Mechanical and Tribological Properties for Bio-Tribological Applications
Sangharatna Ramteke, Pontificia Universidad Catolica De Chile, Santiago, Santiago, Chile; Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile

This study focuses on the development of CoCr matrix composites with improved tribological performance using additive manufacturing and 2D materials. The composites were produced using SLM and reinforced with graphite, graphene, graphene oxide, reduced graphene oxide, and Ti3C2 MXenes. The structural and chemical alterations that occurred during SLM were analyzed to confirm the presence of 2D materials in the manufactured samples. The mechanical characteristics, including surface roughness and hardness, as well as the tribological performance were assessed using steel and ceramic ball-on-disk tribometer tests under both dry and lubricated conditions. The results showed that the fusion of additive manufacturing with MMCs based on 2D materials offers significant potential for the development of custom-made implants and prosthetic devices with exceptional durability against wear.

9:40 am - 10:00 am
4002174: MXene Nanosheets as Additives in Synovial Fluid
Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile; Cotty Quiroz Esteban, Andreas Rosenkranz, Universidad de Chile, Santiago, Chile

There's a pressing need to enhance wear resistance in load-bearing joint implant materials. Traditional metals like CoCr alloys, while widely used, can generate harmful wear debris. Additive manufacturing (AM) offers potential for personalized implants, but achieving sufficient wear resistance remains challenging. Current research focuses on low-friction, minimal-wear materials, including 2D materials. However, integrating 2D materials into joint implants, especially in synovial fluid (SF), remains poorly understood. This study aims to bridge these gaps by adding 2D MXene nanomaterials to SF and reduce wear in additively manufactured metal implants. Ti_3C_2Tx and Mo_2TiC_2Tx MXenes were synthesized, and their dispersibility in SF at varying concentrations, contact angle, and surface tension were studied. Additionally, the interaction with CoCr alloy samples from selective laser melting (SLM) AM and the effect on friction and wear in reciprocating ball-on-disk experiments were investigated.

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

10:40 am - 11:00 am
4004290: Tribocorrosion Influence of PEEK in Metal on Polymer Joint Replacements: 3D Printed versus Conventional Manufacturing
Dilesh Raj Shrestha, Nazanin Emami, Lulea University of Technology, Lulea, Sweden; Rob Beadling, Richard Hall, Michael Bryant, University of Leeds, Leeds, United Kingdom

This study explores tribocorrosion in MOP contacts with implication in joint implant applications, with a specific focus on polyetheretherketone (PEEK). FDM 3D-printed and extruded PEEK against CoCr alloy was studied, along with VIT E-UHMWPE as a reference material. Potentiostatic tests were conducted in-situ by integrating an electrochemical cell into a tribometer, followed by post tribology surface analysis. Surface roughness, attributed to manufacturing methods, emerged as a critical determinant for tribocorrosion. Using Serum as a lubricant reduced CoCr electrochemical loss compared to PBS, possibly

due to faster re-passivation. Notably, after polishing PEEKs, the manufacturing method had no significant effect on the total electrochemical loss of CoCr. CoCr exhibited significantly higher electrochemical loss when in contact with PEEK than with VIT E-UHMWPE. This study highlights the pivotal role of material selection and lubricants in influencing wear and corrosion properties.

11:00 am - 11:20 am
4023547: Superlubricious Double-Network Hydrogels with Excellent Mechanical Properties Based on the In-Suit Inhibition Strategy for Biomedical Application
Jian Song, Sun Yat-sen University, Shenzhen, Guangdong, China; Yuhong Liu, Tsinghua University, Beijing, China

Osteoarthritis (OA) is the most common joint disorders and hydrogels could be an effective tool to solve this problem. In this work, we explore the mechanism of tribology properties of double-network hydrogel (DN hydrogel) under effect of free radical polymerization inhibitors. Fe^{3+} is added to the DN hydrogel as highly efficient and easily adjustable inhibitor, and the friction coefficient can be reduced to 0.0038 by adjusting the concentration. Even after 6 hours of continuous tribological testing, the DN hydrogel remains a surprising sustained superlubricity. Furthermore, the strength of the hydrogel can be 20 times higher than that of the SN hydrogel. The optimum concentration of Fe^{3+} is explored to achieve the synergetic improvement of lubricative and mechanical properties. This work opens innovative technology routes for developing superlubricious and tough hydrogels, which is a brighter future for artificial cartilage applications.

11:20 am - 11:40 am
4042223: Slide-Ring Hydrogel Friction
Angela Pitenis, Andrew Rhode, Juan Manuel Uruena, Christopher Bates, University of California, Santa Barbara, Santa Barbara, CA

Hydrogels are highly hydrated three-dimensional networks of crosslinked polymer chains. Conventional crosslinking strategies have used covalent linkages, which create permanent and rigid attachment points between polymer chains. Alternative routes include dynamic bonds, or “flickering” linkages, that allow greater network rearrangements at the cost of strength. Another involves mobile rings of crossslinker constrained along linear polymer chains that together form slide-ring gels, first described in 2001 by Okumura and Ito. In this work, we incorporated pseudorotaxanes into hydrogel networks to create tough yet soft slide-ring gels. In this study, we investigated the tribological, rheological, and mechanical properties of slide-ring gels in an effort to characterize their structure-property relationships. Our results suggest that the chemical formulation of slide-ring gels can be tuned to control friction coefficient and the elastic modulus.

Session 3F — 101 G

Nanotribology III

Session Chair: Arnab Neogi, University of Illinois Chicago, Chicago, IL
Session Vice Chair: Pranjal Nautiyal, Oklahoma State University, Stillwater, OK

8:00 am - 8:40 am
4028860: Invited Talk: Impact of Third Body on the Friction and Conductivity of Van Der Waals Interface
Ming Ma, Yuqing He, Tsinghua University, Beijing, China

Third bodies are ubiquitous at the interface under ambient conditions. They significantly influence the contact state, further leading to the variation in friction and interfacial conductivity. Here, their impact on the microscale structural superlubric (SSL) graphite/graphite van der Waals interface is explored. The maintenance of the SSL state is observed with an adsorbate-rich interface, which challenges previous understanding that SSL requires an ultra-clean contact interface. Besides, cyclically switchable conductivity of adsorbate-rich graphite/graphite interface is observed. Especially, the ON-OFF current ratio of 10^5 and the leakage current of underscore the potential of SSL microscale graphite/graphite contact as a switch.

8:40 am - 9:00 am
4001110: Clarifying Mechanism of Superlubricity of Solids
Bo Zhang, Saga Daigaku Riko Gakubu Daigakuin Kogakukei Kenkyuka, Saga-shi, Saga, Japan

Friction process is an energy dissipation process. It is found that MoS_2 and graphite have zero-friction, a superlubricity. It is proposed that incommensurate contact surfaces are associated with the super lubricity. However, engineering surfaces in contact are almost incommensurate because there are always exist misalignment in crystal orientation between two contact surfaces and crystal defects within the surfaces, while the superlubricity belongs to very limited special cases. Friction-induced low energy basal plane and hydrogenation of carbon-contained materials are also considered as possible mechanisms of superlubricity. Both give a good explanation of low friction, but they are definitely not sufficient to explain the superlubricity. Structural superlubricity (SSL) is proposed but the physical mechanism is not clear. A clarifying mechanism of superlubricity of solids is proposed and potential materials of superlubricity are listed.

9:00 am - 9:20 am
4002638: Nanotribological Study of MoS_2 Coatings Enhanced with Ti_3SiC_2 Nanoparticles
Robert Fleming, Morgan Diamond, Arkansas State University, Jonesboro, AR; Sujan Ghosh, Nihal Ahmed, University of Arkansas-Little Rock, Little Rock, AR

Molybdenum disulfide (MoS_2) is a widely used solid lubricant owing to its low coefficient of friction (COF) and high chemical and thermal stability. Bulk MoS_2 is composed of layered sheets, and weak van der Waals interactions between adjacent layers impart lubricity, but also a relatively high wear rate. To address this, Ti_3SiC_2 nanoparticle additives have been used to improve the wear resistance and mechanical cohesion of MoS_2 coatings. Ti_3SiC_2 is a layered hexagonal carbide in the family of MAX phase materials, which is noted for its mechanical fatigue resistance. In this study, laser sintering was used to prepare both pure MoS_2 coatings and MoS_2 coatings doped with 5-10% Ti_3SiC_2 nanoparticles by weight. The coatings were characterized with nanoscratch testing, scanning wear, and nanoscale dynamic mechanical analysis (nanoDMA) to assess frictional performance, wear rate, and fatigue performance, respectively.

9:20 am - 9:40 am
4004339: Interlayer Friction Behavior of Molybdenum Ditelluride with Different Structures
Lina Zhang, Tsinghua University, Beijing, China

The interlayer friction behavior of two-dimensional transition metal dichalcogenides as crucial solid lubricants has attracted extensive attention in the field of tribology. In this study, the interlayer friction is measured by laterally pushing the $MoTe_2$ powder on the $MoTe_2$ substrate with the atomic force microscope tip. The lower interfacial friction of 1T'-$MoTe_2$/1T'-$MoTe_2$(2.025×10^{-4}) compared to 2H-$MoTe_2$ /2H-$MoTe_2$ interface(3.086×10^{-4}) can be explained by the relative magnitudes of the ideal average shear strengths and maximum shear strengths obtained based on the interlayer potential energy, while the smallest interlayer friction of the 1T'-$MoTe_2$ /2H-$MoTe_2$ heterojunction(6.875×10^{-5}) is related to the weak interlayer electrostatic interaction and the weakening of the potential energy corrugation caused by the incommensurate contact. This work suggests that $MoTe_2$ is expected to

reduce interlayer friction in the future by inducing the 2H-1T' phase transition.

9:40 am - 10:00 am
4006096: Single-Step Metal-Catalyzed Synthesis of Graphene: An Exploration of Tribological Behavior
Behnoosh Sattari Baboukani, Kyriakos Komvopoulos, University of California, Berkely, Berkely, CA; Zhijiang Ye, Miami University, Oxford, OH

Graphene is renowned for its exceptional thermal, mechanical, and tribological properties. This study focuses on a one-step catalyzed synthesis of graphene involving an ultrathin amorphous carbon (a-C) film precursor deposited on an ultrathin catalyst sublayer. The process utilizes radio-frequency sputtering and filtered cathodic vacuum arc deposition to create a stack of Si/ultrathin alloy catalyst sublayer (NiFe, CoFe, and Co) /ultrathin a-C film. Controlled annealing results in a thin layer characterized by a hybrid a-C-continuum graphene structure. To understand the transformation from amorphous carbon to graphitic structures, the study employs Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), and transmission electron microscopy (TEM). The tribological behavior of the a-C films is assessed using a nanoindenter. Molecular Dynamics (MD) simulations of the Si/alloy catalyst/a-C film stack provide insights into the graphitic transformation during thermal annealing.

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

10:40 am - 11:20 am
4072234: Invited Talk: 2D Films for Friction Reduction: Key Characteristics and In-Situ Synthesis Investigated by Ab Initio and Machine Learning Molecular Dynamics
M. Clelia Righi, University of Bologna, Bologna, Italy

Thanks to their inert nature, bidimensional materials can efficiently reduce the reactivity of the surface areas they adsorb onto, thus reducing the interfacial adhesion and shear strength. I will compare these functions for MXenes and phosphorene with well-established solid lubricants [1,2]. I will also show that slippery layered materials can be synthesized in situ thanks to tribochemical reactions. In particular, I will show that selenide layers can be formed by sprinkling Se nanopowders onto sliding contacts [3] and graphene can be obtained by the tribologically induced polymerization of aromatic molecules [4]. Finally, I will discuss the potentiality of machine-learning molecular dynamics in describing tribochemistry processes by considering the case of self-assembled monolayers as friction modifiers [5].

[1] Advanced Materials 35, 2207757 (2023). [2] Journal of Nanostructure in Chemistry 13, 497 (2023).
[3] Advanced Materials 35, 2302076 (2023). [4,5] To be published.

11:20 am - 11:40 am
4004960: Nanotribology and Nanomechanical Factors Governing the Formation of Graphene Auto-Kirigami
Li Yuan, Jacob Goell, Cangyu Qu, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Graham Cross, Trinity College Dublin, The University of Dublin, Dublin, Ireland

2D materials such as graphene have remarkable mechanical and tribological properties. Recently, it was shown that graphene can spontaneously assemble into out-of-plane structures through self-folding followed by self-tearing and self-propagating, which involve overcoming the sliding friction over a graphene sheet below. We call these structures graphene auto-kirigami (gr-AK). To evaluate the nanomechanics and nanotribology of gr-AK, we cut graphene with atomic force microscope (AFM) tips. This produces structures with asymmetric self-tearing orientations, attributed to in-plane fracture anisotropy. Combining Raman spectroscopy, electron backscatter diffraction, and lattice-resolved lateral force imaging, we reveal how the cutting direction with respect to the graphene lattice affects the tearing and propagation and assess the role of interfacial incommensurability on interlayer friction. This gives insights into applications of 2D materials involving out-of-plane structures.

11:40 am - 12:00 pm
4095074: Effect of Silicon Nitride Balls and Rollers on Rolling Bearing Static Load Rating
Iqbal Shareef, Bradley University, Peoria, IL; Erwin Zaretsky, NASA, Cleveland, OH; Jacob Pitman, Caterpillar Inc., Peoria, IL

This paper investigates hybrid rolling-element bearings with silicon nitride balls and AISI 52100 bearing steel races. Objectives include determining the load and maximum Hertz stress for plastic deformation onset, as well as the Static Load Capacity. Tests involve applying 15 different loads ranging from 2,229 N to 22,290 N on discs of Rockwell C hardness from 54 to 68. Results include measurements of indentation depth, diameter, perimeter, horizontal surface area, cavity area, and volume. Based on Yhland, the Static Load Capacity for steel-on-steel, at a ball-race conformity of 52%, was found to be 3.71 GPa, and for roller bearings 3.34 GPa. For hybrid ball and roller bearings, the Static Load Rating is reduced by 29% and 15%, respectively, compared to that of all-steel ball bearings of the same size and geometry. Thus, the static Load Rating for a hybrid ball and roller bearing listed in the manufacturer's catalog can be adjusted using correction factors of 0.71 and 0.85, respectively.

Session 3I — 101 J

Commercial Marketing Forum III

8:00 am - 8:20 am
4094297: ExxonMobil: High Performance Electric Vehicle (EV) Fluid Solutions Via Novel PAO Technology
Manish Patel, ExxonMobil Chemical Company, Spring, TX

Evolving regulations and consumer trends will continue to drive the automotive industry to reduce CO_2 emissions. This in turn will drive growth in the adoption of alternate powertrain vehicles such as BEVs, FCEVs, HEVs and PHEVs. Next-generation EV hardware designs aimed at maximizing energy efficiency are likely to require new, optimized, high performance, low viscosity fluids. Integrated electric drive units which combine an electric motor, power electronics and a gearbox will challenge lubricant formulators to deliver low viscosity fluids that balance traditional lubrication with electro-performance, material compatibility and thermal management (cooling). Therefore, base oil selection is a critical consideration when developing next-generation EV fluids. This presentation summarizes recent evaluations documenting benefits in energy efficiency, and other key EV fluid performance areas, made possible via a new low-viscosity/low-volatility PAO technology platform.

8:20 am - 8:40 am
4079428: SI Group; Antioxidant and Antiwear Additives to Address Regulatory Challenges of Greases
Tyler Kuchta, Timothy Chipuk, SI Group, Painesville, OH

The lubricants and greases industries are facing regulatory challenges. Several critical chemistries may be impacted by these pressures including common antioxidants that are already, or may be in the near future, labeled as reprotoxic or environmentally hazardous and antiwear additives containing heavy metals are under continuous scrutiny by regulatory bodies who want to minimize environmental impact. New additive options are under development to address these regulatory challenges while maintaining the performance of traditional technologies. This study explores a new combined antiwear and antioxidant technology that can provide equivalent performance to traditional additive technologies found in automotive and industrial greases. The data generated in this study indicates that this new additive technology can replace traditional antiwear and antioxidant technologies and minimizes environmental impact by removing the need for heavy metal-containing antiwear additives in greases.

8:40 am - 9:00 am
4093574: Nouryon: Achieving Future Performance Objectives with Better Labeling Components
Alvaro Jose Ortiz, Nouryon, Houston, TX

Additives and lubricants contribute to sustainability in many ways. Formulators are constantly seeking to improve fuel efficiency, reduce emissions and increase durability. New regulations are progressively limiting the usage of current chemistry that are deemed hazardous. The industry will require to move to safer chemistries as replacements for traditional chemistry, while delivering the same or better performance. Future lubricants must enable engine technology to meet new emissions standards with friendlier components, requiring some fundamental shifts in formulation and additive chemistry to meet this challenge. Nouryon has being exploring components with improved labelling that meet or surpass performance vs mainstream chemistries across different functionalities like antiwear, friction modifiers and emulsifiers, enabling additive and lubricant companies to have more flexibility when formulating their products to meet regulatory requirements and achieve performance specifications.

9:00 am - 9:20 am
4093069: The Lubrizol Corporation: Mineral IGO — Additive Enabled Field Flexibility
Jared Cornett, The Lubrizol Corporation, Wickliffe, OH

Industrial gear oil is used in a variety of modern equipment on a job site. The need for different oil solutions for each OEM represented leads to higher inventory levels and increased complexity while compounding the risk of misapplication, resulting in potential equipment failure in the field. A top tier performing fluid that can meet the demands of multiple OEMs will lower carrying costs, simplify job sites and reduce the potential for costly application errors. In this talk, we will discuss how Lubrizol balances performance with enabling field flexibility to meet the demands of even the most challenging applications. Lubrizol has kept the end users' needs at the center our of next generation Industrial Gear Oil additive development, leading to better outcomes for oil marketers, distributors, and end users alike.

9:20 am - 9:40 am
4089034: Münzing: FOAM BAN® 204: Alternate to Fluorosilicone Based Antifoams for Electric Vehicle Driveline Fluids
Safia Peerzada, Münzing North America, LP, Bloomfield, NJ

Perfluoro and polyalkylfluoro substances (PFAS) have become of high concern due to health concerns and their nature of low degradation/decomposition. Regulatory agencies all over the world, such as ECHA and US EPA, have initiated regulatory programs to limit the use of these substances. The upcoming PFAS regulations may limit the use of fluorosilicone-based antifoams causing lubricant formulators to search for alternate chemistries. This has become an important issue for non-aqueous Electric Vehicle (EV) driveline fluids as fluorosilicone based antifoams consistently provide strong foam control under high stress conditions. Münzing will present a comprehensive study to show the effective foam control performance of FOAM BAN® 204 against fluorosilicone antifoam in EV driveline fluids based on different base oil groups. The testing will be conducted using Münzing's High Shear-Air Sparge Test that is designed to simulate the high stress environment that EV fluids are exposed too.

9:40 am - 10:00 am
4093130: LANXESS: Naugalube® APAN S – Sustainable, Liquid Aminic Antioxidant for High-temperature Applications
Travis Benanti, LANXESS Corporation, Naugatuck, CT; Su Mi Beack, LANXESS, Toronto, Ontario, Canada

Naugalube® APAN S, from LANXESS, is an innovative, alkylated PANA antioxidant with sustainability in mind. After several years of development, LANXESS experts have optimized the process chemistry to produce a premium liquid antioxidant with very low residual PANA content. The liquid form provides

easy handling and ensures good solubility in group I to V base oils. The composition is designed to protect high temperature lubricants such as turbine engine oils, oven chain conveyor oils, and other essential industrial lubricants. LANXESS is a backward integrated, leading aminic antioxidant producer with a global footprint, serving local markets with a just-in-time model. LANXESS continues to leverage its technical expertise to bring innovative products to meet ever-changing market demands.
In this presentation, LANXESS is pleased to share an overview of its comprehensive aminic antioxidant portfolio and the latest encouraging test results for Naugalube® APAN S.

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

10:40 am - 11:00 am
4089550: Sasol Chemicals: Surfactants Enhance Industrial Hard Surface Cleaning Capabilities
Jonathan Villalta, Sasol Chemicals, Houston, TX

Contaminants and residue cause increased downtime, shorter machine life, and a multitude of safety, heath, environmental, regulatory and quality concerns to manufacturers. For over 40 years, Sasol Chemicals has been providing surfactant solutions that meet your cleaning requirements. Ethoxylates and alkoxylates, nonionic surfactants, can be used in a variety of hard surface industrial cleaning applications. These unique surfactants will maximize your cleaning formulations with their fast-cleaning kinetics and high-performance characteristics. Sasol's product range is characterized by high detergency and surface activity, hard water stability, foam control, excellent wetting properties, favorable environmental characteristics, emulsifying power, chemical stability over a wide pH range, and user-friendly viscosity and storage behavior. These products are an ideal building block for cleaning metal surfaces from industrial deposits, oils, greases, and soils.

11:00 am - 11:20 am
4080066: Falex: Four-Ball Applications
Erin Kerr, Falex Corporation, Sugar Grove, IL

This presentation will focus on the application of electricity through wheel bearings specific with the newest generation of Four-Ball testers offered by Falex, the Model 89, in conjunction with the team at Flucon.

11:20 am - 11:40 am
4092535: Hanna Instruments: Improving Your Efficiency Through Lab Instrumentation
Conor McAnespie, Hanna Instruments, Smithfield, RI

To ensure quality, lubricant manufacturers must maintain appropriate levels of acidity and moisture in their products. Effective management is crucial for this to occur. However, the power of management in manufacturing Quality Control labs is only as strong as the procedures in place. The effectiveness of any procedure relies on its data. Typically, data for these two parameters is collected from wet chemistry instrumentation. However, some may have outdated instrumentation in their labs, hindering their ability to establish a solid foundation that can withstand external business factors, such as new ventures requiring increased production of lubricants. Through my time at Hanna Instruments, I have had the opportunity to gain knowledge on wet chemistry instrumentation and the industries that need this instrumentation. I would like to share the information have amassed during this time that can aid lubricant manufacturers in establishing the solid foundation I described earlier.

Electric Vehicles III

Session Chair: Christopher Cleveland, Afton Chemical Corporation, Richmond, VA
Session Vice Chair: Hyeok Hahn, Chevron Lubricants, Richmond, CA

8:00 am - 8:40 am
4004284: Development and Validation of Structure-Performance Ester Models for EV Fluids
Jared Nelson, Emery Oleochemicals LLC, Cincinnati, OH; Kevin Manouchehri, The Lubrizol Corporation, Wickliffe, OH

Lubrication and thermal management are key challenges in the development of next generation fluids for electric vehicles (EV). A Design-of-Experiment (DoE) approach was used to systematically explore a variety of molecular structures. An array of 23 esters was synthesized and statistical models were developed to understand correlations between structure of an ester and its performance properties. These models will be validated in their ability to predict thermal properties (specific heat, viscosity, density) and tribological behavior (frictional/tractional). The results of this study will be essential to optimizing the product development cycle for EV applications.

8:40 am - 9:00 am
3981183: SAPS-Free Bio-Based Additives for Lubrication in Next-Generation Vehicles
Xin He, Christelle Chretien, Solvay, Bristol, PA

Commercial vehicle OEMs rely heavily on engine oil containing sulfated ash, phosphorus, and sulfur (SAPS) to achieve superior lubrication performance, while these elements are detrimental to the environment and sustainability. To overcome this issue, Solvay has developed an advanced synthesis technology enabling the production of SAPS-free bio-based twin-tail amine derivatives that exhibit similar lubrication properties. Experiments have been conducted in Group III base oils for various aspects. The top candidates outperformed the benchmark additives in terms of wear resistance and friction coefficients. The copper corrosion is negligible for the newly developed additives. Additional analysis suggested that the recently invented additives possess significant possibilities for use in the realm of electric vehicles (EVs).

9:00 am - 9:20 am
4001106: Improving Electric Vehicle Energy Efficiency Using the High-Performance Base Oil and the Film Forming Friction Modifier
Moeka Okamura, Toshitaka Nakamura, Mari Iino, Akira Tada, Shingo Matsuki, ENEOS Corporation, Yokohama, Kanagawa, Japan

Improving the efficiency and cooling performance of electric vehicles is an essential technology for EV drivetrains. Low viscosity lubricants contribute to improving efficiency by reducing stirring resistance under mild conditions. However, there are concerns about a deterioration of durability performance under severe conditions. To develop technologies specially designed for EV drivetrains, we optimized base oils and other additives. First, a high-performance base oil with low viscosity and low traction coefficient was investigated, which led to achieve high efficiency and reduce heat generation on sliding surfaces. This base oil also improved fatigue life effectively. Then, effect of a newly developed friction modifier was compared to that of conventional friction modifiers. The novel friction modifier enables to reduce friction coefficient in mixed lubrication area by forming thick adsorption films, and it indicated higher gear efficiency and better cooling performance.

9:20 am - 9:40 am
4000942: Ester Base stocks for Electric Vehicle Drivetrains: Tailored Performance for Challenging Needs.
Pieter Struelens, Oleon NV, Evergem, Belgium

As the rise of the electric vehicles (EVs) is taking massive leaps, the development dedicated EV fluids cannot lack behind. Especially the fluid design for integrated electrical drivetrains is challenging since these require properties that go beyond traditional specs. These fluids will need to provide wear and friction reduction at very high rpm, they must be di-electric, conduct heat, be copper compatible and show outstanding cold flow properties. Furthermore, since a mayor driver for EV introduction is sustainability, these fluids should display a low environmental impact. In this work novel esters will be presented that can take up this challenge and meet all above requirements. Specific focus will be on thermal management, cold flow, dielectric properties, safety and material compatibility of these newly designed synthetic esters. Moreover, it will be discussed how ester technology can fit this bill at the lowest environmental footprint possible.

9:40 am - 10:00 am
4086935: Novel EV Fluid Technology Platforms
Jason Carter, SK enmove, Clarkston, MI

Every electric vehicle system on the market has its own unique set of demands for the EV fluids: load carrying, anti-corrosion and traction boosting. How do these technologies work together or against one another in finished fluid applications? What combinations can be made to bring out the best performance in your hardware? Data and example fluids from in-house blending and testing of mock finished EV fluids.

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

10:40 am - 11:00 am
4005324: High Speed Air Entrainment Test Method Development for e-Fluids
Masahiro Ishikawa, Scott Campbell, Infineum USA LP, Linden, NJ

In automotive electrification, motors and gear boxes run at extremely high speeds >20,000 rpm, for which fluid foam and air entrainment issues may arise, e.g., leakage, churning and hydraulic losses. E-fluids must have good aeration performance under extremely high-speed operations. Commonly used foam tests (ASTM Seq. I-IV) use airflow to generate foam and may not represent the air entrainment running at high speeds under shear in spinning parts. To simulate this, we have developed a High-Speed Air Entrainment Test, utilizing a homogenizing aggregator that generates extremely high speeds under shear up to 27,000 rpm. Foam and air entrainment volume are measured at oil temperatures between 40°C and 140°C. This paper addresses the test method development and learning summary based on Infineum e-fluid technology (including correlation to ASTM foam, effects of viscosity, base oil, additive and oil aging).

11:00 am - 11:20 am
3981837: Low Foaming/Aeration and Low Traction Coefficient Sustainable Synthetic Lubricant Solutions for High-Speed Electric Drivetrain Fluids
Philip Ma, Donna Mosher, Chad Steele, BASF, Tarrytown, NY

Internal combustion engines (ICE) are being replaced by electric motors as power sources for both passenger cars and heavy-duty trucks. OEMs are using off-the-shelf lubricant fluids, such as automatic transmission fluids (ATF), manual transmission fluids (MTF), etc., as electric drivetrain fluids (EDF). EDFs are driving toward lower viscosity for better heat transfer capacity and better energy efficiency. In this paper, we will highlight the importance of low foaming/aeration, low traction coefficient which are

critical for the performance of low viscosity EDF during the high rotation-per-minute (rpm) speed applications. Sustainable EDFs with ultra-low foaming/aeration can potentially reduce electric induced bearing damage (EIBD), thus provide better bearing protection and life, and in the meantime provide better heat transfer capacity. Low traction coefficient fluids will also contribute to better lubricant energy efficiency in comparison to other fluids with the same viscosity.

11:20 am - 11:40 am
3997228: Electric Vehicle Drive System Exceptional Fluids
Anant Kolekar, Valvoline Global Operations, Lexington, KY

The recent growth in the electric vehicle (EV) market has significantly affected the automotive industry along with the lubricant industry. For the lubricant industry, EV requirements are unique compared to internal combustion engine vehicles (ICEVs) where electrical, thermal, extreme pressure and foam performances are becoming more critical. In EVs, gears and bearings experience significant fluctuations in power, torque and speed which demand for more precise testing work. This motivated us to develop new tests and worked with OEMs to formulate exceptional fluids. Tribological, analytical, benchtop and vehicle testing for EV DSFs were conducted to evaluate the performance and further understand the effect of fundamental properties of these specialty lubricants. There were significant improvements in the overall vehicle efficiency (3+%), driving range (15+ miles) and reductions in operating temperatures (13+°C) as tested by OEMs and third-party labs.

Session 4A — 101 B

Materials Tribology II: Tribute to Michael Dugger

Session Chair: John Curry, Sandia National Laboratories, Albuquerque, NM
Session Vice Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

2:00 pm - 2:40 pm
4077153: Frontiers Research on Solid Lubricants for Superlubricity
Ali Erdemir, Texas A&M University, College Station, TX

Solid lubricants have been around for so long and are the most desired options for applications involving extreme conditions. In recent years, interest in solid lubricants increased noticeably, especially for the design and development of 2D materials (i.e., graphene, MoS2, MXene, black phosphorous, etc.) and other carbon nanostructures providing friction coefficients as low as 0.001 [1]. In this presentation, a comprehensive overview of recent progress in solid lubricants will be provided together with many intrinsic and extrinsic factors that can affect their superlubricity. Overall, these and other novel approaches involving solid lubricants are leading the way for the design and production of next-generation solids that can further increase efficiency, reduce carbon footprint, as well as extend machine life in future moving mechanical systems.

[1] Superlubricity (2nd Edition), Erdemir, A., Martin J.M., Luo, J., Editors; Elsevier, Amsterdam, 2020.

2:40 pm - 3:00 pm
4002627: Friction and Wear of Composite MXene/MoS_2 Coating Under Dry and Hydrocarbon-Lubricated Conditions
Ali Zayaan Macknojia, Diana Berman, Andrey Voevodin, Samir Aouadi, University of North Texas, Denton, TX; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Friction and wear-related failures remain the greatest problems in moving mechanical assemblies operating under various conditions. This study demonstrate lubricity achieved by spray-coating solution-processed multilayer Ti_3C_2Tx-MoS_2 blends onto rough 52100-grade steel surfaces. Blends exhibited lower frictional performance for individual pristine materials, MoS_2 and Ti_3C_2Tx, under high pressure, sliding speed. Study investigated the processing, structure, and property correlation to gain a deeper understanding of the underlying phenomena. Raman spectroscopy, scanning electron microscopy, and transmission electron microscopy results revealed the formation of an in-situ robust tribolayer responsible for the outstanding performance observed at high contact pressures and sliding speeds. This study has broad implications for the development of solid lubricants that can operate under extreme conditions and low viscosity fuel environment, inspiring further research and development in this field.

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

4:00 pm - 4:40 pm
3994581: Elucidating the Chemical and Structural Characteristics of Mechanocatalytically-Formed Carbonaceous Films on Platinum-Gold Surfaces
Filippo Mangolini, Camille Edwards, Hsu-Ming Lien, The University of Texas at Austin, Austin, TX; Tomas Babuska, John Curry, Frank DelRio, Michael Dugger, Sandia National Laboratories, Albuquerque, NM; Jason Killgore, National Institute of Standards and Technology, Boulder, CO

Nanocrystalline Pt-Au alloys have emerged as a promising class of wear-resistant materials for various applications, including electrical contacts and electromechanical devices. While the formation of carbonaceous layers on Pt-Au alloys has been reported to decrease friction in tribological tests carried out with different countersurface materials, remarkably little is still known about their chemistry and structure. Here, we employed four different Pt-Au alloys ([Au] from 0 at.% to 10 at.%) to perform contact pressure-dependent tribological experiments in nitrogen gas containing trace organics. The results of the multi-technique analytical characterization of the mechanocatalytically-formed, carbon-rich surface layers did not only shed light on their chemical composition and local atomic structure, but also revealed insights into the dependence of the mechanocatalytic activity of Pt-Au alloys on the Au content. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

4:40 pm - 5:00 pm
4000873: Environment Dependence of MoS_2-Based Dry Film Lubricants
Samuel Leventini, Ashlie Martini, University of California, Merced, Merced, CA; Tysen Mulder, Brian Dykas, Scott Kihara, Blue Origin, LLC, Kent, WA

MoS_2 is an effective and widely used dry film lubricant (DFL) coating in space applications, but its friction and wear life behavior are very sensitive to the environment, particularly humidity. Materials like Ni or Au can be co-sputtered with MoS_2 to form nanocomposite coatings that can exhibit reduced environmental sensitivity when compared to non-composite MoS_2 films. This study seeks to quantify the environmental sensitivity of three MoS_2-based DFLs; one non-composite ("pure") MoS_2 film, a MoS_2 + Ni nanocomposite film, and a MoS_2 + Sb_2O_3 + Au nanocomposite film. The study utilized unidirectional sliding tests in both open air and in a nitrogen-filled enclosed chamber to measure differences in friction and wear life between the two environments. Samples and wear tracks were examined using X-ray photospectroscopy and scanning electron microscopy to characterize the elemental composition and surface topography at high magnification.

5:00 pm - 5:20 pm
3996626: Investigation of MoS_2-Coated NITINOL60 for Triboelements in Extreme Environments
Adam DeLong, Catherine Fidd, Thomas Lockhart, Brandon Krick, Florida State University, Tallahassee, FL; Tomas Babuska, John Curry, Steven Larson, Sandia National Laboratories, Albuquerque, NM; Christopher DellaCorte, The University of Akron, Akron, OH; Samuel Howard, NASA Glenn Research Center, Cleveland, OH; William Scott, Matthew Mazurkivich, Sara Rengifo, NASA Marshal Space Flight Center, Huntsville, AL

60NiTI is a pseudo-shape memory alloy with excellent corrosion resistance, high strain to failure, and a hardness of 60HRC (~8GPa). These properties give NITINOL60 the potential to be used in triboelements for harsh environments like space. Dry film lubricants, like MoS_2, have a low vapor pressure, low operating temperatures, and long life giving it the potential to be used in space. Although MoS_2 is compatible with most bearing steels, its compatibility with 60NiTi is not well documented. 60NiTi and 440C stainless steel substrates had magnetron sputtered MoS_2 coatings with and without Ti interlayers to compare the wear and adhesive properties of MoS_2 coated 60NiTI samples to 440C with the same coatings. Wear and scratch tests showed both 60NiTi and 440C substrates with Ti interlayer had improved wear life and bond strength compared to samples without Ti interlayers.

Session 4C — 101 D

Lubrication Fundamentals II: Marine Lubrication

Session Chair: Xin He, Syensqo, Levittown, PA
Session Vice Chair: Nicole Dörr, AC2T research GmbH, Wiener Neustadt, Austria

2:00 pm - 2:40 pm
4004463: Alternative Energy Carriers — Impact of Ammonia on Engine Oil Performance
Nicole Dörr, Adam Agocs, Charlotte Besser, AC2T research GmbH, Wiener Neustadt, Austria; Maria Rappo, Nicolas Obrecht, TotalEnergies, Courbevoie, France

Decarbonization requires fundamentally different energy systems enabled by using alternative energy carriers such as green electricity and green fuels which are preferably free of carbon such as hydrogen and ammonia. Ammonia is especially considered as future fuel for marine vessels. However, there is little knowledge about the interaction of ammonia and its combustion products with engine oils. This paper reports on a methodology based on artificial oil alteration and performance tests which was designed to elaborate corrosion properties, deposit formation, and load-bearing capability of fresh and aged engine oil. It could be shown that the selected performance parameters were severely impacted by the presence of ammonia or nitrogen dioxide compared to air. Exemplarily, nitrogen dioxide contamination resulted in higher oxidation and acidification of the oil than ammonia or air.

2:40 pm - 3:00 pm
4004576: Oil Film Thickness of Two-Stroke Marine Diesel Engines at Different Operating Conditions
Oliver Spenceley, University of Sheffield, Leeds, United Kingdom

In light of emergent maritime emission legislations, ensuring increased efficiency and emission reduction in marine engines is paramount. A pragmatic approach to these requisites involves meticulous management of cylinder lubricant oil within the combustion chamber, specifically the film thickness. A non-invasive system, leveraging ultrasonic technology, has measured the leading, instantaneous and trailing films as a piston ring passes the transducer on a full-scale marine test bed through a range of operating conditions. This work emphasizes the commercial viability of ultrasonic technology as an in-situ, non-destructive tool for continuous monitoring and data acquisition over extended operational

periods, revealing interplays between lubrication, operational parameters, and emissions outside of a laboratory. This approach enables the strategic optimization of lubricant feed rates, thereby boosting engine efficiency, curbing emissions, and ensuring compliance with sustainability.

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

4:00 pm - 4:20 pm
3982139: Base Oil Properties Effect on Friction, Oil Film Thickness and Pressure Characteristics — Comparison to Multigrade Oils
Polychronis Dellis, National Technical University of Athens, Athens, Attiki, Greece

Various base lubricants' rheological behavior was assessed as well as their additive chemistry, in an idealized single-ring simulating test rig. Different oils are tested, the properties of which are provided by the manufacturer. The successful sensor implementation at the single-ring test rig in the past, enabled robust and reliable testing for different test cases. Oil film thickness, overall friction, oil film pressure measurements are derived from the fitted sensors at different speed, load and temperature conditions. Trends from the measurements are demonstrated and a useful comparison to the multigrade lubricant testing from previous studies is provided, in terms of cavitation (initiation and development), viscosity, power losses and absolute measurements. These datasets assessment will promote the likely field performance of base finished monograde marine engine lubricants.

4:20 pm - 4:40 pm
3997421: The Impacts of Biodiesel on Properties of Marine 4-Stroke Diesel Engine Oil
Jie Zhang, Richful Lube Additive Co. Ltd., Xinxiang, Henan, China

Biodiesel as one of the alternative fuels in future had attracted more and more attention from researchers and customers. Biodiesel has been proved to be applied in marine transport without any modification of engine system. Due to its recyclable raw material, Biodiesel is considered as a fuel choice to achieve carbon neutral in shipping industry. But biodiesel contains more oxygen content compared with traditional diesel from petroleum. Because of fuel dilution, risk from biodiesel remains to properties of marine 4-stroke diesel engine oil. In this paper, simulating tests were carried out to measure anti-oxidation, anti-corrosion, detergency and friction control abilities for marine engine oil, and bench test was run to measure the general performance of it.

Session 4D — 101 E

Grease III

Session Chair: Lang Chen, ExxonMobil, Annandale, NJ
Session Vice Chair: Salil Bapat, Purdue University, West Lafayette, IN

2:00 pm - 2:40 pm
4001725: Influence of Processing on Polyurea Grease from Preformed Thickener
Cindy Liu, Lauren Huffman, Matthew Thorseth, Pete Rozowski, Dow Chemical Company, Midland, MI

Preformed urea thickeners have gained attention in recent years as new and safer way to polyurea greases. We studied thickening process of grease formation from a preformed urea thickener, and we found post-production homogenization largely boost the viscosity and yield stress. Furthermore, different types of homogenizers showed effects on grease consistency, and the dispersion and microstructures of the thickener were examined by microscope and TEM. The work provided that shear throughout grease manufacturing is essential to maximize its thickening power.

2:40 pm - 3:00 pm
3999326: Multiscale Approach for the Consideration of Limited Grease Availability in the Tribological Component Design
Cesar Pastor, Robert Bosch GmbH, Renningen, Germany

The majority of the tribological design elements used in industrial applications are greased and sealed for life. The maintenance is therefore reduced to a minimum being extremely cost-effective. Nevertheless, important questions arise at early development phases as: How much or which type of grease is needed? Is the grease active lubricating the contact or is there a risk of starvation or failure? Increasing computational capabilities open new scenarios in which costly experiments can not only be avoided but also a great number of parameters can be numerically replicated before having physical samples or prototypes. A multiscale approach is proposed for systems with risk of limited lubricant availability, specifically greased contacts. From system (macro) level to contact (micro) level, different modelling methods are used to show how the grease behavior affects the contact conditions through the lubricant presence at the vicinity of contact and the alteration of the meniscus geometry.

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

4:00 pm - 4:20 pm
4000256: Estimating Grease Degradation at the Inlet of a Cylindrical Roller Bearing Using CFD and Experimental Data From the Grease Worker
Robert Meijer, University of Twente, Enschede, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

One of the mechanisms that limits the lifetime of lubricating grease in a rolling bearing is mechanical degradation by shear. Shear results in a change of the micro-structure of the thickener–oil system, leading to a change in bleed and consistency. A novel approach will be presented, where the grease worker can be used to measure the rheological properties of a grease in situ, while aging the grease, giving the change in rheology as a function of the imposed mechanical energy. A CFD model is used to calculate the power density, shear rate and temperature distribution of the grease inside the grease worker and for the inlet of a cylindrical roller bearing under pure rolling conditions. This is used to estimate the actual degradation of the grease leaving the contact.

4:20 pm - 4:40 pm
3998241: A Simple and Novel Method Determining the Suitability of a Grease Related to the White Etching Crack Phenomenon
Saba Mottaghi, Julian Wald, TUNAP GmbH & Co. KG, Wolfratshausen, Bavaria, Germany

A novel, but simple methodology is presented to predict conflicts that might appear in the life cycle of grease lubricated bearings. Greases in high-speed bearings are exposed to high centrifugal forces leading to grease loss in the contact zone by slinging. This grease will stay and not contribute further to lubrication. The re-entry of the grease from starving to the contact, is random and will happen incidentally. While standard rheometry simulates the shear and temperature related viscosity, less attention is paid on the aspect of the structural rearrangement of a grease by temperature. Grease loss in high-speed bearings by centrifugal force displacement may be crucial in applications such as White Etching Cracks (WEC). As WEC is commonly attributed to marginal lubrication, friction and static electricity, the aspect of centrifugal force induced grease loss becomes critical. A way how to measure the changes in the “inner” structure of a grease by a simple methodology is presented.

4:40 pm - 5:40 pm - **Grease Business Meeting**

Session 4E 101 F

Biotribology II

Session Chair: Meagan Elinski, Hope College, Holland, MI
Session Vice Chair: Quentin Allen, Brigham Young University, Provo, UT and Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile

2:00 pm - 2:40 pm
4004279: Best Practices – Rheological and Tribological Testing of Soft Materials
Kartik Pondicherry, Paul Staudinger, Anton Paar GmbH, Graz, Austria; Julius Heinrich, Anton Paar Germany, Ostfildern, Germany

Anyone who has spent a reasonable amount of time in a testing lab understands the complexities associated with developing novel test and analysis methodologies. Even after that, implementing the process is still challenging. Over the past decade, the authors have been often approached to clarify on some of the basic operating processes encountered during rheological and tribological testing and this work is aimed at addressing this issue. It provides some clarifications on areas such as sampling, sample handling, choice of test geometries, configurations, parameters, etc. Additionally, aspects of data acquisition and handling are also presented here. This topic assumes a greater significance for softer materials such as tissues, hydrogels, etc., as their viscoelastic properties play a significant role in determining their tribological characteristics. This work also covers case studies on select bio-tribological interfaces and also presents lessons learned in the process.

2:40 pm - 3:00 pm
4004005: Sliding Induced Integration of Nanoparticles into Hydrogel Surfaces
Meagan Elinski, Connor Bovia, Griffin Gleeson, Brianna Couturier, Lauren Buckley, Morgan Platz, Hope College, Holland, MI

Dynamic interactions between nanoparticles and soft materials will be increasingly encountered in the body as nanomaterials continue to be explored for a range of therapeutic applications. However, little is known about the surface effects of nanoparticles sliding against soft material surfaces. This work seeks to gain a fundamental understanding of the interactions between nanoparticles and hydrogels at sliding interfaces. Utilizing polyacrylamide (PAM) hydrogels, in situ macroscale friction tests were conducted with a rheometer with a tribology adapter. Comparing different nanoparticle compositions, citrate capped gold nanoparticles exhibited a 50% increase in friction relative to water due to hydrogen bonding, vs nanodiamonds exhibiting a 50% decrease in friction due to a higher solution viscosity. Post-sliding characterization of the PAM surfaces with confocal Raman microscopy and SEM imaging points towards integration of the nanoparticles within the hydrogel matrix.

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

4:00 pm - 4:20 pm
4005448: Polyglycerol-Functionalized Nanodiamonds for Improved Lubrication of Artificial Joints in Simulated Body Fluid
Mohammad Eskandari, Asghar Shirani, Diana Berman, Ali Zayaan Macknojia, University of North Texas, Denton, TX

Friction and wear are the major causes of osteoarthritis, the degenerative joint disease-causing pain and loss of functioning in the elderly population. propose to use diamond nanoparticles (NDs) in natural and artificial joints as the remedy to alleviate or even reverse friction and wear-induced damage. NDs, functionalized with polyglycerol to add to their biocompatibility and dispersibility, are introduced to the sliding interfaces of common polymer-on-metal and metal-on-metal implant systems and subjected to tribological evaluation. A detailed analysis of the produced wear tracks is employed to unravel the effect of surface functionalization of NDs and to optimize the concentrations needed for effective and prolonged friction and wear reduction. The findings suggest that the surface reactivity of NDs significantly affects their performance as non-toxic biolubricants.

4:20 pm - 5:00 pm - **Biotribology Business Meeting**

Session 4F — 101 G

Seals I

Session Chair: Aaron Harcrow, Ultool, LLC, Duluth, GA
Session Vice Chair: Jing Tang, Ultool LLC, Duluth, GA

2:00 pm - 2:40 pm
4001211: Numerical Study of Textured Impulse Gas Seals
Noel Brunetiere, Jean Bouyer, Institut Pprime, Futuroscope Chasseneuil Cedex, France; Andriy Zahorulko, Sumy State University, Sumy, Ukraine

Impulse gas seals are a kind of mechanical seals equipped with deep grooves on both seal faces to generate a load carrying capacity and avoid contact and wear of the rings during operation. One face has feeding grooves connected to the high-pressure side and the other face has chambers that are periodically facing the feeding grooves during rotation. The mechanism of load generation in the fluid film is due to a transient impulse periodic process of chambers pressure feeding and pressure release. The behavior of these seals is thus complex compared to spiral groove gas seals. In this presentation a numerical study of an impulse gas seal is carried out. The effect of the seal design parameters is analyzed.

2:40 pm - 3:00 pm
4031054: Experimental Study of EHD Seals
Aaron Harcrow, Jing Tang, Hanping Xu, Ultool LLC, Duluth, GA; Sevki Cesmeci, Georgia Southern University, Statesboro, GA

The EHD seal is a non-contact shaft seal with an elastic sleeve surrounding the shaft with a narrow gap in between. Simulation results show that it restricts the gap leakage through self-adjusting deformation under pressure differentials, thereby improving energy efficiency and limiting wear. A preliminary test rig was utilized to confirm estimated EHD seal performance by simulating different seal materials, geometries and working fluids. This work was reported in a separate presentation. For supercritical carbon dioxide (sCO_2) applications up to 35 MPa pressure and 700°C, EHD seals will be tested in a complex, dynamic test rig having flow conditions similar to the Brayton cycle. Three test phases: Phase 1, an EHD seal fabricated from 316 SST was tested with a fixed rotor and ambient temperature N2. Results confirmed a throttling effect beginning around 800 psi (5.52 MPa), Phases 2&3, work ongoing, the seal will be incrementally exposed to higher working fluid temperatures, pressures and rotor RPM.

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

4:00. pm - 4:20 pm

4004004: Topology Optimization for Low-Leakage and Low-Friction Surface Textured Face Seal

Iwa Ou, Eagle Industry Co., Ltd., Sakado-shi, Saitama-Ken, Japan; Kentaro Yaji, Osaka University, Suita, Osaka, Japan

A face seal with both low leakage and low friction was realized by surface texturing technology [1]. A surface texture consists of several micro-grooves. The friction coefficient and leakage rate are estimated by pressure distribution solved by the Reynolds equation. In a conventional way, shape optimization is carried out using a genetic algorithm, which restricts the degree of freedom and performance. We adopted topology optimization which is one of the gradient-based optimizations capable of generating free-form shapes. Several studies [2,3] based on the level set method have been carried out, which can only use one depth. Owing to the recent development of laser processing technology, the depth of the surface texture can be precisely and accurately controlled industrially. Therefore we propose topology optimization based on the density method and present computational and experimental results in the presentation.

4:20 pm - 4:40 pm

4012791: A Low-Leakage and Low-Drag Elastohydrodynamic Seal for Supercritical Carbon Dioxide Turbomachinery

Mohammad Fuad Hassan, Sevki Cesmeci, Mohammad Towhidul Islam, Ali Akbor Topu, Md Wasif Hasan, Jonah Henry, Joshua Bunting, Georgia Southern University, Statesboro, GA; Hanping Xu, Aaron Harcrow, Jing Tang, Ultool, LLC, Duluth, GA; Shuangbiao Liu, Northwestern University, Evanston, IL; David Dewis, Consultant, Bath, ME

Current Supercritical carbon dioxide (sCO_2) turbomachinery suffers from high leakage rates, which is creating a major roadblock to the full realization of sCO_2 power technology. As a potential solution, we propose an elastohydrodynamic (EHD) scalable, high-temperature, high-pressure shaft end seal for sCO_2 turbomachinery. In this study, we experimentally carried out a proof-of-concept study for the proposed seal design and proved that the EHD seal restricts the leakage to minimal values at high pressures. The maximum leakage rate recorded was 272.51 LPM at 5.00 MPa. Following that, the leakage rate began to drop down to 108.72 LPM as the pressure increased to 15.00 MPa, generating a bell-shaped curve. At a 95% confidence level, the estimated confidence intervals for the mean were ±1.81 LPM and ± 2.58 LPM for pressures of 5.00 MPa and 15.00 MPa, respectively. These preliminary findings suggest that the proposed EHD seal design can potentially be applied to sCO_2 turbomachinery.

4:40 pm - 5:00 pm

4018310: Optimal Design of Sealing Unit for Multi-Stage ROT (Radial Outflow Turbine) Considering Ratio of Tip Clearance

Yongbok Lee, Korea Institute of Science and Technology, Seoul, Republic of Korea; Yunseok Ha, Yeongdo Lee, University of Science and Technology, Seoul, Republic of Korea

This paper investigates the leakage phenomena and performance of radial outflow turbine (ROT) with various sealing unit configurations according to tip clearance in a steam environment. Computational fluid dynamics (CFD) analysis was conducted to analyze the various fluid passage phenomena at each stage of an ROT with a sealing unit. A tip clearance of 0.1 mm between the stator and rotor was set up, and the total energy heat transfer model with adiabatic no-slip walls was defined. The k-e turbulence model and scalable wall function were applied for the analysis. The inlet boundary conditions were the total pressure and temperature, and the mass flow rate ranged from 0.208 to 0.5 kg/s. The analysis was conducted according to circumferential velocity to check the flow phenomena and turbine performance.

The flow phenomena occurring in each stage of the ROT were mainly investigated through energy dissipation and entropy contours to check the effect of various shroud configurations.

5:00 pm - 6:00 pm - **Seals Business Meeting**

Session 4I 101 J

Commercial Marketing Forum IV

2:00 pm - 2:20 pm
4092108: BASF: Emgard 7148 XFE 75W-80, A New Fuel Efficient, Shear Stable Axle Lubricant to Meet New US Green House Gas Emission Requirements.
Arjun Goyal, Donna Mosher, BASF, Florham Park, NJ

EPA and NHSTA on behalf of DOT have enacted rules to reduce Green House Gas emissions in HD vehicles. OEMs developed new reduced weight axle designs and lower oil level in axle sump. To meet new 2027 GHG requirements, axle oils contribute to higher fuel savings and reduction in CO_2 emissions. BASF's new 75W-80 lubricant consists of a unique combination of synthetic base oil (PAO) and proprietary viscosity improver (thickener) which results in superior low-and-high temperature properties with excellent extended-length shear stability. Emgard 7148 lubricant meets the SAE J2360 and leading North American axle manufacturers rigorous extended drain specification requirements. The new axle lubricant meets sustainability goals with fuel savings of 0.79% and front axle temperature reduction of 5.2C over a leading fuel-efficient SAE 75W-90 lubricant. Using EPA estimates, the use of new lubricant is estimated to save over $300M in fuel and reduce CO_2 emissions by 6.6B lbs/yr. in the US.

2:20 pm - 2:40 pm
4079639: VBASE® OIL Company: Secondary Polyol Ester™ Technology – Expanding the Portfolio of Novel Sustainable Base Oils
Martin Greaves, Jeff Dimaio, Zach Hunt, Ben Bergmann, Michelle DiMaio, VBASE Oil Company, Pendleton, SC

VBASE® Oil company has commercialized a novel family of Secondary Polyol Ester™ (SPE™) base oils that are high performance sustainable API Group V synthetic base oils in the range ISOVG 32-100. Our company is expanding our portfolio with new grades in the range ISOVG 100-460. SPE™ base oils have been 'Designed for Sustainability' by linking building blocks that have high levels of biodegradability to create novel base oils that can help formulators meet the highest technical performance and environmental accreditation requirements. The presentation will introduce the VBASE® Oil Company and highlight some of the unique properties and applications of SPEs. This oxygen-rich family of base oils, with in-built detergency, offers some special attributes such as excellent deposit control, hydrolytic stability, friction control and low heats of combustion making them a versatile building block for formulators of industrial, marine and automotive lubricants.

2:40 pm - 3:00 pm
4093023: The Lubrizol Corporation: Improved Performance for Open Gear Lubricant Systems
Jennifer Clark, Robet Dura, Gareth Fish, The Lubrizol Corporation, Wickliffe, OH

Open gear lubricant technology for heavy industrial equipment is continually evolving. Historically most base fluids for open gear applications were asphaltic and brightstock based, moving more recently towards Polyisobutylene to assist with visual inspection and to maintain viscosity. Though brightstock and PIB options are cost effective, they do not provide differentiating performance, and while polyalphaolefin (PAO) base oils have also been used to boost efficiency and lower operating

temperatures; other more efficient alternatives are now available. As an alternative and complement to Brightstock, PIB and PAO, Lucant™ provides additional benefits in open gear applications. Lubricants designed utilizing Lucant™ deliver lower operating temperatures, improved efficiency, reduced lubricant consumption, and work synergistically with Lubrizol's phosphorus-based chemistries. This presentation will provide an overview of Lucant™ and Lubrizol's additive benefits in open gear applications.

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

4:00 pm - 4:20 pm
4095150: Evonik: High Performance, Energy Efficient Industrial Gear Oils Enabling Short-Timeline Cost Savings
Mark Petit, Evonik, Rochester Hills, MI

Industrial gear oils are a critical component in the efficient operation of machinery and equipment and the use of high-performance lubricants can significantly reduce energy consumption and maintenance costs. NUFLUX® is a high-performance industrial gear oil technology, proven by broad OEM approvals and multiple applications in the field. Besides high performance and oil life extension, the utilization of this cost-effective technology leads to a return of investment of only a few months. This paper will present selected Evonik in-house cases showing that energy savings are just an oil change away.

4:20 pm - 4:40 pm
4086170: ExxonMobil: Introducing Elevexx™ LAO and Exxal™ 1315 LE Alcohol
Kyle Lewis, ExxonMobil, Spring, TX

The global supply of materials serving the lubricant markets has been disrupted in recent years. Ensuring reliable access to critical chemical feedstocks is a priority for lubricant component producers.
For more than 60 years, ExxonMobil has served the lubricants industry with chemical intermediate products. Backed by a global manufacturing and supply footprint, our higher olefins and Exxal™ alcohols are trusted as integral components of many additives and synthetic base stocks. ExxonMobil is once again leveraging its integration and manufacturing scale to bring high quality chemical products to the lubricants market. Global customers can confidently rely on our new Elevexx™ linear alpha olefins to strengthen your production of high-performance lubricant components. We have also grown our portfolio with Exxal™ 1315 LE, an LAO-derived alcohol, which can broaden your access to linear alcohols for the production of additives and esters.

4:40 pm - 5:00 pm
4094293: ExxonMobil: Alkylated Naphthalene: A Booster and a Base Stock
Manish Patel, ExxonMobil Chemical Company, Spring, TX

Lubricant markets continue to push for extended fluid life while improving the lifetime and operational efficiency of equipment. To increase efficiency, OEMs are focusing on better engine performance, longer oil life and smaller sump size. To help achieve those goals Synesstic™ alkylated naphthalene AN5 & AN12 can be incorporated into the base oil blend as a booster. Synesstic™ base stocks enhance thermo-oxidative stability, augment additive performance, extend fluid operating life, increase blend stability and improve engine cleanliness. This performance is achieved with the added benefits of improved seal compatibility and hydrolytic stability compared to esters. This presentation will demonstrate how Synesstic™ AN5 and AN12 Group V base stocks can work as a booster to improve performance to meet lubricant industry needs and expand base oil formulation flexibility.

Session 4J 200 DE

Electric Vehicles IV

Session Chair: Carlos Sanchez, Southwest Regional Research Institute, San Antonio, TX
Session Vice Chair: Vinod Radhakrishnan, Afton Chemical Corporation, Richmond, VA

2:00 pm - 2:20 pm
4006626: Probing the Effect of Electric Fields on Behaviors of Lubricant Additives Confined between Surfaces at the Molecular Level
Zhaoran Zhu, James Ewen, Daniele Dini, Imperial College London, London, United Kingdom

The increasing demand in electric vehicles has propelled advancements in lubricant technology for new operational environments under electric fields (EFs). However, it has been pointed out that the change in lubricating effect at electrified interface behave differently for bulk liquid-solid interfacial systems and nanoconfined systems, which are not well understood. Therefore, in this study, we perform nonequilibrium molecular dynamics (NEMD) simulations with a reactive force field (ReaxFF) to study the effect of EFs on phosphate-based lubricant additives, in between two metal surfaces, under nanoconfined and sliding conditions. Meanwhile, two charge equilibration methods implemented in NEMD are also investigated and compared, known as Qeq and QTPIE. These findings provide an atomistic understanding of the effect of EFs on lubricant additives' behaviors during the redox reactions.

2:20 pm - 2:40 pm
4005300: Viscosity Dependence of Oil Churning Losses in an Electric Vehicle Gearbox at High Speeds
Alexander MacLaren, Amir Kadiric, Imperial College London, London, United Kingdom; Ning Ren, Valvoline Ltd., Lexington, KY

The accelerating uptake of electric vehicles (EVs), and the drive to extend vehicle range has brought EV powertrain efficiency sharply into focus. The continuing trend towards reducing transmission oil viscosity has multimodal implications for both transmission efficiency and reliability. Predicting oil churning, the principal load-independent power loss, is a particular challenge as drive pinion speeds surpass the range of validity of existing models. Finding an optimum fluid viscosity for any given system therefore remains challenging. In this study, oil churning torques are measured in an EV drive unit over a wide range of transmission fluid viscosities. The transmission is temperature-controlled and instrumented to enable control of viscosity and torques derived by inertia rundown are compared to those obtained in the steady state. Finally, the task of optimizing lubricant viscosity to maximize both transmission efficiency and reliability is addressed.

2:40 pm - 3:00 pm
4007600: Unraveling the Complex Tribochemistry of Lubricated Surfaces Under Electrified Sliding Conditions
Ali Erdemir, Pushkar Deshpande, Cagatay Yelkarasi, Seungjoo Lee, Texas A&M University, College Station, TX; Leonardo Farfan-Cabrera, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico

Electric vehicles (EVs) are becoming the provider of future transportation needs due to their environmental benefits. However, there exist some tribological challenges that can adversely impact the longer-term functionality of such vehicles due to stray electricity. In this presentation, we report some of the complexities that can adversely impact the tribochemistry and hence the formation of protective tribolayers under electrified sliding conditions. Specifically, using a wide range of surface and structure analytical techniques, we unravel the structural chemistry of tribofilms forming under electrified

condition and relate such findings to friction and wear. Results show that the passage of electric current through the contact interfaces increases wear by the formation of harder and more abrasive debris particles mostly composed of iron oxides and carbides. These findings may help in the development of better fluids and materials to mitigate such wear problems in real applications.

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

4:00 pm - 4:20 pm
4005532: Optimization of EV Drivetrain Efficiency Through Lubricant Selection
Amir Kadiric, Joseph Shore, Imperial College London, London, United Kingdom

The ability to systematically study and minimize drivetrain losses provides an important avenue for improving the efficiency, and hence the range, of an EV. This paper uses a recently developed, tribological model for prediction of EV gearbox efficiency to systematically study the effect of lubricant properties, including viscosity, pressure-viscosity coefficient, thermal conductivity, and boundary friction coefficient on the EV drivetrain losses over real-road and standardized duty cycles. The model uses experimentally obtained lubricant rheology parameters to enable it to discriminate between nominally similar oils. The temperature evolution in the gearbox, including the effect of motor cooling, are accounted for through a suitable thermal network. The results are discussed in terms of relative importance of different fluid properties on EV efficiency and the overall efficiency gains that may be achieved through lubricant optimization.

4:20 pm - 4:40 pm
4015266: Simulation and Test-Based Methodologies for EDU Fluids Development
Thomas Wellmann, Jonathan Palmer, Kiran Govindswamy, FEV, Auburn Hills, MI

The use of innovative electrified propulsion systems is expected to play an important role in helping OEMs meet fleet CO_2 targets. A key aspect for customer acceptance of BEV's is the driving range. Hence, it is critical to increase the drivetrain efficiency without sacrificing vehicle performance. Due to the integration of power electronics, electric motors, and geartrain into one compact drive unit, unique system evaluations will be required. Specifically, the behavior of the e-fluids can have a significant influence on the EDU performance. This presentation will showcase key drivetrain components and how their performance can be evaluated via simulation and testing. Methods specifically for fluid development on sub-component level will be shown. Subsequently, fluid evaluations in a complete EDU will be discussed, and influence of fluids for cooling and lubrication will be highlighted. The influence of EDU efficiency to the drive range will be estimated using vehicle-level simulations.

4:40 pm - 5:00 pm
4005366: Electrified Rheology and Elastohydrodynamic Lubrication (EHL) Behavior of Graphene-Based Low Viscosity Lubricants for EV Application
Leonardo Farfan-Cabrera, Tecnologico de Monterrey, Monterrey, Mexico; Peter Lee, Carlos Sanchez, Southwest Research Institute, San Antonio, TX; Ali Erdemir, Texas A&M University, College Station, TX

Lubricants with carefully balanced levels of conductivity have been proposed as a promising option to overcome the shaft/bearing damage caused by currents present in electric drivelines. This can be achieved through the use of conductive fluids or by adding conductive agents like additives or nanoparticles to lubricating oils. Limited research has been published on the topic to elucidate this notion. Hence, in this work, a synthetic base oil (polyalphaolefin oil (PAO_4)) and a Group II base oil were blended with 0.5 %wt./v of graphene nanoplatelets (GnPs), respectively. They were evaluated as potential nanolubricants for electrified environments. Their rheology, elastohydrodynamic, traction, and wear behavior were evaluated under non-electrified and electrified conditions using an adapted Anton Paar rheometer and a PCS mini traction machine (MTM). The changes in shear viscosity, traction coefficient, and wear of the nanolubricants under various electrical conditions are presented.

5A 101 B

Materials Tribology III

Session Chair: Tomas Grejtak, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: Nicolas Molina Vergara, The University of Texas at Austin, Austin, TX

8:00 am - 8:40 am
3998720: Crystal Rotation Kinematics and the Activation of Different Twinning Systems Due to Tribological Loading
Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Baden-Württemberg, Germany

In 1950, Bowden and Tabor pointed out that in metallic tribological contacts the majority of the dissipated energy is spent to change the contacting materials' microstructures. This, in part, explains why most metals show a highly dynamic subsurface microstructure under the shear load imposed by a sliding contact. One key process involved therein is the reorientation of the crystal lattice. Model experiments performed with high-purity copper bicrystals shed light on the early stage, fundamental mechanisms of tribologically induced lattice rotation kinematics. Electron backscatter diffraction (EBSD) performed directly on the wear track reveals a crystal rotation process around the transverse direction, irrespective of sliding direction, grain orientation and normal load. By making use of CoCrFeMnNi single crystals, we could identify that depending on the friction coefficient, different deformation mechanisms like dislocated mediated plasticity and twinning are being activated.

8:40 am - 9:00 am
3981220: Synchrotron In-Situ Study of Scuffing Evolution
Cinta Lorenzo Martin, Dawid Bachnacki, Athena Butler-Christodoulou, Harvey Campos-Chavez, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL; Jun-Sang Park, Peter Kenesei, APS, Lemont, IL; Farida Koly, David Burris, University of Delaware, Newark, DE; Nikhil Murthy, Scott Walck, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Scuffing, a type of surface damage in highly stressed and poorly lubricated sliding contacts, is characterized by a rapid increase in friction and severe plastic deformation of the near surface material. Scuffing is difficult to study directly due to a lack of access to the contact interface and the speed of failure. This talk presents real-time characterization of scuffing failure of lubricated steel in a reciprocating contact using high-energy, high-speed synchrotron X-ray diffractometry. In-situ XRD of the contact interface during scuffing showed a sharp increase in the peak FWHM, which is attributed to grain refinement and increase in dislocation density. Additionally, ex-situ experiments consisting of 1-micron step XRD depth profile before and after scuffing showed a reversal and enhancement of a sinusoidal strain pattern of the near-surface region with localized tension in the loading and compression in the sliding directions after scuffing.

9:00 am - 9:20 am
3998829: Microstructure of Self-Mated Steels Before and After Severe Wear Due to Scuffing
Stephen Berkebile, Nikhil Murthy, Scott Walck, Dawid Bachnacki, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Cinta Lorenzo Martin, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL; Jun-Sang Park, Peter Kenesei, APS, Argonne National Laboratory, Lemont, IL;

Farida Koly, David Burris, University of Delaware, Newark, DE

A type of severe wear called “scuffing” occurs when materials in sliding mechanical contacts undergo significant adhesive and plastic deformation that propagates quickly through the contact area. Scuffing is proceeded by microstructural changes in the material during sliding. Further, plastic deformation during scuffing alters the material structure significantly. Using Scanning Electron, Focused Ion Beam, and Transition Electron Microscopies, we have studied the microstructure of steel at different stages of sliding and scuffing in reciprocating contacts. During sliding, a small layer of grain refinement occurs at the surface and small areas of oxide are formed. The layer of grain refinement deepens significantly during scuffing to several micrometers. We also observed elongation of the grains in the direction of sliding but not in the transverse direction. We will discuss the relationship between areas of plastic deformation and grain refinement.

9:20 am - 9:40 am
4002756: Experimental Investigations of Scuffing Initiation and Coatings for Scuffing Prevention
Kelly Jacques, Andrey Voevodin, Samir Aouadi, University of North Texas, Denton, TX; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Diana Berman, University of North Texas, Denton, TX

To improve high-pressure fuel injection system operation in low-viscosity fuel environments and expand compatibility to different fuel chemistries, further examination of state-of-the art materials and their resistance to scuffing is needed. In this work, a high-frequency reciprocating tribometer was used to perform pin-on-flat load-progression experiments on hardened 52100 steel, additively manufactured steels, and several coating candidates in multiple fuel environments. These experiments were followed by microscopy/spectroscopy to characterize the friction coefficients, wear, and chemical alterations of the material surfaces. It was found that the ability of the surfaces to prevent scuffing largely depends on the characteristics of the materials, such as hardness, surface energy, and corrosion resistance. The use of multi-layer coatings with each layer optimized for different fuel chemistries inhibits the onset of scuffing when applied to steel surfaces otherwise prone to wear.

9:40 am - 10:00 am
4011602: High Temperature Tribology of Inconel Alloy B4C Reinforcement
Ana Maria Fuentes Caparros, Anton Paar TriTec, Corcelles-Cormondreche, Switzerland

Inconel 625 and similar alloys have excellent thermal stability and are therefore often used in high temperature applications. These alloys are also used for surface protection of less wear resistant load-bearing structures. However, protective layers from pure HT alloys usually suffer from low wear resistance; this is why they are generally reinforced with ceramic particles. The goal of our work was to investigate the wear and mechanical properties of Nibasit 625 (similar to Inconel 625) layer with B4C particles as well as the effects of the B4C particle size and heat treatment. The CoF of all samples were studied at different temperatures, between 25°C and 750 °C. The smaller B4C grain size resulted in much lower (~3x) wear rate at 750°C compared to pure Nibasit and the large grain size samples. SEM observations of the wear tracks on all samples revealed that the improved wear resistance was due to re-deposition of the Nibasit matrix on the B4C particles

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

10:40 am - 11:00 am
3985728: Deformation Mechanisms of Refractory Multi-Principal Element Alloys at Extreme Temperature
Morgan Jones, Irene Beyerlein, University of California, Santa Barbara, Santa Barbara, CA

Numerous body-centered cubic (bcc) refractory multi-principal element alloys (RMPEAs) exhibit high-temperature strength that surpass the performance of Ni-based superalloys. The superior properties of RMPEAs have been shown to stem in part from the unique dislocation glide mechanisms in a compositionally disordered system. Here, we use a phase-field-based mesoscale model incorporating ab initio energies and atomic-scale thermal fluctuations to predict the favorable glide mechanisms of edge and screw dislocations at elevated temperature in quinary RMPEAs. Specifically, the model is used to uncover the mechanistic origins of the strength plateau that occurs from ~900K- 1200K in some quandaries. Ultimately, these findings help to inform the design and development of next-generation superalloys.

11:00 am - 11:20 am
4004898: Thermal Modeling of Shear Localization and Stick-Slip in High-Speed Machining of Metals
Ravi Srivatsa Bindiganavile Narasimhan, Dinakar Sagapuram, Texas A&M University, College Station, TX

We present an analytical framework for modeling heat generation and non-steady temperature fields underlying shear-localized chip formation in high-speed machining of metals. This chip formation mode is characterized by periodic localization of flow (shear bands) in the plastic deformation zone, and concurrent stick-slip motion at the tool-chip contact. In this study, analytical methods based on planar heat sources (stationary and moving type) and the heat partitioning principle are developed to model both the transient and long-time (quasi-steady-state) characteristics of the shear-localized zone and tool-chip contact temperatures. Quantitative temperature predictions are made for the case of orthogonal machining of Ti-6Al-4V alloy and good agreement with the experimental data from the literature is found. The description of stick-slip, time-dependent heat sources, and related temperature effects should be of more general interest than their particular application to machining.

11:20 am - 11:40 am
3983882: Tribological Performance of MoS_2 Coating Enhanced by Ti_3AlC_2 MAX Phases
Sujan Ghosh, Nihal Ahmed, Joshua Manley, University of Arkansas at Little Rock, Little Rock, AR; Bo Shen, Wan Shou, University of Arkansas at Fayetteville, Fayetteville, AR

This study aimed to develop a novel, multi-functional coating with enhanced oxidation resistance and durability. The coating consists of MoS_2 with a composition of 10% Ti_3AlC_2 nanoparticles on a 6061-T6 aluminum substrate. The results demonstrated a significant improvement in the coefficient of friction (COF) and durability of the MoS_2 + MAX phase coatings compared to the bare Al and MoS_2 coatings. The optimized coating with two sintering cycles exhibited a 72% increase in durability from 1,173 cycles (for pure MoS_2) to 3,193 cycles and maintained a COF of 0.32. The better oxidation resistance and higher mechanical strength of the MoS2+MAX phases coating were responsible for the superior tribological behavior of these coatings. This novel MoS_2 + MAX phase coating has potential applications in various industries requiring stable, low-friction, and durable lubrication solutions.

11:40 am - 12:00 pm
4003493: Achieving Superlubricity and High Adhesion Strength of Hydrogenated Amorphous Carbon Film with Al/Cr/Si-Doping
Quansheng Ma, Tsinghua University, Beijing, China

Excellent tribological properties of hydrogenated amorphous carbon films make it an important candidate for friction reduction in industry. In this work, a novel Al, Cr and Si co-doped hydrogenated amorphous carbon film was prepared by high-power impulse magnetron sputtering method. The AlCrSi/a-C:H film showed favorable mechanical performance and high adhesion (~80 N), which was attributed to the controlled elements doping and special transition layers produced by HiPIMS method. Meanwhile, superlubricity was obtained with coefficient of friction 0.0014. Detailed characterizations suggested that doping elements played significant roles in tribo-chemical reactions during friction. On one hand, doping elements can promote shear-induced graphitization and formation of graphite-like

layers at the friction interface. On the other hand, the preferential oxidation of doping elements can protect the formed graphite-like layers from oxidation.

Session 5B — 101 C

Condition Monitoring I

Session Chair: Alfredo Garcia, Luval SA, Santiago, Region Metropolitana, Chile
Session Vice Chair: Marc Yarlott, Veolia North America, Vancouver, WA

8:00 am - 8:40 am
4000850: Taking a Holistic Approach to Fluid Analysis
Randy Clark, POLARIS Laboratories®, Indianapolis, IN

Fluid analysis plays a significant role in condition monitoring and is crucial for achieving our reliability objectives. However, we often tend to be reactive and only act when we receive a high-severity report. While this approach may help prevent catastrophic failures, it also results in reactive maintenance. This course will adopt a more comprehensive approach to fluid analysis, use historical trends to identify the causes of high-severity fluid analysis reports and learn ways to prevent these high-severity reports from reoccurring.

8:40 am - 9:00 am
4000240: Oil Condition Monitoring Based on Diagnostic Evaluation Using an RGB Sensor
Takeshi Hiraoka, Takashi Honda, Makoto Miyajima, Noriko Ayame, Tadashi Oshio, ENEOS Corporation, Yokohama, Japan

Proper management of lubricants is important for extending the lifetime of machinery. Conventional diagnosis methods often require periodic analysis to evaluate the degree of lubricant deterioration, leading to time-consuming operations which need much manpower. Under the circumstances, our group has developed a method to monitor the condition of industrial lubricating oils easily and quickly by tracking their color changes resulting from deterioration or abnormality of them. In this report, we introduce a method for detecting water contamination and estimating the residual rates of various antioxidants by quantifying the oil color using an RGB sensor. This makes it possible to properly determine the timing to replace the oil, and greatly reduces the effort to maintain the lubricating oils.

9:00 am - 9:20 am
3999491: Chemical Cleaners for Varnish Removal from Component Surfaces
Jose Morales, Ashlie Martini, University of California, Merced, Merced, CA; Zhen Zhou, Jason Bahora, Zefu Zhang, Nathan Knotts, Chevron Lubricants, Richmond, CA

Varnish that forms on metal surface due to oil degradation is detrimental to the function and operational life of mechanical components. Here, we used a custom test rig to evaluate the varnish removal characteristics of chemical cleaners under different conditions. The method enables varnish removal from real mechanical components to be directly observed and quantified. Particularly, a series of tests was performed to quantify varnish removal from heat exchanger surfaces, demonstrating the utility of the test method for comparing chemical cleaner performance under application-relevant conditions. The results of this testing contribute to enabling heat exchangers to have a longer lifespan, proper functionality, and better performance.

9:20 am - 9:40 am
4005086: The Critical Role of Hydraulic Oil in Keeping System Clean
Lin Wang, James Hannon, ExxonMobil, Annandale, NJ

The most common failure mechanism of a hydraulic oil in service is contamination which can be generated through oil aging, leakage, wearing or condensations. Contamination control is typically considered mainly a maintenance issue. Few have recognized that hydraulic oil formulation can play a critical role in resisting contamination. Given the same equipment conditions, a hydraulic oil formulated specifically to control contamination can last three times longer than a basic hydraulic oil. The mechanism and benefits of keep-clean hydraulic oil to reliably extend oil and equipment lives, will be discussed in detail in this presentation.

9:40 am - 10:00 am
4001416: Lubrication Condition Monitoring via Ultrasonic Reflection Technique
Pan Dou, Min Yu, Tom Reddyhoff, Imperial College London, London, United Kingdom

Lubrication-related parameters, such as film thickness, viscosity, and temperature, are important indicators that reflect lubrication conditions and transmission efficiency in mechanical equipment, therefore their monitoring is highly important. Recently, ultrasonic-based measurement has been widely studied, showing promising potential in the practical industry owing to its non-destructive characteristics. This paper develops an ultrasonic reflection technique to monitor these lubrication-related parameters simultaneously. The echo amplitude information is used to obtain the film thickness and viscosity by combining EHL theory and acoustic simulation. The time difference of adjacent echoes is used to reverse the oil film temperature based on the acoustic speed-temperature relationship. To assess the efficacy and reliability of the proposed method, a reciprocating rig, specifically designed to emulate line-contact tribopair scenarios, is employed for the experimental verification.

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

10:40 am - 11:00 am
3998352: Experimental Investigation of an In-Situ, Temperature-Based Lubrication Gap Height Determination for Plain Bearings
Thao Baszenski, Georg Jacobs, Tobias Gemmeke, Kevin Kauth, Karl-Heinz Kratz, Benjamin Lehmann, RWTH Aachen University, Aachen, Germany

Plain bearings are increasingly being used in areas of mixed friction, which causes an increased damage risk. A relevant criterion for the detection of mixed friction in plain bearings is the lubrication gap height. The concept of the DIN-standardized Gümbel curve provides a relationship between the lubrication gap height and the shaft displacement angle for hydrodynamic radial plain bearings solving the Reynolds' differential equation. The shaft displacement angle, in turn, can be determined from the temperature field on the bearings running surface. In this work, the development and experimental testing of a temperature-based condition monitoring system (CMS), which is based on the Gümbel curve relationship is developed. The CMS is fully integrated into the bearing. Experimental investigations of the CMS for the calculation of gap height determination, which are derived from the temperature map using the Gümbel curve relationship, are presented and are validated by simulative results.

11:00 am - 11:20 am
3988395: Sensors for Wind Turbine Main Sliding Bearings
Gary Nicholas, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Sliding bearings, typical in hydroelectric plants and marine propellers, are becoming increasingly prevalent in wind turbine (WT) drivetrain applications. They are replacing conventional roller bearings due to their reduced maintenance and failure rate potential. This reduces operational costs and the

initial investment capital for large WTs (10MW+). However, little is known of their field operational performance (failure mechanisms, service life) under the slow and transient loading conditions of WT drivetrains. There is also no field experience for their operation in the wind sector. This project intends to address the knowledge gap by providing the underpinning data through development of a multi-sensor measurement suite for WT sliding bearings. The sensing system will comprise of thermocouples, capacitance, strain, ultrasonic and acoustic emission sensors intended for measuring bearing temperature, oil film thickness, pad loading, touchdown and wear.

11:20 am - 11:40 am
4006600: Predicting Friction and Analyzing Surface Wear Mechanisms in Sliding Contacts Using Acoustic Emission
Robert Gutierrez, Imperial College London, London, United Kingdom

There is a keen interest in developing acoustic emission (AE) methods in the machine condition monitoring market, as it is proving to be an effective method of monitoring contact properties such as friction and wear. Herein, AE and coefficient of friction (CoF) have been recorded from HFRR sliding tests. AE data is used to train machine learning (ML) models to predict CoF from new tests. Strong predictions are given for tests done at different conditions. However, the mechanisms relating asperity interactions to AE are still not fully understood. To address this, scratch tests were done using aluminum specimens with different oxide coating thicknesses while recording AE. The scratch images show wear mechanisms involving surface crack initiation and propagation. Correlations of AE with scratch image features can then be investigated. Overall, the sliding test ML models allow for AE measurements of friction, while the scratch tests provide an insight into how wear mechanisms produce AE.

11:40 am - 12:00 pm
4002576: Reactive, Preventive, Predictive, Corrective Maintenance, and a Proactive Plan — Where Does It All Fit?
Michael Holloway, SGS, Highland Village, TX

Work performed that is planned versus work done due to failure requires different procedures and protocols. The delineation of duties and tasks are outlined for predictive maintenance vs corrective maintenance. By implementing the appropriate strategy can increase equipment availability and increase staff utilization. In this session, attendees will learn how to establish safe work practices, preserve, and optimize the reliability and safety requirements while satisfying the operational requirements. Attendees will be able to establish lubrication tasks, set task intervals, and develop clearly worded procedures. This session will also cover how to execute periodic, nonrecurring lubrication tasks and how to convey the difference to staff.

Session 5C — 101 D

Lubrication Fundamentals III: Sustainable Lubrication

Session Chair: Ashish Jha, Chevron, Richmond, CA
Session Vice Chair: Chanaka Kumara, Oak Ridge National Laboratory, Oak Ridge, TN

8:00 am - 8:40 am
4000339: Lubricant Inerting – A New Route to Sustainability
Hugh Spikes, Jie Zhang, Janet Wong, Imperial College, London, United Kingdom

The recent availability of portable nitrogen concentrators that filter O_2 from an air flow to provide an almost pure N_2 stream now makes it feasible to blanket closed lubrication systems in inert gas. This

offers enormous potential benefits in terms of preventing lubricant oxidative degradation in operating components; promising increased lubricant life, higher lubricant operating temperatures and a much wider range of applications of bio-based lubricants that are especially susceptible to oxidation. This presentation describes research both to identify lubricant formulations that can provide low friction and protection against wear, scuffing and rolling contact fatigue in zero or very low oxygen atmospheres and to quantify the potential benefits in terms of lubricant life and operating window provided by a very low oxygen-containing environment

8:40 am - 9:00 am
3981034: Flows Around a Contacting Asperity Modeled in the Micro and Nanometer Scales
Nicole Dorcy, Henry Soewardiman, Shuangbiao Liu, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Mixed lubrication conditions can often arise around asperity contacts. Understanding how the flow is interrupted at such points is crucial at the molecular scale where the flow is dominated by intermolecular forces. Using molecular dynamics simulations, this work studies a shear-driven wedge flow approaching a fixed incline narrowing and ultimately blocking the exit gap. Attention is paid particularly to the narrowest point of the wedge and boundary layer of the flow. Approaching a blockage, the flow is interrupted and deviates from the otherwise no-slip boundary condition. This deviation is quantified by calculating the boundary-layer velocity along the channel length. Simulations were run to explore the impact of key factors such as incline steepness, wall speed, and intermolecular properties with the goal of producing an equation to describe wall slip and the flow around a fully blocked asperity contact.

9:00 am - 9:20 am
3987063: Lubrication Using Hydrogen
Jie Zhang, Janet Wong, Hugh Spikes, Imperial College London, London, United Kingdom; Tushar Bera, Shell Global Solutions (US) Inc., Houston, TX

There is growing interest in using hydrogen as a carbon-free gaseous fuel to replace liquid hydrocarbons in crankcase and turbine engines. This gas must be pumped and injected into a combustion chamber, and both pump and injector require effective lubrication to limit friction, wear and seizure of rubbing surfaces. Unfortunately, hydrogen gas is a poor lubricant for most engineering metals, so additional lubrication must be provided, for example as an oil or grease or employing coatings on rubbing parts. This presentation describes the use of a sealed tribometer to study the friction and wear properties of hydrogen and how these may be improved via lubrication.

9:20 am - 9:40 am
3985385: The Fast Response Regulation Mechanism of Friction Coefficient Induced by Microviscosity in the Contact Region
Caixia Zhang, Lihui Wang, Beijing University of Technology, Beijing, China; Zhifeng Liu, Jilin University, Changchun, China

The friction coefficient control is important in intelligent manufacturing. This study found that the microviscosity is a key factor influencing the fast response of the friction coefficient variation. The friction contact region of polymer coatings is creatively subdivided into core, corona, and blank regions according to functional specificity to investigate microviscosity. The synergism of the three areas were explored. The high microviscosity core region of the polymer coating is the basis for keeping the friction coefficient at a low level. The microviscosity exhibited by ions that are more readily adsorbed in the corona region is the key to determining changes in the friction coefficient. The blank region ensures low shear viscosity during friction. Regulation of the friction coefficient can be achieved by controlling the microviscosity in each region. This study provides a theoretical basis for the intelligent regulation of

friction.

9:40 am - 10:00 am
3998464: Understanding the Growth Dynamics of Capillary Bridges for Enhanced Grease Lubrication
Vincent Siekman, Dirk Van Den Ende, Frieder Mugele, University of Twente, Enschede, Overrijsel, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

In this study we (experimentally and numerically) explore the dynamic growth of a capillary bridge formed when a bearing ball gently touches an approximately 100-micron thin film of silicon oil on a glass substrate. Fluorescence microscopy measurements reveal the formation of a dimple, i.e. a local minimum in the height profile, near the oil-ball contact, resulting in a large resistance to oil flow towards the oil bridge. Describing the flow in the thin film with lubrication theory, while the driving pressure is predicted by the momentary curvature of the liquid bridge, we calculate the height profile as a function of time. These profiles match, for a wide variety of initial film thicknesses, very well with the experimentally observed evolution of the capillary bridge and with the dimple profiles obtained from the fluorescence measurements. To reduce the large flow resistance, further research will focus on the effects of coating the substrate with a polymer brush or grease thickener.

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

10:40 am - 11:00 am
4001256: Controlling Friction with an Electric Field
Janet Wong, Yun Zhao, Hugh Spikes, Imperial College London, London, United Kingdom

Lubrication by demand can be achieved if the properties of our lubricants can respond to changes in operating conditions. Active control is achieved if we can regular these conditions at our will. Many potential regulators exist, one of which is via applied electric field. Using surfactant aqueous solutions as our model lubricants, we examine how an applied electric field can regulate the friction of a steel-steel conduct in a range of lubricating conditions. The effects of concentrations, molecular structures and addition of salt on the response of the lubricants will be explored.

11:00 am - 11:20 am
4004481: Ion-Specific Ice Provides a Facile Approach for Reducing Ice Friction
Chang Dong, Liran Ma, Tsinghua University, Beijing, China

Ice friction plays a vital role in both fundamental research and practical applications. Here, we report the discovery of an ion-specific effect of hydrated ions on ice friction. By simply changing the initial type and concentration of ions in ice-making solution, the ice friction coefficient can be reduced by 75 percent. The direct link was revealed between ion charge density and the ice friction coefficients by analyzing experimental spectra and molecular simulation results. Part structure of ice was destroyed and turned from ice-like water structure to liquid-like water structure by adding ion. Moreover, lower charge density ions lead to weaker ionic force with water molecules in bound layer and perform greater ability of turning ice-like water structure to liquid-like water structure. This work serves to provide guidance for the design of low friction coefficient ice-making solution and deeper understanding of the molecular structure of ion-containing water at low temperature.

Gears I

Session Chair: Nikhil Murthy, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD
Session Vice Chair: Chengjiao Yu, Hebei University of Technology, Tianjin, China

8:00 am - 8:40 am
4000448: Oxide Formation During Loss of Lubrication and the Effect on Friction
Aaron Isaacson, Todd Palmer, Penn State University, University Park, PA

The mechanisms governing loss of lubrication gear failure in rotorcraft gearboxes are not well understood. Industry convention suggests that better material hot hardness leads to longer gear life without lubrication. It is well documented that mesh friction increases as scuffing occurs during loss of lubrication induced gear failure. Changes in the coefficient of friction due to oxide film formation at high temperatures are studied using the ball on disk test for four carburized aerospace gear steels (SAE/AISI 9310, Pyrowear 53, Ferrium C-64, and Pyrowear 675). Results show that formation and destruction of the surface oxide layer affects the friction behavior of these alloys. Finally, gear tests performed in an inert atmosphere provide validation that the presence of surface oxides can improve gear performance during significantly reduced lubrication.

8:40 am - 9:00 am
3985183: Investigations on the Influence of Synthetic Lubricants on the Pitting Load Carrying Capacity of Cylindrical Gears
Markus Brummer, Thomas Tobie, Karsten Stahl, Gear Research Center (FZG), Technical University of Munich (TUM), Garching near Munich, Germany; Johannes König, ZF Group, Friedrichshafen, Germany

Synthetic lubricants show advantageous properties compared to mineral oils. In gearboxes, a higher pitting load carrying capacity can be achieved, enhancing the power density. ISO 6336-2 is a well-known standard for calculating the safety factor against pitting for gears. The standard was mainly developed based on test results with mineral oils, giving limited assessment on the pitting load carrying capacity for synthetic lubricants. In this research, pitting load carrying capacity tests were conducted on an FZG back-to-back gear test rig with different lubricants based on mineral oil, polyalphaolefine and polyglycole, each of ISO VG 100. The results are analyzed with the standard ISO 6336-2 and an alternative approach according to Knauer (1988), which addresses lubricating properties more in-depth. The analysis of the test results shows the limitations of the standard and further need for research to adequately quantify the pitting load carrying capacity of synthetic lubricants.

9:00 am - 9:20 am
3998690: Optimization of Gear Oil Formulation for Achieving Energy Efficiency & Long Life
Kavita Rai, Chanakya Tripathi, Sumit Bhaskaran, Rahul Meshram, Ajay Harinarain, Mukul Maheshwari, Indian Oil Corporation Ltd., Faridabad, India

The power losses in gear systems are mainly caused by friction. The gear box efficiency can be improved by reducing the friction. The carefully designed lubricants not only improve gear transmission performance but also helps to reduce the friction coefficient between the mating surfaces through the use of special additive chemistry & base oils. The present paper highlights the importance of gear oil chemistries to achieve higher oxidation stability, better EP properties and energy efficiency. A systematic study for developing a novel formulation of an energy efficient gear oil meeting all the

national and international specifications with energy saving characteristics has been taken. The present paper discusses the methodologies used for development of high-performance gear oils and its comparison with conventional gear oil chemistry w.r.t physico-chemical properties, viscosity temperature behavior and tribological test properties viz. frictional and load bearing properties.

9:20 am - 9:40 am
4000249: Improving the Tribological and NVH Properties of Sintered Gears by Mechanochemical Surface Finishing
David Chobany, Boris Zhmud, Linus Everlid, Tribonex AB, Uppsala, Sweden

In recent years, there has been a growing interest to manufacture gears using the powder metallurgy (PM) process that provides a cost-effective alternative to conventional gear cutting. Surface specifications and tooth microgeometry of PM gears have a big impact on their efficiency and noise characteristics. In the present communication, the application of a novel mechanochemical surface finishing method—Triboconditioning CG—for improving the tribological and NVH characteristics of PM gears is described. Mechanochemical surface finishing combines elements of mechanical burnishing with a tribochemical deposition of a solid lubricant tribofim. This allows one to obtain, via a single finishing operation, a smoother surface with a significantly reduced coefficient of boundary friction and improved wear-resistance and load-carrying capacity. Triboconditioned gears reveal better efficiency, higher resistance to micropitting and scuffing, and lower noise.

9:40 am - 10:00 am
4000269: The Behavior of Tribofilms Under Realistic Gearbox Conditions
Marc Ingram, Thomas Baldwin, Ingram Tribology Ltd., Carmarthen, United Kingdom

Tribofilms are formed on steel surfaces under mixed, boundary or high shear EHD conditions. It is common to study the formation of the tribofilm under short (sub 3-hour) tests equating to a few thousand contact cycles. It is less common to study the effect of these tribofilms under realist conditions of lambda ratio, contact pressure and contact cycles, effectively stimulating the contact conditions of a gearbox. This is important to observe the tribofilm formation of oils under realistic conditions and the longevity of the film over an extended period of operation. Here we study the effect of different lubricants and different steels used in gear manufacture. We use a sliding/rolling contact of 2 GPa, and custom finished surfaces to achieve the require lambda ratios. We find the growth of the tribofilm to be rapid at lambda ratios of 0.4 and 0.05. Then the thickness of the tribofilm decreases slowly between 5 M and 30 M contact cycles.

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

10:40 am - 11:00 am
4002020: The Importance of Multi-Metal Compatibility in Modern Industrial Gearboxes
Paul Norris, Helen Dyer, Afton Chemical Ltd., UK, Bracknell, United Kingdom; Andrew Gant, Afton Chemical Ltd., Bracknell, Berkshire, United Kingdom

Multi-metal compatibility has been a discussion topic in Industrial Gear and Wind turbine applications for several years now, mainly due to the increasing use of journal bearings in some applications. Deployment of bearings containing bronze alloys raises a number of concerns over the compatibility of the lubricant with copper and the impact this may have in terms of both corrosion concerns and on system cleanliness through the lifetime of the oil. Compatibility of typical gear chemistry with other metal options such as aluminum and tin has also been considered. Interactions of the lubricant with potential bearing metallurgies has been at the forefront of recent development efforts in both synthetic Industrial Gear and Wind Turbine lubricants. Strategies to limit interactions have been deployed and this in turn has provided additional cleanliness benefits. Data will be shared comparing recent developments to existing commercial technologies and the potential benefits will be explored.

11:00 am - 11:20 am
4002476: Experimental Investigations on Spin Power Losses Generated in a Planetary Gear Set
Marie Winger, Fabrice Ville, INSA Lyon, Villeurbanne, France; Yann Marchesse, Christophe Changenet, ECAM LaSalle, Lyon, France; Patrice Gédin, Safran Transmission Systems, Colombes, France

Planetary gear sets are widely used for to their compact size and high gear ratio. It is of the utmost importance that their efficiency is as high as possible. To achieve this, it is necessary to understand and analyze the sources of energy dissipation. The aim of this study is to determine and investigate the spin losses generated in a planetary gear set, namely the drag and the pocketing losses. The gearbox configuration studied features a rotating ring gear and is oil-jet lubricated. The analysis is based on experiments carried out on a specific test rig composed of a reduced-scale planetary gear set. On this test rig, gearbox losses are measured under different operating conditions (mainly oil flow rate, oil temperature, rotational speed). A thermal network is used to determine the losses distribution. In this way, each individual energy dissipation is studied, and the impact of different operating conditions is highlighted.

11:20 am - 11:40 am
4002907: Varnish Detection in Gear Systems by Microscopy
Brandon Van Horn, POLARIS Laboratories®, Indianapolis, IN

Analyzing wear and contaminant particles in in-service lubricants is essential for identifying the root cause and severity of potential damage in various mechanical systems. However, conventional lubricant analysis methods may fail to detect the presence and extent of harmful varnish deposits, especially in gear systems where they can cause serious problems. Join us in this session, where we will demonstrate how applying ASTM D7684 and qualitative microscopic techniques helps to identify damaging varnish particles (and the resulting wear) in a variety of affected gear systems. Don’t miss this opportunity to learn how to protect gear systems using this approach to investigate and eliminate the source of the problem before a major failure occurs.

11:40 am - 12:00 pm - **Gears Business Meeting**

Session 5E — 101 F

Tribology of Biomaterials I

Session Chair: Tomas Babuska, Sandia National Laboratories, Albuquerque, NM
Session Vice Chair: Quentin Allen, Brigham Young University, Provo, UT

Session Starts at 9:00 am

9:00 am - 9:20 am
4004743: Polyamide with Nanocellulose and Carbonaceous Reinforcements: Sustainable and Functional Tribomaterials
Lucas Kneissl, Roberts Joffe, Nazanin Emami, Luleå University of Technology, Luleå, Norrbotten, Sweden; Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Polyamides (PAs) are widely used in various applications, including tribological, due to their good friction and wear properties, favorable strength-to-weight ratio and chemical resistance. Moreover, their hydrophilicity benefits compatibility with cellulosic reinforcements to create sustainable composites

without fossil-based reinforcement. In this work, bio-based PAs were reinforced with nanocellulose to produce functional tribomaterials. To add further functionality, carbonaceous materials were employed. A higher wear resistance was obtained in dry conditions, while the frictional performance was mainly influenced by the secondary filler. The testing conditions clearly influenced the friction and wear mechanisms. Morphological and microstructural features further showed a notable dependence. Therefore, novel, sustainable tribomaterials with additional functionality can be produced for e.g. the automotive industry to be used in gears, steering systems or bearing cages.

9:20 am - 9:40 am
4017800: Morphological Characteristics of Biomass Materials as Supercapacitors
Mrudul Velhal, Kailash Arole, Hong Liang, Siddhi Mehta, Texas A&M University, College Station, TX

Morphology of materials in supercapacitors is one of the important parameters for their performance. In this work, we studied the morphology and density of biomass material lignin on the electrochemical performance as a supercapacitor. Synthesis, material characterization, charge–discharge performance was conducted and data was analyzed. Results showed that porous material provided networks that enabled an electrolyte to penetrate resulting desirable electrochemical performance. This presentation will discuss about the development of biomass electrochemical devices and the role of their morphological performance.

9:40 am - 10:00 am
3998077: Instantaneous Frictional Behavior of Corn Stover Biomass Particles
Cinta Lorenzo Martin, Oyelayo Ajayi, George Fenske, Jacob Lasso Garifalis, Argonne National Laboratory, Lemont, IL; Jordan Klinger, Yidong Xia, INL, Idaho Falls, ID; Benjamin Davis, Ricardo Navar, Los Alamos National Lab, Los Alamos, NM

Controlled and reliable flow of solid particulate biomass materials from bins, hoppers, etc. is essential for successful operation of bio-refineries making bio derived fuel (such as SAF) and chemicals. Friction is one of the critical material properties governing the flow of biomass materials and an important input into material handling equipment design. A bench top tribometer was adapted to measure instantaneous friction of biomass materials by attaching copious amount of biomass particles unto sliding surfaces. This paper presents results of instantaneous friction measured for whole corn stover particles of 2 mm and 4 mm size at different loads (pressure) and speeds (shear rate). In general, the particle-particle friction coefficient decreases with increasing normal pressure, while the wall-particle friction is nearly independent or a very small increase with the normal pressure. There was minimal effect of sliding speed (shear rate) on average friction.

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

10:40 am - 11:00 am
4005801: Rate-Dependent Detachment Dynamics from Gradient-Stiffness Hydrogels Using AFM Nano-Indentation
Md Mahmudul Hasan, Alison Dunn, University of Illinois at Urbana-Champaign, Urbana, IL

Crosslinked hydrogels with intentional softer surface layers have vanishing stiffness. Our previous research revealed that these layers control contact mechanics and display strong relative adhesion when fewer polymer chains come in contact. This finding provides opportunity to study the detachment dynamics of hydrogel chains from glass probe over varying depths(range:0.3-1.2 μm) and retraction rates(range:0.1-10 μm/s).Here, the force response in unloading phase of nanoindentation on polyacrylamide hydrogel was analyzed using Discrete Fourier Transform (DFT).DFT frequency spectrum showed discrete, hierarchical detachment events at various length scales only after maximum adhesion point. Furthermore, we found unloading rate-dependent adhesion behavior, even though apriori negligible viscoelastic effect was reported in literature. This in-depth dynamic analysis provides a deeper

understanding of the interactions between gradient-stiffness hydrogels and other analogous surfaces at nanoscale.

11:00 am - 11:20 am
3986778: Examining Stopper-Syringe Contact in Freeze-Thaw Cycling of Prefilled Syringes
Catherine Fidd, Kylie Van Meter, Adam DeLong, Santiago Lazarte, Grace Lin, Brandon Krick, Florida State University, Tallahassee, FL; Nestor Rodriguez, Ludovic Gil, William Leverd, Becton Dickinson, Le Pont-de-Claix, France

Deep cold storage of prefilled syringes down to a range of cold temperatures, some less than -80°C, is often required to ensure the stability of biologics and drugs like mRNA vaccines. Thermal expansion and compression combined with mismatch of material CTE, and phase changes of syringe materials, lubricants and contents during freeze/thaw cycling can impact the integrity of the stopper-syringe seal and the sterile barrier between syringe contents and outside environment. This presentation studies the stopper-syringe interface using a custom cryostat to thermally cycle prefilled syringes combined with in situ optical microscopy. Optical methods are used to visualize and measure the real contact area and the position of the stopper as a function of temperature. The optically determined contact/loss of contact is compared to an annular flow model developed to correlate differential pressure measurements of the system to measure at stopper-syringe barrel separation or leakage temperature.

11:20 am - 11:40 am
4005726: Exploring Structure-Property Relationships in 3D-Printed Polymeric Biomaterials
Santiago Lazarte, Brandon Krick, Florida State University, Tallahassee, FL; John Tolbert, Diana Hammerstone, Juan Mendoza, Lesley Chow, Lehigh University, Bethlehem, PA; Tomas Babuska, Sandia National Laboratories, Albuquerque, NM

Interactions between cells and biomaterials are essential to regenerate functional tissue. Cells are affected by chemical and physical cues in their microenvironment. These cues can be functionally embedded in 3D-printed scaffolds to direct human mesenchymal stromal cell (hMSC). By controlling the cues embedded in the 3D-printed scaffolds, hMSCs differentiation can be spatially directed. In many load-bearing tissue regeneration applications, including osteochondral tissues, the mechanical properties of the scaffold must be locally tuned to perform a physiological function while new tissue is forming. This work investigates how changing the scaffold architecture correlates with the mechanical properties. Scaffolds with matching compressive moduli but different material properties and programmed filament spacing were printed and characterized. This approach enables us to design scaffolds with properties that match and support the native tissue and its function.

11:40 am - 12:00 pm
4004331: A Nature-Inspired Lubricant-Infused Surface for Drag Reduction Prepared Using Porous Polydimethylsiloxane
Xiao Sang, Liran Ma, Tsinghua University, Beijing, China

Lubricant-infused surfaces (LIS) inspired by Nepenthes pitcher have been found to have excellent application prospects in reducing frictional drag in recent years. However, the complicated preparation process and easy depletion of lubricant have limited their practical applications. In this paper, inspired by the mucus secreted from the fish, we propose a simple method to prepare a LIS that can be replenished with lubricant in real-time. Porous Polydimethylsiloxane (PDMS) was prepared by foaming method. Lubricant was injected and stored in the PDMS cavities, which could be released when the lubricant on the surface was depleted. The material has excellent slipping properties and high durability and achieves excellent drag reduction when water is used as the ambient liquid. This study can provide ideas for the design of new intelligent drag-reduction materials.

Session 5F 101 G

Sustainable Power Generation I

Session Chair: Ramesh Navaratnam, Patech Fine Chemicals, Dublin, OH
Session Vice Chair: Manish Patel, ExxonMobil Chemical Company, Spring, TX

8:00 am - 8:40 am
3988918: Assessing the Potential for Improved Lubricants to Reduce Wind Operations and Maintenance Costs
Michael Blumenfeld, Kathy Cooper, ExxonMobil, Annandale, NJ; Aubryn Cooperman, Jon Keller, Matthew Prilliman, Shawn Sheng, Gabriel Zuckerman, National Renewable Energy Laboratory, Golden, CO

Currently, the US wind turbine fleet satisfies approximately 10% of the overall US electricity demand. As with any mechanical system, lubrication plays an important role in ensuring that turbines are operated in a reliable and cost-effective manner. However, there are few sources of publicly available information on the financial impact of improved lubrication on the wind turbine fleet at a national scale. In this study, open-source simulation and modeling tools developed by the National Renewable Energy Lab were used to quantify the potential for improved gearbox lubrication to reduce the levelized cost of energy of the US wind turbine fleet. Specific cases were developed for baseline, realistic and stretch goals to determine the magnitude and relative priority of key lubricant performance properties in optimizing wind turbine lubrication.

8:40 am - 9:00 am
4042610: Empowering the World's Lower Carbon Ambitions Through Metallocene Base stock Technology in Industrial Lubricant Solutions
Lindsey Bunting, ExxonMobil, Spring, TX

For over a century, lubricants have been essential for efficient operation of machines critical for modern life. As the world pursues a lower carbon future, synthetic base stocks can play a significant role in improving energy efficiency and productivity. ExxonMobil is committed to developing solutions that enable lubricant manufacturers to produce next generation lubricants which meet society's evolving needs. In the industrial segment, lubricants based on metallocene PAO (mPAO) technology can unlock not only a reduced total cost of ownership vs. mineral-based incumbents, but also increase energy efficiency, therefore reducing energy consumption. In this presentation, we will discuss oxidation and thermal performance, as well as energy efficiency benefits for mPAO, which underpins the increased adoption of synthetic-based industrial lubricants. We will also illustrate the economic and efficiency/durability benefits of designing synthetic lubricants leveraging mPAO technology.

9:00 am - 9:20 am
3986294: Wind to Wheels – Efficiency of the All-Electric Powertrain
Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Geo-political forces that shape our planet push us to electrification. Wind to wheel expresses how wind kinetic energy is captured, converted to electricity, transported, stored, and converted back to electric vehicle kinetic energy. There is a 'powertrain' of mechanical and electrical components to achieve this. This talk identifies from published data the energy efficiency of each stage. As an example, a 3MW turbine in the London Array wind farm charges a Tesla Model 3 EV at home in central London. Wind

speed data is averaged to predict turbine loading. The grid is assumed to be functioning at a base load of half peak. The data is assembled into a Sankey diagram to identify the power flows. Whilst there are many simplifications and assumptions in the analysis it is interesting to display the data graphically in this way. It becomes possible to compare the magnitude of mechanical (tribological) losses with electrical losses, and to see how mature technologies compare with newer ones.

9:20 am - 9:40 am
4002147: Foaming in Wind Turbine Gearboxes: Causes, Impacts and Treatment — Part III
Michael Blumenfeld, ExxonMobil Research & Engineering, Annandale, NJ; Kurtis Hartlen, Imperial Oil, Brights Grove, Ontario, Canada; Marianne Rodgers, WEICan, Tignish, Prince Edward Island, Canada

Wind turbines are a demanding and cost-sensitive application where high availability and low maintenance costs are critical. One of the most frustrating issues a wind turbine operator can experience is a foaming gearbox lubricant, which can trip oil-level sensors and cause unexpected downtimes. These foaming events may result in lost revenue, messy clean-ups and difficult troubleshooting. In this presentation, we will provide an update to the case study shared at previous STLE Meetings documenting the impact of problematic gearbox foaming on the operation of a fleet of five 2MW turbines at the Wind Energy Institute of Canada. Results will be shared on identification of the proper flushing/conversion protocol for foaming gearboxes as well as converting lubricants on other oil and grease systems. Data showing the lubricant performance over time after different conversion strategies will also be presented as well as troubleshooting unusual challenges that occur post lubricant conversion.

9:40 am - 10:00 am
4001960: Screener Test Development for Wind Turbine Gearbox Journal Bearings
Andrew Gant, Afton Chemical Ltd., Bracknell, Berkshire, United Kingdom; Paul Norris, Helen Dyer, Afton Chemical Ltd., UK, Bracknell, United Kingdom

A new laboratory-based screener test to assess the compatibility of bronze journal bearing materials with lubricants specifically aimed at the wind turbine gearbox market has been developed, proven and key aspects of lubricant behavior correlated with medium term field trial performance. The work involves a rotary tribometer specifically adapted for the study of friction behaviors; both transient (full Stribeck curves) and medium duration steady state friction. Oil ageing is correlated in terms of chemical changes with tribofilm formation and compatibility between active sulfur chemistries and the tribo-pair metallurgies.

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

Session 5G — 101 H

Fluid Film Bearings I

Session Chair: Amruthkiran Hegde, Kingsbury, Inc., Philadelphia, PA

8:00 am - 8:40 am
3975548: Elasto-Hydrodynamic Lubrication Analysis of a Porous Misaligned Crankshaft Bearing Operating with Nanolubricants
Benyebka Bou-Saïd, INSA Lyon, Villeurbanne , France; Mustapha Lahmar, Reda Hamel, Guelma University, Guelma, Algeria

The combined effects of the characteristic size and concentration of inorganic fullerene-like tungsten disulphide nanoparticles (IF-WS2 NPs) on the nonlinear dynamic behavior of a gasoline engine crankshaft bearing are theoretically and numerically investigated using the V. K. Stokes micro-continuum theory. It is assumed that the crankshaft is rigid, and the main bearing consists of a thin poroelastic liner. The Krieger-Dougherty law is included in the proposed EHD model to account for the viscosity variation with respect to the volume fraction of nanoparticles. The Reynolds equation is derived in transient conditions and modified to account for the size of nanoparticles and the bearing-liner permeability property. According to the obtained results, the combined effects of the size and concentration of fullerene-like nanoparticles on the dynamic behavior of a compliant dynamically loaded crankshaft bearing operating with dynamic misalignment are significant and cannot be overlooked.

8:40 am - 9:00 am
3984268: Performance of Orifice Compensated Hole-Entry Hybrid Spherical Thrust Bearing Operating with ER Lubricant
Satish Sharma, Nitin Agrawal, Indian Institute of Technology, Roorkee, India

This study deals with the theoretical investigation of an orifice compensated hole-entry hybrid spherical thrust bearing system operating with ER lubricant. A mathematical model based on FEM is developed to solve the modified Reynolds equation governing the flow of lubricant in the clearance space of spherical thrust bearing together with the restrictor flow equation and appropriate boundary conditions. The influence of applied voltage on the bearing performance has been analyzed. The study reveals that ER lubrication may significantly affect the bearing performance. For a hole-entry hybrid spherical thrust bearing lubricated with ER lubricant (at V =1200, and) the value of stiffness and damping coefficients may improve by an order of 124.25 % and 128.27 %, respectively, as compared to Newtonian lubricant (at V =0, and). The numerically simulated results presented in this work are expected to be useful to bearing designers and academic community.

9:00 am - 9:20 am
3985494: Exploring the Impact of Non-Newtonian Oils on Refrigerator Compressor's Journal Bearing: A Thermo-Hydrodynamic Investigation
Mateus da Silva Cardoso, Diego Berti Salvaro, Aloisio Nelmo Klein, Álvaro Toubes Prata, Cristiano Binder, Universidade Federal de Santa Catarina, Florianópolis, Brazil

Sustainability is a pressing concern, particularly in the refrigeration industry, which accounts for ~ 20% of global electricity use. Miniaturization while increasing rotation speeds lead to higher shear-rates. In these conditions, oils may exhibit non-Newtonian behaviors. Assessing these effects becomes essential for selecting and developing more efficient lubricants. This study delves into the impact of employing different non-Newtonian oils in a refrigerator compressor's bearing. A THD model is introduced, utilizing a power-law viscosity model. The cavitation boundary is determined using the conservation of mass equation. Parameters for the viscosity model are determined through fitting experimental data. Even slight deviations from Newtonian behavior significantly affected performance. Under identical operating conditions, using an alkylbenzene oil results in a 67% lower load capacity, a 64% lower friction force, and a 90% lower consistency parameter compared to a polyolester oil.

9:20 am - 9:40 am
4005390: Comparison Between Prediction and Measurement of Start-Up Torque Reduction by Hydrostatic Lift Recess in Tilting Pad Journal Bearings
Hiroki Hatori, Wei Li, Manish Thorat, Elliott Group, Jeannette, PA

Hydrostatic lift is applied in Tilting Pad Journal Bearings on Turbine driven equipment to provide rotor lift during turning gear application or on applications where the starting torque of the drive is lower than breakaway torque at the bearings. Torque reduction is estimated using well known correlations for hydrostatic lift available in literature. Measurements of start-up torque reduction with the assistance of

hydrostatic lift on API 617 compressors are presented in this study. The influence of supply oil pressure and oil flow on start-up torque reduction is measured. The results indicate a start-up torque reduction on the order of 4% to 31% of the original torque without hydrostatic lift. The start-up torque reduction estimate using the theoretical correlations is generally conservative when compared against measurements.

9:40 am - 10:00 am
3979929: Cryogenic Hydrostatic Bearing Failure from Pneumatic Hammer Instability During Liquid Nitrogen Supply
Keun Ryu, Minsoo Wee, Hyunsung Jung, Kyuman Kim, Hanyang University, Seoul, Republic of Korea

Cryogenic turbomachinery requires reliable, low-friction, and wear-resistant support systems. Operating conditions and fluid properties have a significant impact on the performance of hydrostatic bearings and rotordynamics in cryogenic turbomachinery. Therefore, testing rotordynamics in a cryogenic rotor-bearing system necessitates a dependable testing environment. Depending on the ambient temperature, the phase transition of cryogenic fluids from liquid to gas can introduce inaccuracies in measurement results. This research focuses on the failure of a rotor and a liquid nitrogen-lubricated hydrostatic journal bearing caused by pneumatic hammer instability. The current study introduces a predictive model to identify the conditions that lead to pneumatic hammer instability. This work outlines the necessary conditions to avoid pneumatic hammer instability using a combination of measurements and predictions.

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

10:40 am - 11:00 am
4000272: A Triangle Based Finite Volume Approach Applied to the Analysis of a Hydrodynamic Bearing Operating with Two-Phase Lubricant
Mihai Arghir, Anthony Voitus, Universite de Poitiers, Futuroscope Chasseneuil, France

The present work introduces a triangle based finite volume method for integrating Reynolds equation. The non-structured grid is needed for analyzing a journal bearing with inclined grooves. The paper shows how Reynolds equation can be discretized on any convex control volume, the triangles being only a particular case. The linear discretization leads to a sparse matrix that can be very efficiently solved. Two triangulation methods from open-source codes are used to generate the grids. The results show that the robustness of the finite volume algorithm is different depending on the constraints used by each open-source code. The bearing operates with a homogeneous mixture of water and air being fed by a pressure difference between its two ends. Thus, the density and the viscosity depend on the local air volume fraction. A parametric study enlighten the impact of the ingested air on the load capacity and torque of the journal bearing.

11:00 am - 11:20 am
4015302: Nonlinear Bump Foil Stiffness Model in Foil Bearings: Experimental Measurements, Analytical Models, and Stability Characteristics
Woongeon Lee, Ehiremen Ebewele, Daejong Kim, The University of Texas at Arlington, Arlington, TX

Nonlinear characteristics of the bump foil of radial foil bearings can be observed because of their inherent structural properties such as bump geometry, forming process, and complicated contact behavior with bearing housing. In this paper, the nonlinear stiffness of bump foils in flat configuration has been experimentally measured and compared with various analytical models. Also, the same bump geometry but with a curved configuration for actual radial foil bearings was used to measure the structural non-linear stiffness in the bearing level in push-pull set up and compared with analytical prediction. Finally, the non-linear bump stiffness model was adopted to the radial foil bearing to calculate overall bearing stiffness and damping coefficients, and stability characteristics through modal

analysis and transient time domain orbit simulations. Lastly, the non-linear stiffness model of the bump foils will be verified by measuring bearing coefficients using shaker systems.

11:20 am - 11:40 am
4016163: Performance Evaluation and Comparison of Hybrid Rigid and Hybrid Foil Thrust Bearings
Ehiremen Ebewele, Woongeon Lee, Daejong Kim, The University of Texas at Arlington, Arlington, TX

The critical issue facing the incorporation of foil-bearing technology into high-speed turbomachinery is the low-load carrying capacity of the foil thrust bearing. Hybridization of the foil bearing has been pursued to overcome this limitation either by load sharing with a magnetic bearing or injecting externally pressurized air to provide bearing clearance. In this work, a comparison is made between a hybrid rigid thrust bearing (HRTB) and a hybrid thrust foil bearing (HTFB) with hydrostatic injection. Both bearings have the same outer diameter of 82mm, with the same taper and orifice location and sizes. The bearing performance for both bearings was evaluated at 30krpm and at 5-bar absolute hydrostatic pressure. The mass flow rate characteristics, film thickness and zero-speed performance were assessed. Power loss and load capacity comparison between both bearings was made at zero speed and at higher speeds. Finally, the experimental results were compared with simulation.

11:40 am - 12:00 pm
4003391: Effects of Top Foil Thickness on Dynamic Characteristics of Hybrid Foil-Magnetic Bearing Systems
Yunseok Ha, Yeongdo Lee, University of Science and Technology, Seoul, Republic of Korea; Yongbok Lee, Korea Institute of Science and Technology, Seoul, Republic of Korea

Air foil bearings (AFBs) are compliant bearings comprised of a top and bottom foil. They find widespread application in oil-free turbomachinery. However, the thickness of the AFB foil significantly impacts the bearing's stiffness and damping coefficients. Additionally, from a manufacturing perspective, excessively thin foils pose challenges in maintaining forming reliability. This paper investigates the influence of foil thickness on the dynamic characteristics of AFBs supported by hybrid foil-magnetic bearing utilizing an excitation signal generated by an active magnetic bearing (AMB). The study involved estimating the dynamic coefficients of an AFB by varying the thickness of the PTFE-coated top foil while maintaining a constant thickness for the bump foil. The least squares method (LSM) was employed to analyze the measured excitation signal and displacement data, while the invariant method (IVM) was used to reduce residuals and extract accurate dynamic characteristics.

12:00 pm - 12:30 pm - **Fluid Film Bearings Business Meeting**

Session 5I — 101 J

Commercial Marketing Forum V

8:00 am – 8:20 am
4094847: Chemours: Automotive Noise, Vibration and Harshness (NVH) Lubrication and the use of Perfluoropolyether (PFPE) Oils and Greases
Rebecca Vieira, Derek Newbould, Chemours, Wilmington, DE

Management of Noise Vibration and Harshness (NVH) in vehicle interiors is a challenge for many automotive suppliers and OEMs. Lubrication is one tool available to engineers to solve these challenges. Understanding the lubricant performance requirements is important when considering it as an option alongside other solutions. Some desired attributes of a NVH lubricant are - low/no Volatile Organic Compounds (VOC), thermal stability, wide temperature range usability, non-migration, ability to

separate surfaces, and materials of construction compatibility. Certain lubricant chemistries can only obtain some of the desired attributes and therefore are not the best choice. This presentation will outline the relevant attributes of hydrocarbon, synthetic, and Perfluoropolyether's (PFPE) based lubricants. It will then highlight several applications where PFPE chemistry has been used for NVH issues.

8:20 am - 8:40 am
4098853: Simerics CFD Software
Raj Ranganathan, Simerics, Bellevue, WA

Simerics develops and sells analysis simulation software used in the automotive, aerospace, marine and hydraulic industries. The software suite includes Simerics-CFD, Simerics-FEA and Simerics-OPT, the latter for design optimization. Key attributes of the software are fast model set-up, fast and accurate multi-node, distributed memory, parallel solver (MPI). All three software are "home grown" therefore strongly coupled within the same GUI. Fast model set-up, starting with unclean CAD geometry, is enabled by GUI based pre- and post-processors, automatic mesh generators, automatic imprinting of thousands of parts and application specific templates. Application specific templates make model setup fast and easy and manage variabilities among users and projects. Example applications include the complete engine lubrication system, complete fuel delivery system, electric motors, gears, bearings, pumps, valves, battery thermal analysis, compressors, heat exchangers, full vehicle models.

8:40 am - 9:00 am
4093439: ExxonMobil: EHC 340 MAX™: Above and Beyond Group I Bright Stock
Toufic Aridi, ExxonMobil, Sarnia, Ontario, Canada

ExxonMobil has previously announced the Singapore Resid Upgrade Project, which is scheduled for startup in 2025 and will introduce a unique high-viscosity Group II base stock — EHC 340 MAX™ — at a large scale. EHC 340 MAX can be used over the wide range of lubricants traditionally served by Group I bright stock-based formulations, with some advantages that are specific to each application allowing lubricant marketers to convert their Group I bright stock tank over to EHC 340 MAX effectively. It also serves lubricant blenders who would like to use EHC 340 MAX to achieve finished fluid differentiation, particularly in the areas of improved shear stability, improved low temperature performance, and improved oxidation stability. With EHC 340 MAX, ExxonMobil's EHC Slate of products is able to meet the broadest lubrication needs, compared to other Group II products. ExxonMobil will continue to partner with global and regional additive companies to deliver market general solutions for our customers.

9:00 am - 9:40 am
4093062: Afton Chemical's Key Driver Seminar: Re-think, Re-define, Re-refine: Formulating Solutions for the Future
Joel Garrett, Safety-Kleen, Norwell, MA; Alyson Wilson, Afton Chemical Corporation, Richmond, VA

The increasing need for support and solutions for sustainability has the industry looking for choices. The right choice for producers, blenders, and organizations starts with rethinking and redefining re-refined base oils. For Afton Chemical's 2024 Key Driver Seminar, we have invited Safety-Kleen's Senior Vice President, Dr. Joel Garrett, to share the trends and challenges faced by re-refined base oils. Dr. Garrett will also discuss the role re-refined base oils play in corporate ESG goals and how thoughtfully chosen formulations can deliver better quality, reliability, and sustainability.

9:40 am - 10:00 am
4092003: Evonik: Collaborative R&D for Next-Gen Electric Vehicle Chemistries
Adam Rice, Evonik Corporation, Richmond, VA

Get ready to embark on a journey of innovation and collaboration with Evonik's presentation on "Collaborative R&D for Next-Gen Electric Vehicle Chemistries." Join Adam Rice, Debbie Lewis, and

Brigitte Sheehan as they introduce themselves and their approach to the topic. The presenters value everyone's perspectives and ideas and are committed to working collaboratively with stakeholders to achieve shared goals through open and honest discussions and feedback. Attendees will gain valuable insights into the latest advancements in the industry, and how they can incorporate them into their work to make a positive impact. The presentation will also highlight Evonik's broad portfolio, which brings new improvements to future formulations. Don't miss this opportunity to collaborate, innovate, and make a difference in the field of electric vehicle chemistries.

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

10:40 am - 11:00 am
4089026: Cargill: Achieving Low Traction and Low Wear in EV transmission Fluids
Scott Davis, Cargill, Carmel, IN

Without globally recognized standards, there are variations in EV fluid specifications and requests to formulators are diverse, but as EVs get heavier and more powerful, transmission fluid requirements become more rigorous. Here we present an overview of the challenges faced by EV fluid formulators and where Cargill Priolube™ and Perfad™ base oils and thickeners help the formulator achieve low traction and low wear in demanding operating environments. Consideration will be given to efficiency, including full-size rig testing as well as wear, compatibility and no-harms data.

11:00 am - 11:20 am
4092643: SEQENS Program for More Sustainability in the Lubricant Industry
Xavier Semery, SEQENS, Porcheville, France

SEQENS is supporting its customers in the development of lubricants with reduced environmental impact. Being Platinum ECOVADIS certified, our French plant is fully involved in the sustainable development of SEQENS activities. To face the challenges of sustainability, SEQENS is offering a range of additives suitable for the formulation of environmentally friendly lubricants (EALs) as well as low labeled lubricants. SEQENS has developed sulfurized extreme pressure additives, that are registered on the LuSC list (Lubricant Substance Classification List) facilitating the formulation of EAL. A push for alternative technologies to lithium is rising due to several challenges in term of supply chain, price and toxicological threats and considering the need of more sustainable solutions, SEQENS is the only one to propose over based calcium sulfonate biodegradable greases with good anticorrosion and water resistance, high thermal stability, extreme pressure performance and mechanical stability.

11:20 am - 11:40 am
4089740: BASF Corporation: The Future of Sustainability with BASF Fuel and Lubricants
Daniel Niedzwiecki, BASF Corporation, Florham Park, NJ

BASF's Fuel and Lubricant Solutions is your preferred partner for sustainable high-performance lubricant components in the industrial market. Driven by the need to reduce greenhouse gas emissions and powered by our industry leading PCF methodology standard, BASF now offers the novel BMBcert™ product series. Replacing fossil-based raw materials with renewable feedstocks, our BMBcert™ products deliver significant CO_2 savings while providing the same high performance and consistent quality products you expect from BASF. This session will highlight our new portfolio of BMBcert™ products, which includes BREOX® base stocks, IRGAFLO® rheology modifiers, SYNATIVE® performance additives, and GLISSOPAL® thickener technologies, to prepare you for a sustainable future.

11:40 am - 12:00 pm
4092863: Emery Oleochemicals DEHYLUB® Esters Engineered for EV Fluid Performance
John Sliner, Emery Oleochemicals LLC, Cincinnati, OH

Emery Oleochemicals is a leading provider of high performance natural-based additives and base stocks for lubricant, metalworking fluid, and corrosion preventive formulators. Our brands include DEHYLUB® Esters, EMERSOL® Isostearic Acids, EMERY® Dimer Acids and Pelargonic Acids, and EMEROX® Azelaic Acids and Corrosion Inhibitors. Principal to our business strategy is our back-end integration to renewable feed stocks, innovative solutions, reliably consistent products, in-depth technical knowledge, and global commercial and technical support. This presentation will introduce our offering of esters that have been engineered to provide outstanding performance as base stocks or additives for fluids used in electric vehicle applications. They provide excellent low temperature properties and oxidative stability. Additionally, these products satisfy the special EV demands for properties including high thermal conductivity, specific heat capacity, breakdown voltage and dielectric constant.

Session 5J — 200 DE

Electric Vehicles V

Session Chair: Vinod Radhakrishnan, Afton Chemical Corporation, Richmond, VA
Session Vice Chair: Andrew Velasquez, Southwest Research Institute, San Antonio, TX

8:00 am - 8:40 am
4005447: Alternates to Fluorosilicone Based Antifoams for Electric Vehicle Driveline Fluids Due to PFAS Regulations
Safia Peerzada, Münzing North America, LP, Bloomfield, NJ

Perfluoro and polyalkylfluoro substances (PFAS) have become of high concern due to health concerns and their nature of low degradation/decomposition. Regulatory agencies all over the world, such as ECHA and US EPA, have initiated regulatory programs to limit the use of these substances. The upcoming PFAS regulations may limit the use of fluorosilicone based antifoams causing lubricant formulators to search for alternate chemistries. This has become an important issue for non-aqueous Electric Vehicle (EV) driveline fluids as fluorosilicone based antifoams consistently provide strong foam control under high stress conditions. Münzing will present a comprehensive study showing alternate antifoam chemistries that provide similar or better foam control in EV driveline fluids based on different base oil groups. The testing will be conducted using Münzing's High Shear-Air Sparge Test that is designed to simulate the high stress environment that EV fluids are exposed too.

8:40 am - 9:00 am
4002326: Combination Effects of Phosphate and Sulfur Additives on Anti-Wear/Anti-Pitting Properties and Tribofilm Formation in Rolling-Sliding Contacts
Yunah Jeung, Kaito Yoshioka, Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika, Tokyo, Japan; Ryotaro Ohashi, Graduate School of Tokyo University of Science, Katsushika, Japan

According to the development of lubricants, there is a growing tendency to lower viscosity oil to enhance power efficiency. This trend towards lower viscosity is increasing the risk of wear and fatigue damage on sliding components. To address these issues, lubricant additives are one of the important technologies. Our previous results have indicated that sulfur-based additives exhibited higher anti-wear properties compared to phosphorus-based additives, and a combination of sulfur-based/phosphorus-based additives showed further improvement of anti-wear performance. However, the effects of tribofilm formation on anti-wear/anti-pitting properties is not fully understood. The purpose of this study is to investigate how the combination oil of phosphorus/sulfur-based additives affects tribofilm formation, and subsequently, how it influences anti-wear and anti-pitting properties as the Sliding-Roll ratio changes using MTM-SLIM.

9:00 am - 9:20 am

4002715: Molybdenum Compounds as Additives in Future PCMO and EV Applications: A Comparative Study

David Boudreau, Vanderbilt Chemicals LLC, Norwalk, CT

In the pursuit of enhanced automotive performance and efficiency, the choice of lubricating fluids and their additives plays a critical role. This work investigates the performance profiles of various molybdenum-containing lubricant additives in PCMO and EV-based fluids. Conductivity, corrosion resistance, friction reduction, wear prevention, and their potential ability to withstand extreme pressure conditions are considered. By presenting a holistic assessment of molybdenum compound additives and their multifaceted impact on lubricating fluid performance, this research focuses on identifying sustainable, high-performance solutions for the ever-evolving automotive industry.

9:20 am - 9:40 am

4004955: Advanced Rheo-Tribological Testing of Greases for Electric Vehicles

Paul Staudinger, Kartik Pondicherry, Anton Paar GmbH, Graz, Austria; Julius Heinrich, Anton Paar Germany GmbH, Ostfildern, Germany

Lubricants used in electric mobility applications have to cater to an additional set of criteria, beyond the existing traditional requirements. If the stray currents produced by frequency converters used to control the motor speed are discharged through the associated ball bearings, over long term, it can damage the bearings. To counter it, development of lubricants for electric vehicles must also consider electrical parameters such as permittivity, conductivity, and breakdown voltage. The primary aim of this study is to present a novel test methodology to investigate different greases at lab-scale to simultaneously characterize their frictional, and electro-tribological response. Additionally, the rheo-tribometer made it possible to measure rheological and electro-rheological properties of the greases. The sum of all these investigations can help us develop a model to understand the behavior of grease-lubricated ball-bearing systems under dynamic conditions.

9:40 am - 10:00 am

3982292: How Can We Measure the Performance of Greases for Connectors? A Hands-On Tribo-Method

Lais Lopes, Dirk Drees, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Emmanouil Georgiou, Hellenic Air-Force Academy, Athens, Greece

The amount of electrical connectors in the automotive industry will likely keep increasing, many systems depend on electronic and electric connections. When disconnects occur, the consequences can range from annoying to critical. In operation in vehicles, connectors are subjected to vibrations that may induce fretting wear damage in the contacts. To extend component lifetime, electrically conductive greases can be used, but to assess their performance in a real contact, we have to test beyond standards such as the ASTM D-4170 four ball or SRV reciprocating tests. We have developed a method that uses actual USB-connector components, and recreates vibratory motions, where both friction and conductivity are used to identify ‘time to failure’. This method uses real USB-connectors and can be modified for other connector types, making it a practical approach to evaluating the complete setup of USB-connector + lubricant. It is found that a specialty lubricant makes all the difference.

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

10:40 am - 11:00 am

4004008: Electrical, Mechanical, and Performance Properties of Electric Vehicle Motor Greases with Silver Nano-Particle Additives

Jack Janik, Sudip Saha, Samuel Bond, German Mills, Robert Jackson, Auburn University, Auburn, AL;

Carlos Sanchez, Peter Lee, Southwest Research Institute, San Antonio, TX

Shaft voltages and bearing currents generated within an electric vehicle's powertrain system can accumulate near rolling element bearings, causing significant damage or mechanical failure. The incorporation of conductive lubricants is a possible solution to mitigating this damage. This work documents the properties of silver nanoparticle colloidal suspensions in polyurea greases for electrified applications. Several variations are considered, including mineral and synthetic base oils, with and without conventional additive packages. All base greases are NLGI Grade 2 consistency and ISO 100 grade viscosity. The rheological and electrical properties of the greases, such as viscosity, conductivity, and dielectric strength, are measured and used to explain the changes in performance observed in previous work.

11:00 am - 11:20 am
4004810: Dedicated e-Fluids for Energy Efficiency
Hitesh Thaker, Changlin Zhao, Infineum USA LP, Linden, NJ

The trends of improved fuel efficiency and CO_2 emission reduction have resulted in automotive manufacturers incorporating greater levels of electrification, and developing more compact, higher voltage designs. The new hybrid and battery electic vehicle designs have led to the development of dedicated e-fluids for these applications that offer reduced energy consumption at lower viscosities while providing necessary hardware protection. Controlled testing conditions with specific electric drive unit helps provide key insights on the impact of e-fluid parameters like viscometrics and additives is key for achieving high energy efficiency.

Session 6A — 101 B

Materials Tribology IV

Session Chair: Mark Sidebottom, Miami University, Oxford, OH
Session Vice Chair: Santiago Lazarte, Florida State University, Tallahassee, FL

1:40 pm - 2:20 pm
4005662: Robust Superlubricity in Mo_2TiC_2 MXenes Facilitated by Tribocatalytic Reaction at the Sliding Interfaces
Anirudha Sumant, Sai Varun Sunkara, Yuzi Liu, Subramanian Sankaranarayanan, Argonne National Laboratory, Lemont, IL; Brian Wyatt, Babak Anasori, Purdue University, West Lafayette, IN; Andreas Rosenkranz, University of Chile, Santiago, Chile

Recent interest in exploring tribological properties of MXene is rooted in their layered structure and ability to shear easily coupled with their robust mechanical properties. However, their chemical stability a critical factor of long-term reliable lubricant has remained unproven, thereby constraining its full application potential within the lubrication industry. In this current work, we study an ordered double transition metal MXene (Mo_2TiC_2) and demonstrate its exceptional tribological performance in dry nitrogen atmosphere using macro-scale pin-on-disc tribo-testing. We demonstrate sustained superlubricity, with a friction coefficient as low as 0.005, persisting over the extensive course of linear sliding of 86 kilometers, with no signs of failure and minimal wear rates. We will elucidate the intricate mechanisms including the pivotal role played by tribo-catalytic reactions at the sliding interface, which yield a stable, lubricious tribolayer.

2:20 pm - 2:40 pm
3976685: Room Temperature Sintering of TiO_2 Nanoparticles: Exploiting Friction to Manufacture

Wear-Resistant Coatings
Pranjal Nautiyal, Oklahoma State University, Stillwater, OK; Michael Moriarty, Parker LaMascus, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Gordon Lee, ExxonMobil Technology and Engineering Company, Clinton, NJ; Robert Wiacek, Pixelligent Technologies, LLC, Baltimore, MD

We exploit friction-assisted sintering mechanism—tribosintering—to manufacture wear-resistant coatings on steel at tribological contacts. A pressurized sliding/rolling contact is run in a processing fluid containing dispersed nanocrystals. The nanocrystals sinter on the contacting surfaces, forming robust surface-bound solid coatings. We used a ball-on-disc tribometer equipped with an optical interferometer to study the deposition and durability of TiO_2 coatings in situ. These coatings sinter at room temperature over all tested slide-roll-ratios (0 to 50%), with higher slide-roll ratios accelerating sintering. These coatings resisted wear in 10-hour durability tests in harsh boundary contact conditions in nanocrystal-free oils. In contrast, uncoated steel scuffs under these conditions. We postulate these coatings' exceptional wear resistance stems from highly effective sintering densification under combined compressive and shear stresses over tens of thousands of contact cycles.

2:40 pm - 3:00 pm
4000936: Novel Organic Friction Modifiers with Extended Performance Durability
Micky Lee, Oleon Port Klang Sdn Bhd, Port Klang Selangor, Malaysia; Pieter Struelens, Oleon NV, Evergem, Belgium

Friction modifiers keep on playing a vital role in reducing energy losses and thus improving fuel economy. However, in the light of the upcoming ILSAC GF-7 standard, the quest remains for high-performance friction modifiers maintaining their performance over an extended period of time, ensuring long-term efficiency and effectiveness. This work focuses on the design and synthesis of innovative organic friction modifiers (OFMs) with improved oxidative and hydrolytic stability allowing them to withstand harsh operating conditions and maintain their friction-reducing capabilities over extended periods of use. More specific it has been shown that the use of a specific oligomerized organic friction modifier allows to achieve a very low friction coefficient (superlubricity effect) at low speed compared to conventional organic or moly based friction modifiers even after prolonged usage and exposure to various environmental factors.

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

3:40 pm - 4:00 pm
4004740: Critical Influence of Contact Temperature for Tribology in Polymer Contacts and Models to Quantify It
Mitjan Kalin, Tomaz Pozar, Shoaib Siddiqui, University of Ljubljana, Ljubljana, Slovenia

The utilization of polymer materials has seen rapid growth across various engineering applications, including gears and bearings. However, when compared to metals, polymers are considerably more sensitive to temperature fluctuations due to their inferior thermal resistance and insulating properties. Consequently, the frictional heat generated affects their tribological performance by causing softening or even melting. In this study, we present some critical parameters that cause risks of thermal degradation of polymers in such contacts. Furthermore, we developed ready-to-use models for polymer/polymer and polymer/steel contact temperatures, which effectively replicates the contact temperatures in polymer contacts in pin-disc studies. These models also aid in comprehending the tribological behavior of polymers in these contacts and enable the prediction of contact temperatures as well as to set proper tribological test conditions and test duration.

4:00 pm - 4:20 pm
4005345: Influence of Polymer Morphology on the Ultralow Wear Behavior PTFE Composites

Kylie Van Meter, Victoria Yang, Brandon Krick, Florida State University, Tallahassee, FL; Christopher Junk, Lehigh University, Bethlehem, PA

Polytetrafluoroethylene (PTFE) is commonly used as a solid lubricant in tribology applications due to its very low coefficient of friction (<0.1), thermal stability, and chemical inertness. Although PTFE has a high wear rate when used under typical engineering sliding conditions, the addition of filler materials like alumina and PEEK to PTFE have resulted in a 10,000x reduction in wear rate ($K< 10^{-7}$ mm^3/Nm). In recent works, polyether ketone ketone (PEKK) was used to create ultralow wear composites that are environmentally agnostic due to the abundance of ketones that accumulate at the sliding interface. It appears that the wear behavior of the composite can be further improved by altering the morphology of the polymer through composite processing control. In this study, the influence of composite processing and polymer morphology was investigated through tribological, thermal, and mechanical characterization of the composites, along with chemical analysis of the sliding interface.

4:20 pm - 4:40 pm
4004823: Tribological Performance of Experimentally Developed 3D Printed High-Performance Polymer Composites
Nayan Dhakal, Nazanin Emami, Luleå University of Technology, Luleå, Sweden; Cayetano Conesa, Ardian Morina, University of Leeds, Leeds, United Kingdom

This work investigates additive manufacturing of polyether-ether-ketone (PEEK) and polyphenylene-sulfide (PPS) composites for hydropower bearings using Fused Filament Fabrication (FFF). Composite filaments were experimentally developed, extruded, 3D-printed, and tested for their reciprocating sliding behavior. In-house developed and 3D printed parts exhibited tribological performance comparable to injection molded parts, with improved surface quality. Carbon fibers (10 wt.%) in PEEK yielded up to 37% friction reduction and a specific wear rate of $2x10^{-6}$ Nm/mm^3 under dry sliding. Water lubrication reduced running-in and friction coefficients of neat PEEK up to 48% compared to dry conditions. Tribological results emphasize that material combination and sliding conditions influence running-in, friction evolution, and wear mechanism. Consequently, this research suggests that 3D printing can be a sustainable option for processing high-performance thermoplastics in tribological applications.

4:40 pm - 5:00 pm
3982319: Investigating the Friction and Wear Properties of Polymer Laser Sintered Components
Kieran Nar, University of Sheffield, Sheffield, United Kingdom

Today, Additive Manufacturing (AM) is ubiquitous within industry. Laser Sintering (LS) in particular is one of the most well-established polymer AM processing techniques due its capability of producing geometrically complex and functional components. However, despite this the adoption of laser sintered components for end-use applications remains hindered due to an incomplete understanding of their in-service behaviors, particularly when subject to dynamic contact. Therefore, this work gives an overview of the pertinent sliding phenomena discovered whilst investigating the friction and wear properties of laser sintered Nylon-12 components. More specifically, ball-on-flat, pin-on-disk, dry sliding tests were performed in accordance with a design of experiments to highlight the individual and compound influence normal load, sliding velocity and contact configuration had on the coefficient of friction and wear rate of sample surfaces examined.

5:00 pm - 6:00 pm - **Materials Tribology Business Meeting**

Session 6B — 101 C

Condition Monitoring II

Session Chair: Marc Yarlott, Veolia North America, Vancouver, WA
Session Vice Chair: Alfredo Garcia, Luval SA, Santiago, Region Metropolitana, Chile

1:40 pm - 2:20 pm
4002620: Comparing New ASTM Methods for FTIR Analysis of Fluid Condition
David Swanson, POLARIS Laboratories®, Indianapolis, IN

Condition monitoring of fluid properties by FT-IR has long been led by the ASTM method E2412. However, ASTM E2412 is a practice in itself and, as such, has no repeatability and reproducibility limits. Recently, ASTM has introduced new methods for oxidation, nitration, soot, phosphate anti-wear additives, and sulfate by-products. How do they compare, and should you challenge your laboratory to switch to them? This informative session will discuss key differences between these newly devised methods and important considerations when evaluating in-service lubricant and machine health objectives.

2:20 pm - 2:40 pm
3970806: Extended Lubricant Analysis Using Nuclear Magnetic Resonance (NMR)
Christoph Rohbogner, OELCHECK GmbH, Brannenburg, N/A, Germany

Nuclear Magnetic Resonance (NMR) is the most powerful analytical method known in organic chemistry today. As lubricants are comprised of organic and metal organic compounds it is of special interest if it can be applied in used oil analysis. NMR allows the specific observation of different elements and their neighboring structure. This may be used to observe the changes within the additive molecules in comparison with fresh oil references. It is known that AW and EP additives are structurally altered during their use. Thus, it is possible to track the concentration of the original AW/EP molecule. As AW/EP Additives are typically based on Phosphorous, the observation of the ^{31}P isotope with NMR is preferred. The combination of already applied methods like ICP-OES analysis with the knowledge of the percentage active AW/EP Additives is an ideal tool for estimating the lifetime of the lubricant thus, leading to a sustainable lubrication strategy.

2:40 pm - 3:00 pm
4002568: Oil, Fuel, and Coolant Analysis – How Each Can Dramatically Extend Equipment Life
Michael Holloway, SGS, Highland Village, TX

Every piece of equipment has a heartbeat, blood stream, temperature and so on. Understanding the overall health and well-being of your equipment can improve your profitability and provide a competitive edge. The analysis of oil, coolant and fuel are methods being used by forward thinking companies that are focused on getting the most out of their equipment and productivity. This presentation explains the latest tools and techniques used for these practices. Whether you are looking to extend change intervals, track down the root cause for equipment breakdowns, or to use for on-going diagnostics, the practice will help drive down costs and keep the assets on the road.

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

3:40 pm - 4:00 pm
4005269: Application of Electrochemical Impedance Spectroscopy (EIS) to Lubricating Oil Condition Monitoring
Tianshi Fang, Jing Ning, Ryan Manthiri, Krystal Henry, Oluwaseyi Ogunsola, Shell Global Solutions (US) Inc., Houston, TX; Rihard Pasaribu, Shell Downstream Services International, Rotterdam, Netherlands; Robert Mainwaring, Shell Global Solutions (UK), London, United Kingdom

In-situ lubricating oil condition monitoring (OCM) has received remarkable interest from various industries, especially in applications where timely oil change is critical but inconvenient or expensive. Electrochemical Impedance Spectroscopy (EIS) has been identified as a promising technique to achieve effective and economic OCM. In this study, an in-house scientific EIS sensor along with a few commercial EIS sensors were tested to understand EIS responses to multiple parameters related to oil degradation. Mathematical models were developed to effectively analyze sensor signal. The EIS sensors responded rapidly to changes in contaminations and ageing in oils. The most indicative parameter of oil condition was identified. It was found that EIS performed differently with lubricant formulations with different levels of additization. Hence, sensor signals detecting a specific type of oil need to be interpreted with a particular model.

4:00 pm - 4:20 pm
4004685: Combining Oil Analysis Tests to Identify the Root Cause of Machine Failures (ASTM D2982-7 (2013) and ASTM D5185)
Ross Master, Bureau Veritas, Suwanee, GA

Case Comparative Study between ASTM D2982-7 (2013) Standard Method for Detection of Glycol-Base Antifreeze in Used Lubricating Oils (Qualitative) and ASTM D5185 Standard Method for Multi-element Determination of Used and Unused Lubricating Oils and Base Oils by ICP-AES (Quantitative) as a Complementary tool on O.C.M.

4:20 pm - 4:40 pm
4025260: Quantifying Severity of Wear and Contamination with a Filtergram
Daniel Walsh, Ray Garvey, Ametek, Chelmsford, MA; Kubale Shamabanse, Bryan Johnson, Palo Verde Generating Station, Tonopah, AZ

Wear debris monitoring and analysis is an extremely effective maintenance approach to ensure machine health. Rotrode filter spectroscopy (RFS), a tool used to process and measure particles greater than 5 micron to detect abnormal wear, has been discontinued. Acid digestion, another methodology used to measure larger wear particles, is cumbersome and labor intensive. Concentrating wear debris on a small footprint disposable filtergram and analyzing the debris for elemental composition by ASTM D8127 (Coupled particulate and elemental analysis using XRF) offers a new approach for wear debris monitoring. The sample preparation for this new method also becomes an ideal alternative for microscopic particle examination. This presentation will describe an overview of the challenges, and the interim results from a site-based study in a power generation facility, with data from oil and grease samples.

4:40 pm - 5:00 pm - **Condition Monitoring Business Meeting**

Session 6C — 101 D

Lubrication Fundamentals IV: Oil Degradation

Session Chair: Chanaka Kumara, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: Nicole Dörr, AC2T research GmbH, Wiener Neustadt, Austria

1:40 pm - 2:20 pm
4027747: Stop Over-heating (Killing) your Bearings with Poor Lubrication Practices
Allan Rienstra, Kaitlyn Dobie, SDT Ultrasound Solutions Inc, Cobourg, Ontario, Canada

The engineering that goes into manufacturing the world's best bearings makes them nearly indestructible and when they are maintained properly, they often outlast the assets they support. But many organizations use archaic, calendar-driven re-lubrication techniques that result in bearings that fall short of their engineered lifespan. New techniques use ultrasound as a guide to achieve optimal grease replenishment while reducing thermally induced degradation. The presentation will include tales of ultrasound techniques used by lubrication technicians around the world and is full of fact-filled anecdotes and case studies with before/after graphs and sound files. Join Rienstra to Hear More. Join Rienstra to grease bearings right.

2:20 pm - 2:40 pm
4004588: Development of a Lifetime Model for the Oxidation Stability of Lubricating Greases
Nicole Dörr, Christoph Schneidhofer, Michael Schandl, AC2T research GmbH, Wiener Neustadt, Austria

Thermal and oxidative stress are key influencing parameters that affect the lifetime of lubricants. By means of a modified microcoking test, 4 lubricating greases with different base oils and thickeners were exposed to temperatures from approx. 100 to 190°C in air. The oxidation stability of the greases was determined by means of an oxidation model developed from grease analytical data. This was used to rank the greases according to their oxidation stability over the temperature range investigated.

2:40 pm - 3:00 pm
3982906: Investigating the Oil Aeration Performance of Lubricants
Tianshi Fang, Eliane Gendreau, Hayley Bunce, Robert Mainwaring, Sarah Matthews, Shell, London, United Kingdom

The ability of automotive or industrial lubricants to handle air has been acknowledged for many years. Excessive foaming, associated with air release, and compromised lubrication, associated with entrained air, being of particular concern. Current hardware trends focused on increased power delivery and reduced size promote a reduction in oil volumes and oil circulation times, both of which are apt to exaggerate air handling concerns. Both trends are prevalent in modern engines and the high-speed transmissions used in e-mobility applications creating an increased interest in aeration phenomena. In these studies, we explored the impact of viscosity, temperature, flow rate and antifoam additive selection on the air entrainment behavior of a modern, high speed engine. Engine, bench top and more fundamental studies were used to create a generic understanding of aeration control that can be applied to a wide range of applications.

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

3:40 pm - 4:00 pm
4000688: Influence of a Transmission Oil Degradation on System-Level Behavior
Busra Duran, Jerome Cavoret, Fabrice Ville, David Philippon, INSA Lyon, Villeurbanne, France; Arnaud Ruellan, Frank Berens, SKF France, Saint-Cyr-sur-Loire, France

During the operation of lubricated mechanical systems, lubricant properties may change. This can influence the performance of the mechanical systems in terms of durability and efficiency, for example. This study analyzes how field operation affects system-level performance in fresh and field-collected transmission oils. Thermal and tribological tests on the FZG machine were carried out to assess the oil performance under various operating conditions by analyzing the different sources of dissipated energy (bearings, tooth friction, churning…). The dissipated energy model used for the analyses is in good agreement with the experimental results. Results reveal that, through variations in efficiency, field-collected oils behave differently from fresh oils.

4:00 pm - 4:20 pm

3999444: The Evaluation of $Ti_3C_2T_z$ MXene Nanofluid (As a Single Fluid) for Balanced Lubrication and Thermal Management
Kailash Arole, Mohsen Tajedini, Micah Green, Hong Liang, Texas A&M University, College Station, TX

Using a single fluid in vehicles for balanced lubrication and thermal management can improve fuel economy, reduce emissions, and improve performance. These fluids can be used as transmission, differential, and power steering fluids where lubrication and thermal management are essential. In this work, we evaluate the performance of $Ti_3C_2T_z$ MXene as an additive to enhance the heat transfer, rheological properties, and tribological performance of silicone & polyalphaolefin (PAO) oils. Experimental results showed that adding MXene improved thermal conductivity by 16 % & 23 % in silicone and PAO oils, respectively. The rheological data revealed that adding $Ti_3C_2T_z$ nanosheets reduced the viscosity by 12.3 % and 18.1 % in silicone & PAO oil, respectively. The addition of $Ti_3C_2T_z$ reduced the friction by 23 % and 65 % in silicone & PAO oils, respectively. The improved properties & reduced fluidic drag in viscosity and friction can offer the utilization of MXene-based fluid in EV applications.

4:20 pm - 5:00 pm - **Lubrication Fundamentals Business Meeting**

Session 6D — 101 E

Rolling Element Bearings I

Session Chair: Ujjawal Arya, Purdue University, West Lafayette, IN
Session Vice Chair: Travis Shive, SKF USA Inc., Lansdale, PA

1:40 pm - 2:20 pm
3983543: Comparison of Fatigue Performance of Different Aerospace Rolling Element Bearing Materials
Nikhil Londhe, The Timken Company, North Canton, OH

In aerospace applications, rolling element bearings are subjected to harsh conditions of severe vibratory stresses, high rotational speeds, elevated temperatures, and aggressive lubrication conditions. To meet application needs, these bearings are made using high strength and clean bearing steels. Hybrid bearing silicon nitride rolling elements paired with steel raceways offer better tribological performance. This study offers an analysis of fatigue life data for 1185 aerospace bearings that were tested between 1995 and 2023. The relative performance of different ring materials, such as 440C SST, CSS42L, M62, 52100, M50, and M50NiL are provided. Comparisons of hybrid ball and roller bearings performance, relative to all steel variants, is also provided under identical load conditions. Bearing life predictions using an advanced stress-based fatigue life model shows good agreement with experimental data.

2:20 pm - 2:40 pm
4005361: Effect of Operation Temperature & Lubrication Regime on Bearing RCF Life Using Computational Modeling Tool
Behrooz Jalalahmadi, Nick Weinzapfel, Sentient Science, Buffalo, NY

It is widely known that operation temperature can affect rolling contact fatigue (RCF) life of bearings. We utilize our DigitalClone for Engineering (DCE) bearing modeling tool to investigate the effect of operation temperature on lubrication regime, contact pressure profile and bearing RCF life. DCE is a physics-based RCF life prediction model which has been developed considering contact stresses, material microstructure, crack initiation mechanisms, damage mechanics, and probabilistic methods. To demonstrate the validation of DCE modeling tool, two different bearing types are studied under RCF loading: a) off-the-shelf AISI 52100 cylindrical roller bearing (CRB), b) custom-made M50 angular contact

ball bearing (ACBB). We perform both experimental RCF testing and computational RCF modeling using our DCE modeling tool. Due to variation of test temperature, two different lubrication regimes of mixed-EHL and boundary lubrication are created.

2:40 pm - 3:00 pm
3988753: Prediction of Bearing Damage Beyond Rolling Contact Fatigue
Patrick Wingertszahn, Oliver Koch, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

The fatigue life calculation of rolling bearings according to DIN ISO 26281 is state of the art and is used in the design and selection of bearings. The calculations are based on the damage mechanism of material fatigue. This covers the safe design of rolling bearings for a wide range of applications. Beyond fatigue, operating conditions and environmental influences can cause other damage to the rolling bearing, such as different wear mechanisms, adhesive and abrasive, or plasticization. Among others van Lier, Wadewitz and Eglinger found critical values, for damage initialization and damage development. These values depend on local contact parameters like contact pressure, relative velocity, effective coefficient of friction, contact ratio and shear stresses. The contact parameters are strongly dependent on external loads. In this work an approach is presented with which damage characteristics for rolling bearings can be determined depending on the system loads.

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

3:40 pm - 4:00 pm
4090980: Linkage between Structural Fatigue and Rolling Contact Fatigue—New P-F-L Curve Analysis and Evaluation Using P-S-N Curve
Shigeo Shimizu, Meiji University, Kawasaki, Kanagawa, Japan; Hiroshi Ozeki, Chiba Institute of Technology, Chiba, Japan; Tsuyoshi Shimizu, Yamanashi University, Yamanashi, Japan; Tatsuya Imai, Yoshihiro Hamada, THK Co. Ltd., Tokyo, Japan

The General Weibull Distribution (GWD) function introduced a minimum life (γ) is adopted under a fixed shape index (m) depending on the distribution shape of the iso-stressed field concerning the critical failure. The discussed items are as follows: (1) Material dependency on stress-life exponents of P-S-N curve using GWD function: (2) 2520-bearing system life distribution by Tallian (1962): (3) P-F-L curve by Lundberg and Palmgren (1947) vs. 500-bearing and 719-bearing life distributions by Snare (1970) and Okamoto et al. (1977): (4) 565-tapered roller, 596-ball and 1161-mixed bearing system lifetime data by Takata et al. (1985): (5) Life distributions of 915-ball bearing for a quarter century by Muro (1987): (6) Life distribution and load-life exponent of 3-lot, 318-ball bearing by Okamoto et al. (2005): (7) Life distributions of 6-lot, 191-ball bearing and their system data by Shimizu (2012).

4:00 pm - 4:20 pm
3986667: The Effect of Current and Lambda on White-Etch-Crack Failures
Nicholaos Demas, Cinta Lorenzo Martin, Aaron Greco, Robert Erck, Argonne National Laboratory, Lemont, IL; Ryan Luna, GE Vernova, Schenectady, NY

In this work, a benchtop test rig was used to investigate the effect of electrical current and operation in different lubricating regimes, defined by lambda (λ). It was observed that there is an inverse correlation between the magnitude of electric current applied to the ring/roller system and time-to-failure. For the same current magnitude, tests conducted in boundary and mixed lubrication regimes showed that time-to-failure increased as λ increased, and the tests resulted in WEC related macropits, whereas tests conducted in near-hydrodynamic regime resulted in surface damage with no macropit. It was also noted that a shift toward near-hydrodynamic lubrication resulted in a distinct surface distress on the roller surface. Sub-surface imaging revealed the presence of WECs in all cases, and broad, branching cracks that were more prevalent under the more severe boundary conditions.

4:20 pm - 4:40 pm
4000734: Particular WEC Triggers and Their Failure Risk: It's All a Question of How Long They Last?
Daniel Merk, Wolfram Kruhoeffer, Jörg Franke, Jörg Loos, Schaeffler Technologies, Schweinfurt, Bavaria, Germany

In particular cases, rolling bearings fail due to White Etching Crack (WECs) before reaching their calculated rating life. This happens if so-called additional loads, like very high friction energy, are applied on the bearing beside the Hertzian rolling contact stresses. But these WEC-critical operating conditions often do not occur over the entire operating period and are therefore not detected and not mitigated in many times. Under such circumstances, it is unclear whether the bearings are then already irreversibly damaged and will fail. To clarify this important question, WEC bearing tests on different WEC test stages with varied impact time of the additional load were made and will be presented.

4:40 pm - 5:00 pm
3998427: Mechanistic Study of White Etching Area Development in Butterflies Through 3D Investigations of Roller Bearings
Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom; Wolfram Kruhoeffer, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany

The investigation of the development of butterflies (BFs) in bearings due to rolling contact fatigue has been a subject of intense research for decades, aimed at elucidating their underlying formation mechanisms. Majority of studies have focused on two-dimensional analysis of the BF microstructure. In this study, BFs at different stages of development, including their capsuled inclusions have been examined in three dimensions using laser-focused ion beam serial sectioning method where several BFs have been fully captured. It is revealed that the structure of fully developed BFs, contradicting to the prevailing characterization in literature, do not comprise of two separated wings, rather that, the white etching areas (WEAs) in a BF bear a closer resemblance to that of a single disc-shaped structure encapsuling an inclusion. A comparison of BFs and white etching cracks has been conducted to enhance the understanding of complex processes underlying the formation of WEAs within bearings.

5:00 pm - 5:30 pm - **Rolling Element Bearings Business Meeting**

Session 6E — 101F

Environmentally Friendly Fluids I

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

1:40 pm - 2:20 pm
4004294: How Ester Technology Contributes to Technical and Sustainability Targets
Matthias Hof, Emery Oleochemicals GmbH, Duesseldorf, NRW, Germany

Achieving sustainability is one of the dominating challenges in our industry today while the technical specifications continue to harshen and become more challenging. This paper will shed a view how ester products are developed now and the years to come. Innovations is constantly requested and expected while the increasing numbers of regulations, chemical listings and classification needs are leading to further challenges. Using raw materials for global products while addressing regional availabilities and supply chains needs to be addressed. Balancing cost and performance is another important factor to position new chemistries in the market. Data will be presented coming from various bench as well as tribological testing along with environmental input. It will be shown how ester technology can address

these various points with existing and new products and what is already accessible to the formulating industry.

2:20 pm - 2:40 pm
3993873: A Brief History of Refrigeration Lubricants
Michael Costello, The Lubrizol Corporation, Midland, MI

Historically, chlorofluorocarbon (CFC) refrigerants were used in the HVAC industry until it was found in 1974 that the chlorine from CFC's was depleting the ozone layer in the upper atmosphere. One of the first non-ozone depleting refrigerants developed was the hydrofluorcarbons (HFC) and the new lubricants proposed were polyol ester chemistry. Subsequently additional lubricants had also been commercialized including polyalkylene glycol, polyvinyl ether, and alkyl benzene. Now that the phase down of the ODP substances is almost complete, extensions to the Montreal Protocol (Kyoto Protocol-1997 and Kigali Amendment-2016) to address the global warming potential of the new refrigerants were adopted. This paper will trace the development of lubricants used as the industry transitions from the CFC and HFC chemistry to the new Low Global Warming Potential (Low GWP) HFO and natural chemistry by focusing on the key benefits and drawbacks that each lubricant type presents.

2:40 pm - 3:00 pm
4005350: Meeting Sustainability Standards in Industrial Lubricants using Specialty Additives
Stefanie Velez, Münzing Chemie GmbH, Bloomfield, NJ

As interest in developing sustainable industrial lubricants continues to increase, so does the number of sustainability standards and strategies in the marketplace. This is a broad topic that involves a balance between environmental impact, health and safety, and economic performance of the lubricant. A review of current sustainability initiatives along with bio-based and biodegradable specialty additives will be discussed. To further investigate the sustainability of an industrial lubricant, a comprehensive study highlighting the considerable positive impacts that high-performance defoamers have on the overall performance and lifespan of the fluid will be explored. Understanding how to balance the different aspects of sustainability using high-performance defoamers can be key in developing more sustainable industrial lubricants including metal working fluids, non-aqueous lubricants, and automotive fluids.

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

3:40 pm - 4:00 pm
4003821: Exploring the Additive Compatibility and Tribological Behavior of Regular and High Oleic Soybean Oil
Piash Bhowmik, Hyunsuk Choi, Clement Tang, University of North Dakota, Grand Forks, ND; Brajendra Sharma, Majher Sarker, USDA/ARS/NEA/ERRC, Wyndmoor, PA; Sougata Roy, Iowa State University, Ames, IA

As the demand for biobased lubricating oils continues to rise in the research arena, there is a growing focus on exploring diverse oil types. Particularly high oleic oils offer enhanced stability and a richer oleic acid content compared to their regular soybean oil counterparts. This study is focused on revealing the compatibility of both regular and high oleic soybean oils with select antiwear and antioxidant additives along with a comparative performance analysis of these additives. Reciprocating friction, wear and electrical contact resistance-based analyses were conducted to evaluate additive compatibility and wear mechanisms at room temperature lubrication conditions. Interestingly, it was observed that additive compatibility for regular soybean oil was better against high oleic soybean oil. Additional physiochemical property analyses of experimented lubricants and surface characterization of sample surfaces were performed to reveal the dominant wear mechanisms.

4:00 pm - 4:20 pm

4002887: Environmentally Friendly Base Oils From Upcycled Plastic Waste
Robert Kennedy, Ryan Hackler, Aeternal Upcycling, Chicago, IL

Environmentally friendly base oils can be made directly from plastic waste. Catalytic hydrogenolysis converts polyethylene and polypropylene, which together make up more than 60% of plastic waste, into base oils with comparable properties to Group III and IV base oils. Plastics-as-feedstocks offer Scope 3 emissions savings to formulators and end users, through diversion of plastic from landfills and incineration and through the energy-efficient hydrogenolysis process, potentially more than halving the cradle-to-gate environmental impact of the base oil.

4:20 pm - 4:40 pm
4003733: Candidate Marine Turbine Lubricant Additives: Ionic Liquids with High Lubricity and Eco-Friendliness
Wenbo Wang, Huimin Luo, Louise Stevenson, Peijia Ku, Tom Geeza, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Tidal energy is able to generate clean, sustainable electricity via turbomachinery as a promising source in the portfolio of renewable energy sources. The development of environmentally acceptable lubricants (EALs) for marine turbomachinery is crucial to reducing the risk of conventional lubricants threatening marine ecosystems due to leakage or spillage incidents. Recently, eco-friendly and high-lubricity ionic liquids (ILs) were successfully invented at Oak Ridge National Laboratory and are being further developed as additives for tidal turbine gearbox lubrication. Compared with the commercial baselines, the 'not toxic' and 'readily biodegradable' IL-additized lubricants performed more effectively in reducing friction, wear loss, and mitigating rolling contact fatigue. In addition, the mechanisms of wear and the protection resulting from the ILs are being investigated through surface and tribofilm analyses.

4:40 pm - 5:00 pm
4005438: An Investigation of Film Formation and Pressure Viscosity Relation of Water-Based Lubricants in Elastohydrodynamic Contacts
Mushfiq Hasan, Marcus Björling, Roland Larsson, Luleå University of Technology, Luleå, Sweden

Recently water-based lubricants (WBL) became a subject of interest because of their sustainability and efficiency aspects. OEMs are considering these lubricants even in sophisticated applications such as automotive transmissions, where fossil-based lubricants have been used for decades. The film thickness variation across different contact conditions is a crucial design parameter. WBLs have a different composition compared to mineral oil, so the film formation needs to be investigated. Moreover, the pressure viscosity relation at moderately high pressure should be studied to better understand its behavior in gears and bearings contact. In this research, the elastohydrodynamic film formation of several formulated water-based lubricants is experimentally investigated. Moreover, the effect of shearing and temperature on film thickness is also studied. Later, the pressure viscosity relation of WBLs was studied up to 0.5Gpa pressure using optical method and high-pressure viscometer.

5:00 pm - 5:30 pm – **Environmentally Friendly Fluids Business Meeting**

Session 6F — 101 G

Sustainable Power Generation II

Session Chair: Elaine Hepley, Solana Consulting Services LLC, Indianapolis, IN
Session Vice Chair: Matthew Hobbs, EPT, Calgary, Alberta, Canada

1:40 pm - 2:20 pm

4002573: Effects of Tribology on CO_2—Emissions in the Use Phase of Products—Contributions of Tribology to Defossilization (3rd Study of the German Society for Tribology)

Vasileios Bakolas, Tim Hosenfeldt, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany; Mathias Woydt, Matrilub, Berlin, Germany; Eberhard Bock, Freudenberg Sealing Technologies, Weinheim, Germany; Rolf Luther, FUCHS Lubricants, Mannheim, Germany; Christoph Wincierz, Evonik Operations GmbH, Darmstadt, Germany

Friction and wear occur all along the value chain. Therefore, tribology is an easy-to-implement technical option for the removal of CO_2 from the atmosphere – the CO_2 saved in the use phase (downstream) need not be generated in the extraction phase (upstream). Reducing friction and extending longevity provide industrial strategies for defossilization because CO_2eq.-savings generated by tribology occur anywhere and anytime. Friction reduction and longevity are thus "negative emission technologies" (NET) producing less or saving CO_2 during operation or are easy-to-implement as drop-in solutions. Tribology is based on a very diverse industrial platform and a key interdisciplinary technology for mitigating the CO_2 overhang expected by 2050. This third GfT (German Society for Tribology) study presents specific solution approaches, estimates the CO_2 value of selected tribological solutions and specifies the ways forward based on the technologies available.

2:20 pm - 2:40 pm

3986386: Evaluation of Experimentally Developed High-Performance Polymer Composites for Hydropower Bearings

Julian Somberg, Kim Berglund, Nazanin Emami, Luleå University of Technology, Luleå, Norrbotten, Sweden

Moving away from fossil-based lubricants in hydropower bearings and the changing operating conditions puts high demands on the currently used bearing materials. With service life being the limiting factor of current materials, there is a need for high performance alternatives. In this work, two experimentally developed multiscale composites are evaluated with respect to commercially available materials. A novel tribometer was used enabling contact pressures of up to 40 MPa. Experiments were performed under dry, water and EAL lubricated conditions, simulating guide vane and Kaplan runner bearings. The results indicated especially low dry sliding friction and wear for the developed composites. The introduction of water did not lead to a consistent friction and wear reduction, which is linked to the absence of a transfer film. The EAL reduced friction and wear by up to 85%. However, the absence of an effective transfer film makes both pin and counter surface more prone to abrasive wear.

2:40 pm - 3:00 pm

3998419: Tribological Characterization of Carbon Composites for High Temperature Gas-Cooled Pebble Bed Reactor

Tomas Grejtak, Wenbo Wang, James Keiser, Nidia Gallego, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

High temperature gas-cooled pebble bed reactors use carbon composite spherical pebbles to encapsulate fuel particles. During operation, pebbles continuously pass through the reactor multiple times before they are discharged. Sliding, rolling, and impact among the pebbles and against the reactor wall cause surface damage and generation of hazardous dust. Tribological behavior of the carbon composite pebbles in these extreme temperatures that can reach 650°C is not well understood. In this work, the sliding wear and friction properties of carbon composite pebbles were characterized using a pin-on-disk configuration. The tests were performed in an argon environment at a range of temperatures up to 650°C. Key parameters such as pebble-on-pebble normal force and sliding speed were estimated from actual operation of the reactor. Morphological characterization and compositional analysis of the worn surfaces were used to determine the underlying wear mechanisms.

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

3:40 pm - 4:00 pm
4001699: Understanding the Biomass Fouling Process on the Screw Feeder for Pyrolysis Reactors
Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Biomass fouling-caused feed line plugging is a major challenge in pyrolysis preconversion. The fouling products are believed to accumulate under combined thermal and mechanical stresses. This work investigated the biomass fouling phenomena via materials characterization, thermal analysis, and experimental validation. A seized screw feeder from an actual reactor was examined to reveal the deposit's morphology, composition, and mechanical properties. Thermal analyses were carried out for both the screw feeder and the conveying biomass using a combined analytical and numerical approach. A bench-scale tribometer was modified to simulate the fouling process with relevant gas environment, temperature, contact pressure, and sliding speed. Results suggested that tailoring the operating conditions, such as a lower contact pressure or a faster sliding, and modifying the screw feeder surface, such as a smoother finish or an anti-sticking coating, could effectively reduce the fouling deposition.

4:00 pm - 4:20 pm
4002597: Lubricant Chemistry Management: the Proactive Solution to Turbine Oil Problems
Matthew Hobbs, EPT, Calgary, Alberta, Canada

Turbines are responsible for 97% of US power generation. The vast majority of this production is from gas and steam turbines, which employ rotating steel shafts that can weigh > 100 tons. Since these are supported by a lubricant, energy availability depends largely on turbine oil performance. Fortunately, many quality turbine oils are available. In general, these are 97 – 99% base oil and 1 – 3% additive (which serves mainly to protect the base oil). Indeed, base oil plays, by far, the most significant role in fulfilling turbine lubrication requirements. Maintaining base oil health should, therefore, be a priority. There has, however, been a recent trend towards allowing oils to degrade, and then altering their chemistries in an attempt to "undo" this harmful breakdown. Evidence suggests that this strategy is problematic, and that turbine performance can best be assured by proactive lubricant chemistry management, which instead maintains base oils so they can perform as intended.

4:20 pm - 4:40 pm
4077163: Impact of the Lubricant Chemistry on Knock Sensitivity of a Gas Engine Running on Hydrogen
Zoe Fard, Thijs Schasfoort, HF Sinclair, Mississauga, Ontario, Canada

Wind and solar power output fluctuates throughout the year. Long term storage of renewable electricity is a big challenge. One possible storage method is conversion of electricity to hydrogen. With a stationary gas engine, the stored hydrogen can be converted back to electricity and useful heat. The combustion of hydrogen, however, comes with its own challenges. Hydrogen ignites easily and burns fast. The risk of pre-ignition and knocking is therefore high. Lubricating oil in the combustion chamber may influence pre-ignition and knocking. In collaboration with a major European OEM, Petro-Canada Lubricants have investigated how the lubricant composition influences the knock sensitivity of an engine running on 100% Hydrogen. A matrix of formulations has been defined and tested at the R&D test bed of the manufacturer. The effects of the lubricant formulation on engine knock as well as lube oil induced pre-ignition have been investigated. This paper describes the test methods and findings.

4:40 pm - 5:00 pm - **Sustainable Power Generation Business Meeting**

Session 6G — 101 H

Tribochemistry III

Session Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

1:40 pm - 2:00 pm
3982296: Tribological Performance and Durability of an In-Situ-Deposited Carbon Tribofilm Derived from Cycloalkane Molecules
Zaid Al Hassan, Harry Wise, Tobias Martin, Shuangbiao Liu, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Wear-protective coatings on tribo-component surfaces are usually applied via vapor deposition methods. Once worn, they can only be restored through component disassembly. In our study, we explored in situ carbon tribofilm deposition using cycloalkane-derived molecules. These molecules, when dissolved in lubricants, can induce tribopolymer formation under stress and temperature at asperities. We tested cyclopropane-carboxylic acid (CPCa) as an additive in polyalphaolefin and dodecane, successfully depositing micron-thick carbon tribofilms in 15 minutes during pin-on-disk testing. These films provided a ten-fold reduction in wear. Even after CPCa removal, these tribofilms continued to provide wear protection for up to 40 hours. Detailed surface examination using Raman spectroscopy helped us unravel the underlying mechanism for such extended durability of these carbon tribofilms. This research suggests a unique approach to provide unlimited replenishment of wear-protective coatings.

2:00 pm - 2:20 pm
4006441: Ultrafast Phonon Energy Dissipation at Multi-layer Graphene Interfaces
Haolei Dai, Tsinghua University, Beijing, China

Phonon is the main source of frictional energy dissipation during the Interfacial van der Waals interactions in graphene interface which holds great potential in achieving superlubricity application. Develop advanced phonon disspation detection technique is necessary for understanding the origin of friction and designing new materials. Here, we observed a greatly enhanced double resonance Raman mode with a distinctive dip-to-peak evolution feature in multi-layer graphene with a home-built broadband coherent anti-stokes Raman spectroscopy. our results may help deepening the understanding of the origins of friction and understand the reason for superlubricity failure due to defect.

Session 6J — 200 DE

Electric Vehicles VI

Session Chair: Cole Frazier, Southwest Research Institute, San Antonio, TX

1:40 pm - 2:20 pm
4000841: Electric Vehicle Testing – Correlation of Benchtop and Rig Tests Using Ester Containing Fluids
Alexei Kurchan, Cargill Inc, Plainsboro, NJ; Gareth Moody, Chris Clayson, David Gillespie, Cargill, Snaith, East Yorkshire, United Kingdom

The testing of electric vehicles using electric drive units offers the best and most realistic data for testing efficiency of gear fluids giving a good insight into performance in the real world and whilst this can be costly, the efficiency boosts obtained by lubricant modifications and variations to components can be evaluated in a range of different driving speeds and loads. This work will discuss the results of EDU

testing of formulations and the benefits of esters whilst also evaluating the importance of simple benchtop tests and how well they can correlate to full size EDU testing.

2:20 pm - 2:40 pm
4005830: High Speed E-Motor Bearings for Electric Vehicles
Jitesh Modi, Schaeffler Group USA, Troy, MI

The performance of electrified powertrains is significantly dependent on their electric motors. Based on performance needs of future Electric vehicles, there are increasing trends of high voltage, compact, lightweight, efficient and high-speed motors. The standard bearings from conventional IC powertrains are not adequate to meet performance requirements of high-speed electric motors. While operating at very high speeds, these e-motor bearings should be capable to handle rigorous motor dynamics of rapid acceleration and deceleration, provide precise shaft guidance and running accuracy, lower NVH and above all higher efficiency with reduced friction and minimal self-heating. Innovative high speed bearing solutions with key design features will be discussed with supporting examples.

2:40 pm - 3:00 pm
3982753: Plastic Thrust Washers Enable Space Savings, Efficiency in Electric Drive Units
Greg Poterala, Solvay Specialty Polymers, Commerce Township, MI

Developers of electric vehicle drivelines are challenged to create systems that deliver maximum driving performance while simultaneously addressing consumer concerns about range anxiety. Efficiencies are gained through design of units integrating the motor, electronics, and geartrain into a single unit. Planetary helical gear sets are growing in adoption due to compact size (lightweighting advantage), power transfer, and noise reduction. Historically metal needle bearings are needed to counter the resultant axial loads. Polyamideimide (PAI) is a moldable, curable plastic with excellent friction and wear properties, making it suitable for plastic thrust washers that can replace metal needle bearings in EDUs. This presentation will illustrate the suitability of PAI in thrust washers for driveline use, including relevant mechanical property data & friction and wear testing. We will also present case history of PAI thrust washer use in serial automotive automatic transmissions

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

3:40 pm - 4:00 pm
4002984: Influence of Ionic Liquids as Lubricant Additives on Electrically-Induced Bearing Damage
Sudip Saha, University of North Dakota, Grand Forks, ND; Jack Janik, German Mills, Robert Jackson, Auburn University, Auburn, AL; Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

In electric vehicles and other applications leakage currents can cross lubricated bearing and gear interfaces to cause significant damage. Electrical arc or plasma initiation causes damage by inducing localized rapid temperature rise and discharge. The discharges may result in micropitting on the surface. Ionic liquids contain charged ions and are known to possess higher conductivity than conventional paraffinic and synthetic oils. Ionic fluids also are shown to improve the friction and wear reducing capabilities of lubricants. Therefore, this study investigates the influence of ionic liquids as additives in PAO-based lubricants on the electrically induced bearing damage. The experiments were conducted using a single spherical rolling element test under a controlled DC current. Initial results showed insignificant benefits of the selected ionic liquids, which may be due to the ionic liquid providing ionic conductive pathways rather than electron or metallic pathways.

4:00 pm - 4:20 pm
3990426: Electrification Effects on Oxidation Performance and Corresponding Changes Dielectric Properties of Drivetrain Lubricants

Joshua Conner, Southwest Research Institute, San Antonio, TX

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

4:20 pm - 4:40 pm
4001995: Shear Stability and Thermal Performance Analysis of Engine Oils for Electric Vehicles
Deepak Veeregowda, Fabio Alemanno, Ducom Instruments, Groningen, Netherlands

As electric vehicle (EV) adoption rises, optimizing lubrication solutions is crucial. Engine oils formulated for EVs are vital for powertrain efficiency and component durability, yet their shear stability is often overlooked. This study assesses and compares shear stability in various EV oils using standard tests like ASTM D4172-B and CEC L-45-99. Applying a custom thermal cycling procedure to the tests reveals differences in friction behavior and thermal properties, both in a Four Ball Tester and KRL Shear Stability Tester. The tribological results were then linked to and justified by the chemical and physical properties of the oils. The results emphasize the importance of choosing EV oils with suitable shear stability for optimal lubrication and system durability. This research aids lubricant manufacturers, engineers, and researchers in selecting appropriate EV engine oils for boundary/mixed lubrication and elastohydrodynamic lubrication applications.

4:40 pm - 5:00 pm - **Electric Vehicle: Engine & Drivetrain Business Meeting**

Thursday, May 23, 2024

Session 7A 101 B

Materials Tribology V

Session Chair: Nikhil Murthy, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

8:00 am - 8:40 am
3998813: The Direct Effect and Slip Strengthening in Nanoscale Rate-and-State Friction
John McClimon, University of Pennsylvania, Conshohocken, PA; Khagendra Baral, Izabela Szlufarska, University of Wisconsin-Madison, Madison, WI; David Goldsby, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Rate-and-state friction (RSF) describes the history-dependent friction seen in many materials. This behavior can be predicted by semi-empirical laws that describe time- or slip-dependent strengthening of the interface. An assumption of these laws is that there is a speed-dependent contribution to the response, referred to as the “direct effect,” which is fully separable from the state effects. Our recent experiments and associated mechanistic modeling suggest that this contention is erroneous, and we will present results of experiments tailored to demonstrate that this is so. Additionally, we will present results demonstrating a phenomenon known as “slip strengthening” is operative at the nanoscale and quantify its effect on interface strengthening. This phenomenon is critical to the validity of an

empirically successful variant of the RSF laws, but mechanistic explanations for its existence are currently lacking.

8:40 am - 9:00 am
4004755: Low Friction Achieved by Diamond-Like Carbon Sliding on Ice Surface
Yuan Liu, Tsinghua University, Beijing, China

Reducing friction between sports equipment and ice surface is crucial for improving performance on ice at the Winter Olympics. With the aim to reveal the underlying mechanism of the friction on ice surface, we investigated the different materials sliding on ice surface. We have demonstrated an amazing finding that the diamond-like carbon (DLC) film has achieved lower friction when sliding on the ice surface. After the DLC film slid on the ice surface, the proportion of sp^2 significantly increased, indicating graphitization in the contact area, ultimately reducing the ice friction coefficient. Moreover, we have characterized the materials surface by sum frequency vibrational spectroscopy (SFG), furthermore, to confirm the arrangement of the water molecules at the surfaces. Here, we propose an innovative friction model considering the arrangement of water molecules. This work may provide a basis for the further study of reducing friction mechanism under water and application of DLC films.

9:00 am - 9:20 am
4082116: PTFE-Cr Systems: Tribofilm Dependance on Counterbody Material
Mark Sidebottom, Faysal Haque, Miami University, Oxford, OH

Certain reinforcing particles (e.g., activated carbon, α-Al_2O_3, etc.) composited with PTFE reduce wear by 3-4 orders of magnitude when slid against 304 SS. Recently, PTFE-Cr, PTFE-Ti, and PTFE-Mn composites achieved similar excellent wear performance when slid against Brass 260. However, these composites showed mixed performance against 304 SS (moderate to ultralow wear). In this study, Cu 110, Zn-galvanized steel, 304 SS, and Brass 260 counterbodies were tested against PTFE-Cr to understand how counterbody properties affect tribological performance. High variation in friction (μ~0.15-0.28) and wear ($8x10^{-9}$ $mm^3/Nm < K < 1x10^{-6}$ mm^3/Nm) were exhibited. Electron microscopy, optical microscopy, profilometry, and surface energy measurements were taken to understand the factors that influenced tribofilm development. Transfer film morphology was highly dependent on the counterbody the PTFE-Cr composite slid against, which likely contributed to the differences in tribological performance.

9:20 am - 9:40 am
4000606: Lubricious Yet Tough Fabric Composites at Cryogenic Temperature by Sulfonated Polyether-Ether-Ketone Reinforcement
Zidan Wang, Tsinghua University, Beijing, China

A novel PTFE/Nomex fiber fabric composite reinforced by sulfonated polyether-ether-ketone (PN-SPEEK) was designed and fabricated, which has comprehensive properties with self-lubricity, high strength and toughness at wide cryogenic temperature range. The tensile strength and toughness were increased by 16.9% and 64.3% at -160°C compared to conventional phenolic-formaldehyde-reinforced fabric (PN-PF). Within the temperature range of -160°C to 25°C, the variation of friction coefficient for PN-SPEEK was flattened between 0.086 and 0.126, which increased dramatically to approximately 0.2 with decreasing temperatures for PN-PF. The transfer film was analyzed comprehensively and thoroughly, demonstrating that the improved stable lubricity was primarily attributed to favorable formation of tribofilm composed of plenty of PTFE and strong chelation between SPEEK and iron base in transfer film. The developed PN-SPEEK is greatly expected for engineering applications.

9:40 am - 10:00 am
3977914: Determining the Rolling Resistance of Golf Balls
Kenneth Budinski, Bud Labs, Rochester, NY

Over the past decade or so, colored golf balls have gained significant popularity. Some golfers believe that the bright colors make the balls easier to find in high grass. Similarity there is a belief among golfers that the colored balls do not roll as good in putting (high rolling resistance) as traditional white balls. This project was initiated to answer that question. The ASTM G194 standard test for determining the rolling resistance of spherical shapes was used to measure the rolling resistance of traditional white golf balls (new and used), new colored balls with a shiny surface finish, and new colored balls with a dull (non-reflective) surface finish. Tests were conducted on simulated grass (carpet) and on a practice putting green at a traditional public golf course. The test ball is rolled down the fixed height ramp and the distance traveled after exiting the ramp is measured. It was determined that shiny colored balls have lower rolling resistance than traditional new white balls.

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

10:40 am - 11:00 am
4006736: Tribological Performances of PEEK Reinforced with Lamellar and Granular Particles
Karl Delbé, Jean Denape, France Chabert, École Nationale d'Ingénieurs de Tarbes, Tarbes Cedex, France; Marie Doumeng, BioTanah, Pau, France; Florentin Berthet, Institut Clément Ader, Albi, France; Olivier Marsan, CIRIMAT, Toulouse, France

PEEK is a polymer used in high-performance engineering, which can be enhanced by adding specific fillers. Granular fillers (SiC and Al2O3) reinforce the mechanical properties, while lamellar fillers (h-BN and graphite) are solid lubricants. This study collected experimental results using the same thermoforming process and tribological parameters and analyzed the effect of the filler's nature, size, and content. The researchers found a link between debris emission and the modification of the interfacial adhesion between the PEEK macromolecules and the reinforcement. High graphite content produced a large amount of wear and debris, while granular fillers or low graphite rates exhibited moderated plastic deformation and slight debris emission.

11:00 am - 11:20 am
4003254: On the Tribology of PEEK-Based Composites
Surojit Gupta, University of North Dakota, Grand Forks, ND

In this paper, we will present some of the recent research in our group on the design and development of polyether ether ketone (PEEK) and particle-reinforced PEEK-matrix composites for different tribological applications in lubrications. In addition, we will present recent research in our group on high temperature tribological studies. The study also quantifies the tribological performance of these materials to explore unique applications where sustainable practices can be implemented using ethanol as a green lubricant, and PEEK as a recyclable polymer. PEEK is a semi-crystalline thermoplastic polymer with high strength, thermal stability, chemical resistance, and wear resistance. Performance-demanding applications usually implement thermosets which are not easily recyclable, whereas thermoplastics are. Hence these new studies will further accelerate the development of PEEK-based composites for demanding applications.

11:20 am - 11:40 am
3984344: An Efficient Testing Strategy for Polymer Materials—Accelerating Data Production Towards AI?
Lais Lopes, Dirk Drees, Pedro Baião, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Erik Schwartz, Sabic HPP, Bergen op Zoom, Netherlands

The tribological properties of engineering polymers are usually characterized by the ASTM D3702 Thrust washer method; a constant pressure and velocity sliding wear test. Although this approach has its advantages, the typical test duration makes it an inefficient method, especially when statistical data are required. We present an alternative approach to data production, that could enable AI to understand

and predict structure-functional property relationships. The multi-station test method produces 10 times more data, and we show sufficient correlation with historic thrust washer data on more than 20 internally lubricated variations. An additional benefit of our methodology is the easy creation of wear evolution graphs for each material, showing distinctly different behavior for different material classes. The high efficiency and low running costs make this an attractive wear production method, helping to develop new formulations, as some additives come under regulatory scrutiny.

Session 7B — 101 C

Condition Monitoring III

Session Chair: Alfredo Garcia, Luval SA, Santiago, Region Metropolitana, Chile
Session Vice Chair: Marc Yarlott, Veolia North America, Vancouver, WA

8:00 am - 8:40 am
4002562: Oil Analysis Addresses Changes in Diesel Engine Design and New Lubricant Formulations
Michael Holloway, SGS, Highland Village, TX

Every year heavy equipment engine manufacturers design product for reduced weight, increased power, lower emissions, and better fuel economy. This seminar highlights changes in the design and how lubricant manufacturers are adjusting to these changes. Oil manufacturers are constantly looking to produce the next generation formula to work in concert with the engine makers. These formulations use new ingredients that require your oil analysis lab to be constantly up to date. This presentation explores the new designs for diesel engines from all the major OEMs as well as what you can expect to see in terms of the oil formulas that are used in these applications and how oil analysis can be used to diagnose issues with new engines and keep an eye on the new oils being introduced.

8:40 am - 9:00 am
3988388: Non-Invasive Detection of Cracks in Bearing Steel Using Ultrasound
Gary Nicholas, William Gray, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom; Marc Ingram, Ingram Tribology Ltd., Carmarthen, United Kingdom

Wind turbine gearbox bearings often fail due to axial cracks linked with white-etching cracks (WECs). Typically, analyzing these failed bearings requires a destructive process where the bearing is sectioned and then examined under a microscope for WECs. This process can be lengthy, especially when searching blindly for areas with high concentration of WECs in large bearings. In this study, ultrasound was trialed as a potential technique to pinpoint regions of high WEC concentrations, facilitating targeted sectioning in those specific areas. WECs were generated within two bearing steel roller specimens using a MPR test rig with critical lubricants. A focused probe was used to transmit ultrasonic waves to the WEC concentrated specimen within a water bath. Amplitude as well as non-linear behavior of ultrasonic reflections were used to deduce the presence of cracks within the roller specimens.

9:00 am - 9:20 am
4004953: Innovative Approach for Evaluating Dispersancy in New Lubricating Oils
Ganesh Natarajan, Sara Rezaee, Ramaratnam Visweswaran, Aparna Bala, Viswa Group, Houston, TX

Soot particles, a common by product of incomplete fuel combustion, often infiltrate the lubricating oil system through gas blowby. Soot contaminated oils lead to wear and the fouling of critical machine components, including injectors and exhaust lines. Lube oils are formulated with Dispersant additives to counter this problem which are designed to keep these contaminants suspended and prevent them from coalescing into larger, filter-clogging particles and minimizing deposition on machinery. For in-

service oils, traditional test methods are available to assess their dispersancy properties. In this study, we have developed a new method for evaluating the dispersancy properties of fresh lubricating oils under different levels of soot contamination. By creating standard samples and assessing them using enhanced blotter spot techniques, this lab developed method enables a comparison of the dispersancy properties of fresh oils across various brands which can lead to informed decision-making.

9:20 am - 9:40 am
4001287: Enhanced Water Separation from Hydrocarbon-based Lubricating Oils with a Novel, Multilayered Hydrophobic, Hydrophilic Coalescer
John Duchowski, Christian Adam, Johannes Staudt, Hydac FluidCareCenter GmbH, Sulzbach, Saar, Germany; Christian Mueller, HYDAC Technology Corporation, Bethlehem, PA

A liquid separator (coalescer) was devised from a multilayered hydrophobic, hydrophilic filter media sheets pleated into a cylindrical structure. The coalescer was applied to extract water from several, differently formulated hydrocarbon lubricating oils in several different applications. Excellent separation efficiencies have been observed with the 32 cSt and 46 cSt turbine lubricating oils. However, and most notably, the separator has proven itself highly effective in extracting water from the highly viscous 220 cSt and even 460 cSt Morgoils where water poses a serious operational problem. Several examples of both the laboratory results as well as practical field applications will be described and discussed.

9:40 am - 10:00 am
4000883: Simplifying Condition Monitoring Starting with Fluid Analysis
Randy Clark, POLARIS Laboratories®, Indianapolis, IN

Today, we have multiple condition-monitoring tools at our disposal. Although each tool is beneficial, the data they provide can sometimes be overwhelming and confined to specific systems, necessitating users to log in to multiple platforms and analyze the combined data to determine the state of the equipment. In this presentation, we will discuss the advantages of integrating condition monitoring tools into a single platform view and generating work orders automatically based on the criteria set by the user.

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

10:40 am- 11:00 am
4003902: Measurement of Wear Debris in Oil Released During Endurance Testing of Bearings and Gears
Kenji Matsumoto, TOYO Corporation, Koto-ku, Tokyo, Japan; Yuji Mihara, Tokyo City University, Setagata-ku, Tokyo, Japan

We have developed a new instrument for measuring wear debris in lubricating oil using the laser shading method. This device has noise immunity, automatic sampling, de-aeration in oil, and remote operation. Using this device, we conducted durability tests on ball bearings and gears and continuously measured particles in the oil during the tests. The results showed that the measurement method was effective in monitoring the condition of the gear during sliding. In the future, this device could be used to monitor the condition of rotating parts in remote locations to detect failures before they occur and to keep maintenance costs low.

11:00 am - 11:20 am
4085308: Development of Oil Monitoring System for Construction Machinery — Investigation of Monitoring Method of Biodegradable Hydraulic Oil and Monitoring System Using Color Difference Sensor
Hideki Akita, Hiroki Ensyuu, Michio Sugawara, Akira Kurasako, Hitachi Construction Machinery Co., Ltd., Tsuchiura, Japan

Currently, oil condition monitoring systems are in operation for hydraulic oil and engine oil in construction machinery. This system is in operation almost all over the world, with the exception of some regions, and the number of units in operation has reached 0,000 and is increasing every year. This system utilizes IoT to “visualize” oil status changes and notify customers of sudden abnormalities. In this time, we will report on the following: (1.) Proposal of monitoring methods other than mineral oil and their results; (2.) Current status of sensors other than physical quantity sensors, including color difference sensors and (3.) Possibility of a stand-alone oil condition monitoring system.

Session 7C — 101 D

Metalworking Fluids I

Session Chair: Nicole Clarkson, Barentz North America LLC, Lisle, IL
Session Vice Chair: Stephanie Cole, Münzing North America, LP, Bloomfield, NJ

8:00 am - 8:40 am
3989978: The Role of Metalworking Fluid Microbicides in an Increasingly Restrictive Regulatory Environment
Frederick Passman, Biodeterioration Control Associates, Inc., Princeton, NJ

During the past two decades, regulatory pressures against the use of microbicides in water miscible metalworking fluids has increased substantially. As a consequence of these pressures, the variety of available active substances has shrunk dramatically since 2000. In particular, regulatory agencies have conflated formaldehyde-condensate and formaldehyde toxicity. This presentation will review the history of metalworking fluid microbicide regulation—highlighting restrictions on formaldehyde-condensate microbicide use. It will also review the most commonly used active substances and the importance of testing microbicide efficacy in each metalworking fluid formulation in which a particular active substance will be used.

8:40 am - 9:00 am
3980496: The Added Value of Friction Measurements in the Pin & Vee Block Method
Lais Lopes, Dirk Drees, Pedro Baião, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium

The popular standard Pin & Vee block test method is mainly used to determine forming or cutting lubricants' EP quality by testing until failure of the pin. This is the easiest way to run a test, but it can cause large variation in data because of minor variations in specimen strength and the stochastic nature of catastrophic failure. Besides, the lubricant behavior before catastrophic failure is equally important. Past researchers have used an initial increase of friction, 'torque pop-up', as additional lubricant performance information, but previously it wasn’t easy to measure frictional torque accurately. The new generation Pin & Vee machines measure temperatures, frictional torque and the dimensional wear (wear teeth) online and allows us to gain more information out of the simple test setup. In this paper, the stochastic nature of the failure event is shown, and the improvements gained by recording the full data available from the instrument, as it correlates to tapping operations.

9:00 am - 9:20 am
3984273: Improving the Sustainability of Metal Cleaners with Ether Carboxylic Acid
Jan Nilles, Kao Chemicals GmbH, Emmerich am Rhein, Germany

Sustainability is one of the key drivers for the development of next-generation metal cleaning formulations. However, improved sustainability must not come at the expense of performance. Ether carboxylic acids are multifunctional high-performance additives and improve the overall performance of

water-based cleaners. These readily biodegradable surfactants are able to extend the lifetime of the cleaning bath significantly by enhancing the tolerance against electrolytes and hard-water ions. Longer bath lifetime results in both less raw material and fresh-water consumption and minimized waste streams. The reinforcing effect of ether carboxylic acids on cleaning performance enables a higher throughput of cleaning cycles to realize a more ecological process. Combining better cleaning performance and the hydrotropic effect to adjust the cloud point allows to reduce the cleaning temperature. Balancing all the described beneficial effects will be key for developing sustainable metal cleaners.

9:20 am - 9:40 am
3987468: Sustainability Strategies from the Perspective of a Performance Additive Manufacturer
Michael Stapels, Kao Chemicals GmbH, Emmerich, Germany

While for decades optimum performance and a competitive price were the decisive factors for the success of a cooling lubricant on the market, sustainability aspects have recently come into focus. In particular, factors such as the product carbon footprint as well as renewable carbon content are at the center of these discussions. The presentation will address various strategies for formulating more sustainable metalworking fluids like, for example replacing mineral oil-based feedstocks by renewable or refined ones. The performance evaluation of this alternatives will lead in a critical discussion if the predominant focus on the carbon footprint always results in the most sustainable solution.

9:40 am - 10:00 am
3987878: Petrolatum- and Sulfonate-Free Coatings for Long-Term Outdoor Corrosion Protection
Amelia Hadler, Christopher Kabb, David Nickerson, Maria Shepherd, Britt Minch, The Lubrizol Corporation, Wickliffe, OH

Heavy duty rust preventives are used for long-term corrosion protection in applications such as underbody coatings for cars and trucks and maintenance coatings for outdoor metal frameworks or equipment. While these products offer excellent corrosion protection, their technology has remained unchanged over the years and largely relies on petrolatum- and sulfonate-based formulations, which can be dark in color, difficult to handle, and often show poor UV stability due to the chemical components used. This talk introduces a new polymer-based coating that is free of petrolatum and sulfonate chemistry, forming a clear, dry film with excellent corrosion protection and UV stability. This versatile technology is easy to handle and can be diluted in solvent and formulated with common additives to enhance usability and protection.

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

10:40 am - 11:00 am
3993724: Towards a More Realistic Approach to Ranking Lubricant Emulsions and Tool Metallurgies with ASTM D-3233A Pin & Vee Block Method
Lais Lopes, Dirk Drees, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Emmanouil Georgiou, Hellenic Air-Force Academy, Athens, Greece

ASTM D-3233A uses a Pin & Vee Block setup to evaluate the performance of cutting fluids. However, this procedure uses a specific steel-steel contact and a small volume of lubricant in a cup. In our previous work, we have modified this method to include different metallurgies (aluminum pins versus steel blocks) and tested with aqueous emulsions, rather than formulated oils. However, to go even closer to a cutting/forming application we have coated the Vee Blocks using electrodeposition and thermal spraying methods, to simulate existing cutting/forming tools used in the field. The aim is to investigate the effect of surface metallurgy on the performance (torque relates to energy consumption during manufacturing) and wear resistance of the cutting/forming tool. This modified approach attempts to provide an additional cost and time efficient method for ranking of cutting fluids and cutting/forming

metallurgies, based on a setup that is already extensively available in the lubricants industry.

11:00 am - 11:20 am
3999427: Machining High-Alloyed and Stainless Steel Without Chlorinated Paraffins
Wilhelm Rehbein, LANXESS Deutschland GmbH, Mannheim, Germany

Chlorinated paraffins prevent adhesive wear between metal surfaces by forming pressure stable adsorption layers under standard metalworking conditions. However, with increased machining speeds, they tend to decompose and can cause chemical wear. Sulfurized esters or olefins are another class of commonly used EP additives that are versatilely used to reduce friction and to prevent adhesive wear in metalworking processes. Compared to chlorinated paraffins, sulfur carriers show many benefits in terms of toxicity, environmental impact and energy efficiency. Despite it is possible to replace chlorinated paraffins by sulfur carriers in most metalworking applications, it's still difficult to achieve a similar performance when machining high-alloyed or stainless steels. Based on tribological test results, the presentation shows how it is possible to meet or exceed the performance of chlorinated paraffins by chlorine-free metalworking fluids when machining high alloyed or stainless steels.

11:20 am - 11:40 am
3998301: A Comparative Analysis in Metalworking Fluids
James Justice, John Deere, Moline, IL

There is always a risk associated with change. With new technologies constantly being developed in the arena of metalworking fluids, there are some headwinds in evaluating and implementing different technologies. In a large-scale global production environment, the risk to possible increases in maintenance, downtime, scrap rates and other costs associated with a process change need to be mitigated. Our company has been on a multi-year journey to utilize and develop a set of tests to evaluate metalworking fluids prior to pursuing an in-production trial. This activity included baselining current technology both used within and outside of our factories. This is being utilized to move towards more aligned product chemistry in manufacturing and a globally scalable strategy. In addition, this data is being leveraged to attempt to predict improvements in other performance aspects of metalworking fluids beyond product cost to drive value from a TCO (Total Cost of Ownership) perspective.

11:40 am - 12:00 pm
3993483: Naturally Derived Surfactants for Multiple Uses In Metalworking Fluids
Garret Bryant, Lucas Moore, Jordan Taylor, Colonial Chemical, South Pittsburg, TN

Metalworking fluids (MWFs) are applied to control temperature, reduce tool wear, ensure product quality, and make it possible to increase productivity. Generally, this is accomplished by combining a series of chemistries to bring the combined synergistic benefit desired by the overall fluid. Emulsion based MWF are typically very complicated and can contain upwards to ~ 7 individual components, including corrosion inhibitors, biocides, coupling agents, lubricity aids, emulsifiers, and oil emulsified in water. A series of naturally derived, modified Alkyl Polyglucoside (APG) chemistries were developed with the desire to reduce the complexity of these MWF emulsions by providing a single chemistry that is multifunctional and can be used as a corrosion inhibitor, emulsifier, and friction Reducer. This presentation will focus on the evaluation of these chemistries in such applications.

Session 7D — 101 E

Rolling Element Bearings II

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

Session Vice Chair: Travis Shive, SKF USA Inc., Lansdale, PA

8:00 am - 8:40 am
3985471: A Novel Multiphase CFD Model for Investigating the Flow Dynamics of Aerated Bubbles in Bearing Lubrication
Ujjawal Arya, Farshid Sadeghi, Purdue University, Lafayette, IN

This study delves into the intricate flow dynamics of aerated bubbles within lubricating oil during bearing operation. To achieve this objective, a novel Computational Fluid Dynamics (CFD) model was prepared in Ansys Fluent, which simulates the movement of these bubbles within the bearing chamber. This model utilizes a coupled solver that incorporates a two-way transition algorithm between the Discrete Phase Model (DPM) approach, which was used to model bubble dynamics, and the Volume of Fluid (VOF) approach, which was used to depict oil starvation inside the cage pocket. Results from this CFD model were validated with the experimental observations for the bubble motion from the Counter Rotating Angular Contact ball bearing Test Rig (CRACTR). This coupled CFD model demonstrates an efficient and thoroughly validated modeling approach to examine the complex phenomenon of multiphase oil flow in bearing lubrication, adeptly accounting for the impact of both aeration and oil starvation.

8:40 am - 9:00 am
4000809: Lubrication of Cylindrical Roller Bearing Cage Pockets in Oil Bath Environment
Saeed Aamer, Farshid Sadeghi, Purdue University, West Lafayette, IN

This investigation aims to determine the effects of cage pocket conformality on lubrication in a cylindrical roller bearing (CRB) cage. A custom Bearing Cage Friction Test Rig (BCFTR) was configured with a sealed enclosure to emulate a lubricant bath environment. The enclosure includes CRB raceway segments and swappable cage pockets with adjustable pocket clearance. Three transparent cage segments were fabricated with differing pocket conformality with respect to the roller surface. A camera was used to visualize the in-situ lubricant flow within the roller-pocket contact for all cage types. An equivalent two-phase computational fluid dynamics (CFD) model was developed using Ansys Fluent software. The findings demonstrated that the impact of pocket conformality was two-fold. The least conformal pocket design experienced minimum pocket friction. However, the same design introduced challenges with retaining lubricant at the roller-pocket contact and increasing air entrapment in the oil.

9:00 am - 9:20 am
3986614: In-Situ Measurement of the Inlet Meniscus Position and Contact Starvation
William Gray, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

Roller bearing starvation occurs when there is inadequate lubricant present at the contact inlet, which leads to an insufficient separating film and surface wear. The level of starvation can be determined by the position of the inlet meniscus, where the raceway and roller films meet. However, a measurement of this position is difficult as the meniscus is thin, in the micron range, occurs over a very small area, and is hidden deep within the rotating bearing. In this work, an ultrasonic technique is developed to measure the raceway film at the contact inlet in-situ. Then, using the theoretical roller film, the thickness of the meniscus is calculated. A Volume Fill Model is introduced which determines the position of the inlet meniscus from its thickness. Results show that load has a surprisingly large influence on starvation, due to contact area enlargement, making it harder for the meniscus to form an adequate distance away from the contact center to allow ample separation.

9:20 am - 9:40 am
3989802: In-Situ Measurement of EHL Film Temperature in Cylindrical Roller Thrust Bearings Using Thin-Film Sensors
Manjunath Manjunath, Patrick De Baets, Dieter Fauconnier, Ghent University, Ghent, East Flanders,

Belgium; Martin Rekowski, Marcel Plogmeyer, Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig, Germany

We investigate the in-situ measurement of contact temperature in EHL in cylindrical roller thrust bearings (CRTB) using resistive thin-film sensors. The sensors, optimized for size and spatial resolution, are strategically embedded at various locations on the stationary bearing washer near the outer radius, the inner radius, and at the mean radius. This configuration should enable the measurement of temperature rise in both pure rolling and rolling-sliding regions of the CRTB. We plan extensive tests to explore how loads, speed, and supply oil temperature affect the temperature rise profile within the EHL film. Due to the higher slide-to-roll ratio at the washer's inner and outer radii, temperature profiles are expected to differ from the center, with higher peak temperatures. The measurements provide valuable insights into CRTB-lubricated contacts for the given operating conditions and serve as validation data for advanced TEHL computational tools developed in the same group.

9:40 am - 10:00 am
4000280: Study on the Tribological Properties of Rolling Bearing under Lubrication with Diketone Lubricants
Shaonan Du, Chenhui Zhang, Tsinghua University, Beijing, China

As an important executive component, angular contact ball bearings have strict requirements on their lubrication performance. This paper studied the effects of lubricant viscosity and type, loading force, bearing speed and lubricant addition amount on bearing friction coefficient. The morphology and composition of the bearing surface were analyzed through SEM and XPS. Systematic experimental results show that the reduction of lubricant viscosity, the increase of axial loading force, and the reduction of lubricant addition amount all contributed to the reduction of bearing friction coefficient. The friction coefficient of bearings lubricated by diketone lubricants was the lowest 0.00035, which was 86.4% lower than that of PAO lubricants of the same viscosity. Surface analysis found that when the lubricant contained components that can react with the bearing, corrosion pits will appear on the surface of the lubricated bearing balls.

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

10:40 am - 11:00 am
4002987: Micropitting, Macropitting, and Scuffing Using Commercial Wind Turbine Greases
Robert Erck, Nicholaos Demas, Aaron Greco, Argonne National Laboratory, Lemont, IL

In this work, a benchtop test rig utilizing a three-ring-on-roller test configuration was used to investigate the efficacy of using two commercial wind turbine greases to reduce both micropitting and macropitting damage on high quality bearing steel samples. The greases incorporated Li complex thickeners with synthetic base oil viscosity of 460 cSt at 40 C. Two ring roughnesses and five grease resupply rates were used. Roller morphology was studied at four intervals during the runs, and reported results include roller images as a function of cycles (typically 0-5 Mcycle), ring images, and graphs of traction coefficients and roller roughnesses as a function of running time.

11:00 am - 11:20 am
4004386: Transfer Film Formation in Dry-Lubricated Rolling Contacts Based on Molybdenum
Dennis Konopka, Florian Pape, Gerhard Poll, Institute of Machine Design and Tribology, Garbsen, Lower Saxony, Germany

Rolling bearings are conventionally lubricated with oil and grease. Dry lubricants, extending the application range, become essential when oil or grease application is impractical. Solid lubricants must reduce friction and wear in machine elements. This study focuses on a molybdenum-based dry lubricating coating applied to bearing steel via PVD. The system includes a molybdenum reservoir with a

top layer of molybdenum trioxide, crucial for lubrication and run-in. The goal is continuous regeneration of this top layer via tribo-oxidation. Prior research showed reduced friction, extended operating time, and reduced wear*. This study applies the coating to complex geometries using commercial radial cylindrical roller bearings. Experiments increased operating time and reduced wear. Material analysis methods (SEM, EDX) helped understand dry lubricant transfer and distribution to bearing components, protecting against wear and system failure. *Konopka et al.: doi.org/10.3390/coatings12050591

11:20 am - 11:40 am
4016219: High Speed E-Motor Bearings for Electric Vehicles
Jitesh Modi, Schaeffler Group USA, Troy, MI

The performance of electrified powertrains is significantly dependent on their electric motors. Based on performance needs of future Electric vehicles, there are increasing trends of high voltage, compact, lightweight, efficient and high-speed motors. The standard bearings from conventional IC powertrains are not adequate to meet performance requirements of high-speed electric motors. While operating at very high speeds, these e-motor bearings should be capable to handle rigorous motor dynamics of rapid acceleration and deceleration, provide precise shaft guidance and running accuracy, lower NVH and above all higher efficiency with reduced friction and minimal self-heating. Innovative high speed bearing solutions with key design features will be discussed with supporting examples.

Session 7E — 101 F

Environmentally Friendly Fluids II

Session Chair: Selim Erhan, Process Oils, Inc., Trout Valley, IL
Session Vice Chair: Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA

8:00 am - 8:20 am
4078856: The Most Sustainable Way to Recycle Used Motor Oil
Uyen Le, Sherry Guo, Blue Tide Environmental, Baytown, TX

Used motor oil (UMO) is a potential hazard if it is not properly disposed of, but it can also be recycled into valuable products, contributing to sustainability. The recycling process consumes less energy and reduces emissions compared to traditional refining from crude oil. However, UMO, coming from different sources and containing contaminants, poses challenges to the recycling process, affecting the yield and quality of re-refined oil. To ensure high-quality recycled products, a fit-in-purpose screening process must in place to ensure to comply with regulations and be compatible with the refinery's design and technology. Enhancing technology and optimizing the re-refining process, including pre-treatment and advanced processes, makes UMO recycling more efficient. The high-quality products (VGO, Base Oil) from the recycling process can be used as valuable feedstock for other refining processes or as the primary ingredient for finished lubricants, which will be returned to consumers.

8:20 am - 8:40 am
4000928: A Comparison of Life Cycle Assessments (LCA) for Different Types of Estolide Production
Travis Thompson, Biosynthetic Technologies, Indianapolis, IN

The Life Cycle Assessment (LCA) tool is becoming increasingly important for characterizing the environmental impact of raw materials. Procurement teams today are inundated with vague terms like sustainability, bio-based carbon, and reduced emissions, oftentimes without understanding the validity or even the meaning of such claims. With the LCA tool, such terms can be better understood, allowing

for more meaningful interpretations and comparisons. In this project, two cradle-to-gate LCAs were created for estolide products that use different feedstocks and manufacturing processes. Feedstocks such as coconut oil, soybean oil, and castor oil have been considered, as well as batch versus continuous processing. This report serves to compare the LCAs and discuss their differences.

8:40 am - 9:00 am
4004831: U.S. Soy: The Sustainable Solution for Lubricants
Ray Balee, Omni Tech International, Midland, MI

As one of the most readily available vegetable oils globally, U.S. soybean oil has continued to be a significant ingredient in lubricants. Renewable by nature, soybean derivatives are economical, consistent in quality and a reliable material. U.S. Soy is currently used as a raw material in thousands of products with diverse applications. The United Soybean Board is committed to bringing insight to companies fulfilling sustainability and supply chain goals while supporting development of new applications and improving products utilizing U.S. grown soy. Due to disruption in supply logistics, companies are rethinking their material supply sources for the future. Soybean oil has relatively stable production volumes year to year and has vast growing acreage and crushing facilities versus other seed oils. This translates to shorter supply chain and lower carbon footprint.

9:00 am - 9:20 am
4004976: Biobased Base Oils for Lubrication Fluids
Lloyd Nelson, Amanda Marquez, Kraton Chemical, Savannah, GA

Pine chemistry has been leveraged to develop SYLVASOLV™, 100% biobased content hydrocarbon oils with high solvency to compatibilize difficult-to-solubilize additives. The high solvency allows for effective solubilization of a wide range of lubricant additives in less time and at lower temperatures when compared to alternatives, while demonstrating outstanding compatibility with standard base oils. Sourced from responsibly managed forests, SYLVASOLV oils are 100% biobased, with a minimal carbon footprint. Additionally, these oils exhibit non-flammability and minimal VOC (CARB LVP-VOC certified). Our discussion will cover formulating metalworking fluids and automotive lubricants with SYLVASOLV. We will showcase how biobased hydrocarbon oils can enhance lubrication formulations by enabling the use of challenging high-performance additives. We'll also delve into their electrical, thermal conductivity, and hydrolytic stability.

9:20 am - 9:40 am
4000930: Biobased Ionic Liquid for Conductive Lubricants
Pieter Struelens, Oleon NV, Evergem, Belgium

Ionic liquids have gained significant attention as promising lubricant additives due to their unique physicochemical properties. Despite the advantages that it will bring in terms of performance, they are known to be toxic and poorly soluble, limiting their applications. In this study, a novel, sulphur- and halogen-free ionic liquid was developed from renewable materials and designed to possess a tailored structure, enabling enhanced solubility and anti-wear characteristics. Benchmarking revealed that this novel IL demonstrates superior performance in terms of solubility, friction and wear reduction. Further, no corrosion on Cu surfaces was observed. Moreover, the biobased IL showed a substantial reduction in resistivity when used various base oils, showing the potential of minimizing the charge build-up and offering electrostatic discharge protection. Overall, this study presents a novel biobased ionic liquid that exhibits exceptional solubility, anti-wear, and conductivity characteristics

9:40 am - 10:00 am
3984321: Using Molecular Modelling to Anticipate Future Toxicity Classifications of Antioxidants and Identify Safer Compounds

Siegfried Lucazeau, NYCO, Paris, France

A recent change in the toxicity classification of a classical aminic antioxidant has raised questions on the long term innocuity of other aminic antioxidants. Should we expect more classifications in the near or remote future? Do phenolics represent a safer alternative in the long run? How can we anticipate the toxicity features of other antioxidants? Computational chemistry and molecular modelling have been used to estimate the probability of a compound to show toxic features like reprotoxicity, carcinogenicity, mutagenicity or even neurotoxicity. The results of extensive evaluation work tend to show that there may not be safe, long-term solutions in the realm of classical aminic or even phenolic antioxidants. However, it appears like some specific oligomeric compounds do show a favorable toxicity profile. Supporting data from in-vitro and in-vivo testing confirm such observations, giving a high level of confidence in this new, future proof antioxidant species.

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

10:40 am - 11:00 am
4004954: Synthesis and Lubricant Properties of Isostearic and Isooleic Based Biolubricants
Brajendra Sharma, Majher Sarker, Helen Ngo, Michael Powell, USDA/ARS/NEA/ERRC, Wyndmoor, PA

The structure of biolubricants impacts physicochemical and tribological properties. Trimethylolpropane (TMP) esters of isostearic and isooleic acids have been synthesized via esterification reactions and characterized using FTIR, NMR, GC-MS, and LC-MS. The presentation will also discuss the lubricant properties including physicochemical and tribological properties. These TMP esters were found to have higher oxidative stability, better antiwear properties, and improved cold flow performance compared to high-oleic sunflower oil (HOSUN) and polyalphaolefins (PAO). These are also miscible with HOSUN and PAO, therefore can be blended to formulate biolubricants.

11:00 am - 11:20 am
4002699: Evaluation of the Interaction Between Biofuels and Lubricating Oils in Achieving IMO's GHG Reduction Goals
Sara Rezaee, Ganesh Natarajan, Aparna Bala, Ramaratnam Visweswaran, Viswa Group, Houston, TX

The IMO's greenhouse gas reduction strategy sets ambitious targets, aiming for a 20% reduction by 2030 and a more aggressive 70% reduction by 2040. In the maritime sector, biodiesel and renewable diesel stand out as promising alternative fuels. They can be readily blended with marine fuels with no or minimal engine infrastructure modifications. Currently, lubricating oils used with biofuels are identical to those for residual fuels. During regular engine operations, it is common for a small volume of incompletely combusted fuel to enter the crankcase and contaminate the system oil. This leads to fuel dilution and potential degradation of lubricating oil quality. Limited information exists on the interaction between lubricants and biofuel blends. This study aims to address this gap through comprehensive testing of operational and performance properties to better understand the interaction between biofuels and lubricating oils, thus assisting informed decision-making.

Session 7F — 101 G

AI and Machine Learning I

Session Chair: Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI
Session Vice Chair: Prathima Nalam, SUNY at Buffalo, Buffalo, NY

8:00 am - 8:40 am

4013926: From Empiricism to Strategy: Targeted Development of Hybrid Plastic-Based Tribological Materials by Combining an Interlocking Experimental Technique with Artificial Neural Networks
Alois Schlarb, RPTU, Kaiserslautern, RPL, Germany

The characterization of tribological systems involves a great deal of effort. If one wants to reproduce a realistic load spectrum to some extent during evaluation of materials, several months of test time must be planned for a single material pairing. This time and cost factor can be significantly reduced by using a new type of intelligent testing technology. However, in order to optimize the tribological pairings, the test results must be appropriately linked to the load spectra. The talk presents a systematic analysis of research results on the use of polymer-based hybrid materials based on the understanding of different wear mechanisms in sliding contact with steel. The use of artificial neural networks in combination with an intelligent experimental technique to reliably generate large amounts of data enables the step from empiricism to strategy (i.e., to systematically optimize materials for tribological applications to different load collectives by their material composition).

8:40 am - 9:00 am
3999074: Transparent Data-Driven Predictions for Formation and Friction of Tribo-Sintered Metal Oxide Antiwear Coatings
Parker LaMascus, Daniel Delghandi, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Marjeta Fusha, Lei Zhang, Robert Wiacek, Pixelligent Technologies, LLC, Baltimore, MD

We utilize machine learning techniques to investigate the key drivers of metal oxide tribocoating formation. Dispersed metal oxide nanocrystals will undergo tribosintering for a variety of tribological conditions, creating durable surface-bound layers that prevent failure. Despite the benefits of metal oxide tribocoatings being seen in a huge diversity of experimental conditions and lubricant formulations, the underlying mechanism of tribosintering is not well understood. We synthesize 6 years' worth of experimental data on metal oxide tribocoatings using machine learning techniques and principles of FAIR (Findable, Accessible, Interoperable, Reusable) data management. We discuss the interpretability and transparency of data-driven predictions, and use these techniques to move toward more rigorous models for the friction and formation of tribosintered metal oxide coatings.

9:00 am - 9:20 am
4002132: Unlocking the Potential of Ensemble Machine Learning in Tribology
Max Marian, Sangharatna Ramteke, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile; Naveen Venkatesh S., Sugumaran Vaithiyanathan, Vellore Institute of Technology, Chennai, India

Ensemble Machine Learning (ML) methods combine the predictions of multiple ML models to enhance overall performance. The presentation will discuss two exemplary cases in the context of tribological applications and condition monitoring. In the first use case, we explore the application of ensemble deep learning methods to extract features from scanning electron microscopy images of wear particles obtained from engine oil. In the second case, we focus on intelligent fault diagnosis from vibration data of dry friction clutch systems. In both cases, we demonstrate how ensemble ML can extract nuanced patterns and relationships in either image or vibration data, leading to more accurate and reliable and robust predictions compared to conventional, individually trained ML algorithms.

9:20 am - 9:40 am
3979196: Machine Learning Assisted Condition Monitoring Using Acoustic Emission Technology on Rotating Mechanical Components
Nikhil Murthy, Vincent Coburn, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Reece Teramoto, Mathworks, Natick, MA

The capability to detect and classify faults in rotating mechanical components would allow for more reliable and less wasteful maintenance practices for many systems. One method of detection is the use of high frequency acoustic emission sensors which has been proven to be a useful method for detecting tribological phenomena however classification of faults with these sensors are difficult and require the interpretation of many complex features within the signal. This study explores machine learning techniques as a method to classify mechanical faults base on the acoustic emission signal. We use acoustic emission data from seeded fault and full life durability experiments performed on a high-pressure fuel pump to train and validate several models. We will discuss the merits of different machine learning methods, the intricacies of training the models, and their applicability in different experimental scenarios.

9:40 am - 10:00 am
4004342: Grinding the Gears of Knowledge: and End-to-End Framework for Tribological Data
Ilia T. Bagov, Christian Greiner, Nikolay Garabedian, Karlsruhe Institute of Technology, Karlsruhe, Germany

Tribological systems are influenced by an enormous number of external factors. That's one of the major reasons why reproducibility of tribological results has been a long-standing challenge. Data science and computational statistics offer a way to handle this complexity. For the success of such approach data quality and the digitalization strategy play key roles. We use the FAIR (Findable, Accessible, Interoperable, and Reusable) data principles as a guide for how to approach the challenges of R&D data. We present an end-to-end solution which enables researchers to describe, store, and connect their datasets. Our suite consists of a terminology service for metadata definition, as well as a module which automatically annotates tribological experiments using these schemas. Additionally, we provide a ready-to-use suite of analytical solutions, which creates reports about the data sets' contents or applies advanced analytical methods such as machine learning to provide additional insights.

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

10:40 am - 11:00 am
3980467: Gaussian Processes Regression: A Powerful Machine Learning Tool for Elastohydrodynamic Film Thickness Predictions
Wassim Habchi, Lebanese American University, Byblos, Lebanon

A general Machine Learning (ML) framework is presented here for lubricant film thickness predictions in elliptical elastohydrodynamic (EHD) contacts. Finite element (FEM) simulations are used to generate substantial training and testing datasets that are used within the proposed ML framework. The proposed ML model consists of a pre-processing stage in which conventional EHD dimensionless groups are used to minimize the number of inputs to the model. The core of the model is based on Gaussian Process Regression (GPR); a powerful ML regression tool, well-suited for small-sized datasets. The last stage is a post-processing one, in which the output film thicknesses are retrieved. The results reveal the capabilities and potential of ML; producing quasi-instantaneous predictions, that are far more accurate than conventional film thickness analytical formulae. Produced central and minimum film thickness predictions are on average within 0.3% and 1.0% of the FEM results, respectively.

11:00 am - 11:20 am
4005195: Prediction of Slender-like Elastohydrodynamic Contacts by Machine Learning Methods
Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile; Marko Tosic, Thomas Lohner, Technical University of Munich, Garching, Bavaria, Germany

Slender-like elastohydrodynamically lubricated (EHL) contacts are characterized by a small angle between the main lubricant entrainment direction and the major axis of the elliptical contact. In this work, we introduce Machine Learning (ML) approaches, including artificial neural networks, which have

been trained using a large dataset obtained from numerical EHL simulations. These ML models were designed to predict the behavior of slender-like EHL contacts with varying directions of lubricant entrainment, along with several other stress-related parameters, such as external load conditions, materials, etc. Thereby, we not only focus on the overall prediction performance and optimizing the ML hyperparameters, but also on achieving highly accurate local predictions within the parameter space and explore approaches to systematically expand and refine the existing dataset with the aim of improving model generalization and local accuracy.

11:20 am - 11:40 am
4000228: Artificial Intelligence in Simulation and Model Generation
Hannes Grillenberger, Andrei Degtiarev, Schaeffler Technologies, Herzogenaurach, Germany

Methods of Artificial Intelligence are increasingly introduced in our daily life of app and internet use. This presentation shows possibilities on the usage of some of these methods in the workflow of CAE tools. Simulation is becoming more and more important and are thus its usage needs to be re-invented in the age of AI. Simulations are crucial in the current design process as they can reduce time and costs. For example, the Bearinx Simulation Suite or the FVA Workbench are tool packages that focus on simulations of bearings in systems. These programs are constantly expanded to better predict bearing performance – like friction, NVH, dynamics, rating life. However, many people need to perform simulations and build simulation chains to fully use this potential. This process should be accelerated and simplified in usage. This could result in faster results, more simulations and possibly higher design quality. AI can make an important contribution to accelerate and simplify this process.

Session 7J — 200 DE

Electric Vehicles VII

Session Chair: Peter Lee, Southwest Research Institute, San Antonio, TX
Session Vice Chair: Hyeok Hahn, Chevron Lubricants, Richmond, CA

8:00 am - 8:40 am
4036435: Synergies of Surface Finish, Coatings & Additive Chemistry on Friction and Wear at the Piston Ring and Cylinder Liner Interface
Lake Speed, Total Seal, Phoenix, AZ

Utilizing Formula 1 and NASCAR piston ring technology, SwRI and Total Seal tested various piston ring face coatings (5), cylinder liner surface finishes (5) and engine oil additive chemistries (5) to evaluate the impact of each variable on the friction and wear of the piston ring and cylinder liner interface. A Plint TE-77 reciprocating rig was used to test the various piston ring and cylinder liner sections as well as different oils. SEM, EDX and ICP testing were also completed on the used liner sections and used oil samples respectively. Whilst the amount of data generated from these tests was immense, distinct patterns did emerge and certain synergies between variables became clear. By utilizing these synergies, the rate of wear was reduced by over 80% and Friction could be reduced by more than 50%. This presentation will cover the details of which coatings, surface finishes and additive chemistries were evaluated.

8:40 am - 9:00 am
4045651: Lubricants for Electrified Commercial Vehicle Part I — Benchmarking Transmission Efficiency: An Investigation and Correlation of Bench Tests and Axle Efficiency Rig Test
Hyeok Hahn, Kuldeep Mistry, Chevron Lubricants, Richmond, CA

The shift to electric vehicles demands a complete rethink of driveline hardware. Moreover, electrification is transforming driveline architecture in iterations by different OEMs, as commercial vehicle electrification expands, the performance demands on lubricants increase for this new paradigm of electrified trucks, especially on axle efficiency is critical. Traditional axles prefer higher viscosity fluids (SAE 75W-80 and above) for extended component durability, whereas the oil-cooled e-motor prefers low viscosity fluids (kinematic viscosity at or below 6 centistokes at 100°C) to minimize power loss. Thus, understanding fluid properties in both systems is crucial. This study aims to align axle oil and e-motor coolant by screening lubricant formulation with different additives, optimizing composition, and correlating bench and axle efficiency rig tests. The goal is to develop formulations meeting the specific needs of electrified drivetrains for superior performance and efficiency.

9:00 am - 9:20 am
4077174: Lubricant Durability Evaluation in a 15L Hydrogen Internal Combustion Engine
Vickey Kalaskar, Southwest Research Institute, San Antonio, TX

This study implemented an SI, 15L Daimler H2-ICE engine based on their diesel engine platform. This study aimed to understand the lubricant durability aspect. Lubricant durability in H2 ICEs is a novel topic and has not been studied primarily due to continual fueling supply challenges for such extended hours. Nonetheless, SwRI has recently installed a liquid H2 facility capable of supplying H2 without disruptions and is currently running an extended test on the engine to understand the long-term test impacts on lubricant properties. The engine is operated over a modified RMC-SET cycle that is repeated multiple times over the 500-hour timeframe and intermittent oil samples are captured to track lubricant properties as a function of time. Several ASTM methods are used to assess the lubricant samples. The test method development, approach, and generalized test sample results are presented in this presentation.

9:20 am - 9:40 am
4070788: Design and Characterization of Environmentally-Friendly Heat Transfer Liquids for Electric-Vehicle Battery Packs
Ioannis Karathanassis, City, University of London, London, United Kingdom

Electric vehicle battery thermal management systems typically comprise indirect cooling using air or water-glycol configurations. High battery discharge rates can generate sufficient heat to overwhelm indirect cooling necessitating a direct cooling strategy that removes the need for heat transfer across a solid interface. In addition, regulations for reducing use of fluorocarbons, often used as coolants, requires consideration of environmentally friendly fluids with low global warming potential. Herein we report methodologies implemented for the design and assessment of novel oil-based viscoelastic heat-transfer liquids in battery immersion cooling concepts. The correlation of liquid chemistry to the desired rheological and thermal behavior is accomplished utilizing a range of numerical and experimental techniques, ranging from molecular dynamics at atomistic scales validated by rheology measurements to computational fluid mechanics and particle image velocimetry at engineering scales.

9:40 am - 10:00 am
4067009: Investigation of the Discharge Voltage in EV Motor Bearings
Liang Guo, Henk Mol, Thijs Nijdam, Lieuwe de Vries, SKF BV, Houten, Netherlands

As the automotive industry shifts towards electric vehicles (EV), the issue of electric discharge in motor bearings is increasingly gaining attention due to its potential to cause damage on bearing surfaces and even lead to premature failures. The level of discharge damage is directly influenced by the discharge energy, which is dependent on the bearing capacitance and discharge voltages. To gain insights into the discharge voltage within EV motor bearings, electric discharge tests were conducted using in-house developed Tractor equipment, which enables the accurate reproduction of real-world application conditions. The test findings confirm that the discharge voltage follows a probabilistic distribution and is

contingent upon the working conditions. The presentation will cover essential aspects, including the design of the test rig, the acquisition and extraction of the discharge signal, the analysis of damaged surfaces and a model explaining the distribution of discharge voltage.

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

10:40 am - 11:20 am
4090927: A Comprehensive Study Comparing Several Fluids Heat Transfer Performance in an E-Machine
Vickey Kalaskar, Southwest Research Institute, San Antonio, TX

With the advent of electrified vehicles and applications, understanding and improving the heat transfer in e-machines is necessary for efficient operation and to reduce losses. Often, e-machines employ lubricating oils as heat transfer fluids. SwRI used an instrumented e-machine from a renowned heavy-duty manufacturer in this study to understand and compare the heat transfer performance of several fluids. The fluids consisted of a range of market, group III, group IV PAOs, and group V esters. Five unique test conditions were chosen at a fixed shaft power of 75 kW and ranging motor speeds. The heat transfer results were correlated with the fluid's properties such as density, viscosity, specific heat capacity, and thermal conductivity.

Session 7K — 200 B

Wear I

Session Chair: Xue Han, Cummins, Inc., Columbus, IN
Session Vice Chair: Kora Farokhzadeh, DSM Engineering Materials, San Jose, CA

8:00 am - 8:40 am
4002592: PQ versus FerroQ: Understanding In-Service Lubricant Ferrous Debris Quantification
David Swanson, POLARIS Laboratories®, Indianapolis, IN

The venerable kittiwake pQ first saw the light of day back in 1985, invented by the Swansea Tribology Group, and since then, has become an essential component of condition monitoring. One of the more modern developments has been the FerroQ device. How do they compare? In this session, we'll cover the differences, benefits, and limitations when analyzing ferrous content to understand best and obtain valuable data to meet your lubricant analysis objectives.

8:40 am - 9:00 am
4025908: A Digital Twin Approach for Evaluating the Real-Time impact of Ice Collision Loads on Wear Development in Ship's Stern Tube Bearings
Ahmed Saleh, Markus Gilges, Benjamin Lehmann, Georg Jacobs, Dhawal Katre, MSE – Institut für Maschinenelemente und Systementwicklung, RWTH Aachen University, Aachen, Germany

Climate change has led to new shipping routes in polar waters, increasing touristic and commercial traffic in these regions. Subsequently, collisions between ship propellers and sea ice become more frequent. Such collisions subject the propellers to extreme impulse loads, which are then transferred through the propeller shaft to the sliding bearings of the stern tube, particularly to the sliding bearing mounted directly next to the propeller. Extreme bearing loads can lead to mixed friction conditions that cause wear in these sliding bearings and eventually cause them to fail. To prevent damage to sliding bearings, the digital twin is a promising solution that is proving effective in the intelligent maintenance and predictive operation for propulsion systems. Thus, this study aims to establish a digital twin

approach based on high-fidelity models. Its primary objective is to evaluate the real-time impact of ice collision loads on the wear development in ship's stern tube bearings.

9:00 am - 9:20 am
3976527: Measuring Wear the Right Way
Mark Malburg, Digital Metrology Solutions, Columbus, IN

The measurement of wear is essential in tribological testing and research. However, the methods commonly used are not well defined and bad practices can lead to costly errors in decision making. In this case study-based talk, we will present modern tools and methods for assessing macro and micro wear based on recent ISO standards for surface analysis.

9:20 am - 9:40 am
4004540: Utilizing Vibration Analysis for Friction Prediction and Scuffing Prevention
Jeng-Haur Horng, Jin-Long Lin, Thi-Na Ta, National Formosa University, Huwei, Yunlin, Taiwan

This study presents a new approach for indirectly predicting friction between machine parts when direct measurement is challenging. Through the analysis of vibration signals, a regression equation is developed to estimate friction coefficients. The results reveal that the friction coefficient increases with the ratio of vibration velocity to sliding velocity (V_v/V_s). Furthermore, this study investigates the influence of different factors, such as the running-in process, vibration, and operating conditions on the occurrence of scuffing failure. Both the experimentally measured friction coefficient and the calculated friction coefficient based on V_v/V_s are employed in the friction power intensity (FPI) criterion to predict the initiation of scuffing. The FPI values obtained using both approaches exhibit similar results, thereby validating the reliability of the proposed methodology.

9:40 am - 10:00 am
4023248: Surface Integrity, Microstructural Evolution and High Temperature Fretting Wear of Wrought and Additively Manufactured Inconel 625 Superalloy
Ali Beheshti, Manisha Tripathy, George Mason University, Fairfax, VA; Lloyd Hackel, Curtiss Wright Surface Technology, Livermore, CA

This presentation covers a microstructural and fretting wear study of LPBF printed and wrought Inconel 625. The wear behavior is evaluated up to 700°C. The samples are studied through advanced surface and material characterization techniques. In addition, samples are subjected to shot peening and laser peening processes to measure the extent of tribological enhancements. Results show that the coefficient of friction of all the samples decreases with an increase in temperature whereas the wear volume is found to increase with temperature. Additively manufactured samples exhibited higher wear at room temperature while showing significantly less wear at elevated temperatures than the wrought samples. Compared to shot peening process, laser peening effect penetrates deeper to the surface with refined microstructures where only laser peened samples show improved tribological properties. Some suggestions to make laser peening effective at elevated temperatures will be also discussed.

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

10:40 am - 11:00 am
4005334: A Quantitative Study of the Galling Resistance of Superalloys Based on Nickel and Cobalt
Michael Fahrmann, Ramanathan Krishnamurthy, Paul Crook, Haynes International, Kokomo, IN

Several Ni-/Co-based superalloys, strengthened via solid solution strengthening (alloys HAYNES 230, 625, HAYNES 25) or via 2nd phase precipitation (alloys HAYNES 282, 718 and Waspaloy) were tested for galling resistance using a variation of the ASTM G98 standard test developed at Haynes International that facilitates comparatively better differentiation in the galling response of superalloys. Wear surface

roughness measurements obtained following LASER scanning of the galling wear scars show that the Co-based 25 alloy suffered less galling damage compared to Ni-based alloys. SEM & optical microscopy analysis of wear samples reveal considerable plastic flow/shear localization underneath the surface of the galled Ni-based superalloys compared to the limited deformation suffered by the Co-based 25 alloy, indicating the extent to which a cobalt base benefits the resistance to galling of such materials.

11:00 am - 11:20 am
3979656: Influence of White Etching Layer on Rail Surface to Rail Wear Behavior and Microstructural Transformations with an Attempt to Generate WEL with Laser Beams
Yue Yang, Roger Lewis, The University of Sheffield, Sheffield, United Kingdom; Klaus Six, Virtual Vehicle Research GmbH, Graz, Austria

Hard white etching layers (WEL) that form in wheels and rail due to high temperatures and pressures during a wheel slides, for example, can cause several types of failures during subsequent wheel passage over rail. This research focused on investigating crack initiation and growth at the WEL/substrate boundary and within the WEL. Different formations of WEL were created artificially by controlling modes, energy densities, and operational time of laser treatment on R260 rail material disc samples before they were tested in a rolling/sliding condition against wheel material in twin disc testing. The material surface and microstructure were analyzed post laser treatment and after the twin-disc tests using optical and scanning electron microscopy as well as using nano-hardness measurements. The WEL formation due to the laser treatment was compared with field examples of WEL and damage formation characteristics were analyzed.

11:20 am - 11:40 am
4001910: The Multifunctional Properties of Amine-Neutralized Phosphate Esters Antiwear Additives
Ezio Amerio, Alina Filin, John Dixon, Nouryon, Deventer, Netherlands

The friction and wear properties of a new class of amine-neutralized phosphate esters were investigated under different contact conditions. The results in base oils indicate that excellent wear protection can be achieved at a relatively low treat rate and P-content compared to ZDDPs in a wide temperature range. Moreover, the selection of specific amine moieties enables independent optimization of wear and friction performances, while also providing access to multifunctional additives. Furthermore, the amine counterion chemistry influences the compatibility with MoDTC and ZDDP, resulting in some cases in synergistic effects. This combination of attributes makes the investigated additives interesting candidates for a range of lubricant applications. This study further highlights the potential of optimal additive combinations to achieve low ash (or low SAPS) formulations while reducing friction and wear, especially in components that operate across different tribological regimes.

11:40 am - 12:00 pm - **Wear Business Meeting**

Session 7L — 200 A

Nonferrous Metals I

Session Chair: Ariane Viat, Constellium Technology Center, Voreppe Cedex, France
Session Vice Chair: Tom Oleksiak, Quaker Houghton, Oswego, IL

8:00 am - 8:40 am
3982448: Simulating Friction in Aluminum Hot Rolling Emulsions on the Lab Scale
Pablo Bakermans, Yao Lu, Bas Smeulders, Quaker Houghton, Uithoorn, Netherlands; Tom Oleksiak, Quaker Houghton, Oswego, IL

Simulating lubrication performance in aluminum hot rolling is a unique challenge. Not only does the process have varying temperatures, reductions and speeds but also the application of the lubricant as an emulsion provides further complications. A roll bite mimicking test approach has been developed which translates field conditions to a lab scale test. The methods have been optimized to differentiate the lubrication challenges in the process. Data has been found to correlate well with pilot mill and field results.

8:40 am - 9:00 am
3985744: Hot Rolling Emulsions and the Importance of Antioxidant Additives
Bill Poynor, Kaiser Aluminum, Spokane Valley, WA; Annie King, Wayne Jenkins, Total Energies, Rockingham, NC

Emulsions are a type of coolant commonly used throughout the aluminum manufacturing process. This presentation will specifically review emulsions used in the Hot Rolling of aluminum and the importance of antioxidant additives. In many hot rolling applications, the emulsion is heated either directly or indirectly to elevated temperatures. In this presentation I will focus on the chemical and physical effects on the in-use emulsion if emulsion chemistry isn't maintained and antioxidants are not managed at an appropriate level.

9:00 am - 9:20 am
4002029: How Metalworking Emulsions Evolve During Usage: The Effects of High Temperatures and Contamination
Ariane Viat, Constellium Technology Center, Voreppe Cedex, France

The aluminum hot rolling process is usually cooled down and lubricated thanks to oil emulsified in water. To both control oil consumption and ensure enough cooling capacity, the emulsion is in a closed circuit and is dimensioned with a large volume. While circulating, the emulsion evolves. Therefore, the emulsion in use has very different properties compared to the fresh emulsion prepared in the lab: firstly, the rolling process generates wear particles that can react at the oil-water interfaces. Secondly, even if the average temperature of the emulsion circuit is kept constant, the emulsion suffers from periodic "heat strokes" during the contact with the hot metallic surfaces. These two phenomena affect the emulsion: enhancing stability through the Pickering effect of the metallic particles, but also destabilizing when the emulsion is subjected to a temperature at which its surfactants are less effective. This paper investigates the balance between these two opposite effects.

9:20 am - 9:40 am
4005002: Lubricity Additives for Fully Synthetic, Nonferrous Formulations
Bradley Arnold, Tiffany Meyers, Clariant, Mont Holly, NC

Metalworking fluid chemistry is ever evolving and changing due to the operation severity, increased nonferrous metal production, and the need for sustainable additives. Metalworking fluid is exposed to various conditions and must withstand harsh conditions during the manufacturing and processing of these nonferrous materials (e.g., rolling, cutting, forming, grinding). Lubricity additives can vary with shape, size, and solubility, contributing to the overall fluid performance. Formulators are looking for additives that simultaneously deliver additional functionalities that help metalworking fluid address today's formulation challenges. This paper will focus on several polyalkylene glycol chemistries as lubricity improvers specific for water-based, oil-free metalworking formulations, and how they perform on nonferrous alloys.

9:40 am - 10:00 am
4005225: The Effects of High Magnesium Metallic Debris on the Lubrication Fluid From Condition Monitoring Testing

Steven Wheeler, Kimberly Williams, Total Energies, Rockingham, NC

Lubricating fluids are formulated to perform at a specific range of physical properties depending on the specific need of the fluid. During the lubricating process, frictional wear introduces metallic debris into the lubricant. Condition monitoring tests can show the effects metallic debris has on the in-use lubricating fluid. This work will add high levels of magnesium to a lubricating fluid and perform condition monitoring tests to show how increased contact with high magnesium alloy over time effects the in-use lubricating fluid.

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

10:40 am - 11:00 am
4025237: Oxidation of Aluminum Hot Rolling Oils — A Case Study
Josef Leimhofer, AMAG Rolling GmbH, Ranshofen, Austria

Oils for the hot rolling of aluminum are complex mixtures of several raw materials. They are used as emulsions for hot rolling, and their composition and properties, which are crucial for their use, are constantly monitored, as they permanently change due to their use: the emulsions are stored at elevated temperature and are exposed to much higher temperatures during hot rolling (i.e., thermally stressed). Due to this thermal stress, the oil phase is prone to oxidation. To prevent oxidation, the rolling oil contains antioxidants. In case the antioxidant function is insufficient, oxidation of the hot rolling oil may start. In this work, the course of an oxidation of a hot rolling oil is shown; the emulsion is investigated with standard analytical techniques as well as with IR- and NMR-spectroscopy. The results given show, which analysis parameters are sensitive for oxidation, which components of the formulation are most prone to oxidation, and which countermeasures can be taken.

11:00 am - 11:20 am
3988984: New Polymeric Antiwear Additives for Non-Ferrous Metalworking Fluids
Lucas Luz, Solvay, Paulínia, São Paulo, Brazil

The increasing usage of lighter alloys for weight reduction, and more regulations leading towards less phosphorus containing additives are important drivers to develop new additives to enable fluid formulators to overcome some of today's and future most pressing challenges. Polymeric additives containing phosphorus are a great strategy to provide the ideal lubricity and stain protection over the substrate while reducing the phosphorus content of the formulation. This presentation is going to introduce polymeric additives under development and some data to demonstrate how they can be incorporated into metalworking fluids formulation as an option of the classical phosphate ester technology.

11:20 am - 11:40 am
4002579: Bio Source Oil for Aluminum Cold Rolling
Gautier Burette, TotalEnergies, Nanterre, France; Annie King, Total Energies, Linden, NJ

Cold rolling of aluminum sheets requires a lubricant based on highly purified mineral oil. This kind of oil has a low viscosity and a high volatility, which leads to a high consumption by evaporation. This poses an environmental problem because the mineral oil comes from a fossil feed stock. To reduce CO2 emissions in industry, a non-fossil alternative can be used. This is the case with Lubrilam Bio, a base oil technology 100% bio sourced from used cooking oil or vegetable oil. Lubrilam Bio allows reducing the carbon footprint and the energy consumption of the rolling process, without compromising the performance and the specifications. The presentation will make a comparison between the physical properties and tribology measurement that can mimic the aluminum rolling process of Lubrilam Bio versus the mineral oil.

11:40 am - 12:00 pm
3987935: Phosphonate from Used Cooking Oil as Biobased Lubricant
Grigor Bantchev, USDA-ARS, Peoria, IL

Used cooking oil was collected form a local pizza restaurant and reacted with dibutyl phosphite to generate phosphonated used cooking oil. GC-MS, NMR and FTIR confirmed that the radical-initiated reaction run to a high degree of completion (no residual double bonds detected). The phosphonate was tested as an additive in polyalphaolefin (PAO_6) in 1 to 5 wt.%. It improved the antiwear performance in both 4-Ball (ASTM D4172) and high-frequency reciprocating rig (modified ASTM D6079, HFRR) tests. In the 4-Ball test, the phosphonate additive resulted in an increase of the coefficient of friction (COF), in the HFRR the COF decreased 20% to 50%. The cloud point and pour points were acceptable at low levels. The results suggest that the phosphonate has a good potential to be used as additive up to 3 wt. %

12:00 pm - 12:30 pm - **Nonferrous Metals Business Meeting**

Session 8A 101 B

Materials Tribology VI

Session Chair: Cinta Lorenzo Martin, Argonne National Laboratory, Lemont, IL

1:40 pm - 2:20 pm
4043046: Do Oxide Coatings Strengthen Metal Nanoparticles?
Tevis Jacobs, Ruikang Ding, University of Pittsburgh, Pittsburgh, PA; Ashlie Martini, University of California, Merced, Merced, CA

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

2:20 pm - 2:40 pm
4065221: Tribological Performance of ATSP Composites in Simulated Lunar Environments for Sealing Applications
M. Akif Rahman, Andreas Polycarpou, The University of Tulsa, Tulsa, OK

In this study, the tribological performance of advanced Aromatic Thermosetting Copolyester (ATSP) composites as potential sealing materials in extreme lunar environments are investigated. Lunar dust abrasive and temperature variable conditions are applied. We focused on frictional and wear characteristics of ATSP composites against bare steel disks of 52100 and 440c steels under a temperature range of -180°C to 150°C and nitrogen environment. The results show ATSP composites exhibit exceptional wear resistance and low coefficient of friction under extreme conditions. Morphological analysis of the worn surfaces of the steel disks were carried out by Scanning Electron Microscopy (SEM) and 3D laser microscopic scanning. The results provided valuable insight into the wear mechanisms and effectiveness of the sealing applications against dust intrusion and will act as a guideline for developing bearings with long lifetime and desired performance for other extreme

condition applications.

2:40 pm - 3:00 pm
4077561: Study of Cast Iron Piston Ring Tribology for Aerospace Application and Discussion of Lessons Learned During Testing
Mary Makowiec, Pratt & Whitney, East Hartford, CT

This presentation will discuss why cast iron piston rings are still used in jet engines and discuss some of the lab-scale testing that was used to understand the wear performance of cast iron in different engine interfaces. In addition, it will review some of the results that were identified during testing that can provide some interesting insight into lightly lubricated surfaces that may cause adhesive wear depending on the surface finish of the parts. Finally, another lesson learned that will be discussed is the sensitivity of the testing results to plate geometry and coating related features.

3:00 pm - 3:20 pm - **Break**

3:20 pm - 3:40 pm
4014563: Tribological Performance of Advanced Polymers for Hydrogen Environment Applications
Ajinkya Raut, Texas A&M University, College Station, TX; Andreas Polycarpou, The University of Tulsa, Tulsa, OK

The global demand for clean hydrogen energy has increased due to the necessity for sustainable energy sources. To meet this demand, it's crucial to minimize hydrogen loss during production and transportation. Polymers are replacing metals in components with sliding contacts such as valves, bearings, and seals. This shift is driven by their excellent tribological performance, resistance to corrosion, and ability to function without external lubrication. Despite their impressive performance in the air, these polymers haven't undergone sufficient testing in hydrogen environments. In this research, we produce multiple composites using ATSP and PTFE matrices and assess their tribological behavior in a specially designed tribometer within a hydrogen atmosphere. The study reports on friction, wear, and durability of these polymer coatings, and it identifies the most effective tribopairs suitable for bearing materials in hydrogen-related applications.

3:40 pm - 4:00 pm
4000592: The Droplet-Luminescence Excited by Contact Electrification on Polymer Surface
Shicai Zhu, Changhui Song, Yu Tian, Liran Ma, Tsinghua University, Beijing, China

Due to the direct conversion of mechanical force into light, Mechanoluminescence (ML) has been widely investigated in sensors, displays, anticounterfeiting and artificial skin. However, since the duration of luminescence is very short, this presents a great challenge for the visualization of trajectory generated by the motion, resulting in existing trajectory visualization applications frequently require an auxiliary device and extra power supply. With the ML material ZnS:Cu, which also has electroluminescent properties, we have found the interesting luminescence from water droplets flowing through scratches on the surface of a flexible ML composite film, which is called as droplet-luminescence. Contact trajectory visualization can be directly realized by the electric field between polar-liquid droplets and residual triboelectric charges on a rubbed surface without an auxiliary device. This provides an extremely simple but efficient way to store and display motion trajectories.

Session 8C — 101 D

Metalworking Fluids II

Session Chair: Stephanie Cole, Münzing North America, LP, Bloomfield, NJ
Session Vice Chairs: Nicole Clarkson, Barentz North America LLC, Lisle, IL & Stefanie Velez, Münzing Chemie GmbH, Bloomfield, NJ

1:40 pm - 2:00 pm
4000605: Investigation of Tribological Properties of Metalworking Fluid Lubricity Additives on Different Metals
Yixing Philip Zhao, Quaker Houghton, Conshohocken, PA

The major driver of new product development in MWF is the sustainability and green chemistry. The important attributes of sustainability are high productivity, energy efficiency, and good tool life, which require formulators to use proper lubricity additives for machining efficiency. The trend is also going towards using additives from renewable sources. Thus, MWF formulators need more understanding of vegetable-based additives. In this presentation, we will report some tribology test results with different types of EP and non-EP lubricity additives on four common metals. We have found that the lubricity can have big changes not only with the additive chemistries, but also on different metal types. The surface roughness values (S_a and S_z) of metal scares from testing were also obtained by profilometer measurements. It is very interesting to see some additives may have low friction forces, but not necessarily generate good finish.

2:00 pm - 2:20 pm
4002646: The Role of Polymers in Quenching Fluids
Jacob Scherger, Functional Products Inc., Macedonia, OH

Quenching fluids are very important in the metal forming process. They control the speed at which a formed metal part is cooled, which in turn helps to control properties and performance of the finished part. Polymer additives play a crucial role in determining the quench rate provided by a fluid and thereby the hardness and ductility of the metal part. Polymers act by altering the rheology and wetting properties of a fluid to encourage heat transfer from a surface. Here the effect of polymer additives and polymer accelerators are examined in straight oil quenching fluid formulations. Different polymer molecular weights and chemistries are compared in terms of the cooling rates they provide.

2:20 pm - 2:40 pm
4002677: Mapping Extreme Pressure Additive Activation from Lathe Machining on High Strength Steel
Ryan Weber, Gabe Kirsch, Britt Minch, John Hogan, Jeanne Petko, Glenn Black, Johnnie Thomlison, The Lubrizol Corporation, Wickliffe, OH

Various industries, including automotive and aerospace, require the use of high strength alloys that are more difficult to machine. Metalworking fluids designed for such alloys require a wide range of lubricity additives including boundary lubricants, antiwear, and extreme pressure (EP) additives to extend tool life and achieve superior surface finish. In this talk, we explore the surface chemistry of metal chips and machined workpieces from a lathe facing operation on high strength steel utilizing three fluids containing a polymeric ester boundary lubricant used in tandem with either phosphate ester or sulfurized olefin EP additives. Chips and workpiece surfaces are imaged using scanning electron microscopy with energy-dispersive x-ray (SEM-EDX) analysis, demonstrating evidence of effective thermal activation of the EP additives during cutting.

2:40 pm - 3:00 pm
4002705: Boundary Lubricant Additive Multimetal Optimization for AISI 1018 Steel, Aluminum, and Copper Alloys Using Twist Compression Tests (TCT) and DOE
Ted McClure, Alexes Morgan, Sea-Land Chemical Company, Cleveland, OH

Electric vehicles (EV) require changes in the way vehicles are manufactured. Materials and manufacturing processes continue to evolve in response to these changing requirements. Electric current and thermal management are important considerations, contributing to increasing use of copper and aluminum. Metalworking fluid end users 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. Previous work, comparing boundary additive responses, using TCT with AA5182-0 and C110 HO2, is extended to include AISI 1018 steel. High performing additives are identified, and combinations evaluated using mixture DOE. Boundary additives evaluated include polymers, esters, fatty acids, alcohols, and amines. The aim is to provide useful data and processes for formulation of lubricants in applications involving multiple metals.

3:00 pm - 3:20 pm - **Break**

3:20 pm - 3:40 pm
4005611: Increasing Metalworking Fluid Performance with Amino Alcohols and Alkanolamides
Kathleen Havelka, Andrew Schiffer, Maxwell Petit, Advancion Corporation, Buffalo Grove, IL

Through covalent coupling of a fatty acid with an amino alcohol, a fatty acid AMP alkanolamide emulsifier with high bio-content was developed, expanding the formulating options for water dispersible fluids containing carboxylic acids and amino alcohols. Formulations that contain both ionic and covalent coupling of carboxylic acids and amino alcohols show excellent heat removal and good lubrication properties. A systematic study will be presented demonstrating the use of fatty acid AMP alkanolamide, conventional emulsifiers and other fatty acid alkanolamides. The structure-property relationships developed will explain the benefits seen with AMP alkanolamide and serve as a formulating model to develop high-performing and sustainable metalworking fluids. The unique multifunctionality of AMP alkanolamide in combination with amino alcohols offers new potential in optimizing next-generation metalworking fluids to produce defect-free parts while minimizing operating costs and reducing waste.

3:40 pm - 4:00 pm
4004910: MWF Formulations and Performance Testing Using Estolides
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Metalworking fluids are required to enable specific metalworking operations on many types of metal workpieces. MWF formulations need to be specifically designed for a given metalworking operation such as cutting/grinding, drawing/stamping, tapping, milling, drilling, and cleaning. Biobased ingredients are typically added to formulations to provide additional lubrication during the metalworking operation, enhance the tool life and efficiency, and improve surface finish. Estolides serve as an exceptional biobased choice for delivering high performance, improved worker health and safety and increased sustainability efforts for the formulator. We have demonstrated the use of estolides in metalworking fluid protype formulations geared toward cutting and grinding, drawing and stamping, and general machining operations. We'll discuss the performance testing results of estolide containing formulations versus conventional base fluid formulations used in metalworking operations.

4:00 pm - 4:20 pm
4014426: Overview on Tribometric Screening Methods for Forming and Metalworking
Ameneh Schneider, Optimol Instruments, München, Germany

The increase in range of materials used in forming technology needs consequently tribological optimization in the forming processes and this called for new tribometric methodologies.
This presentation will provide an overview of the possibilities of tribological testing of materials and lubricant in lab scale by choosing the test condition and geometries close to the chosen metal-forming process with SRV tribometer. These methodologies illuminate test conditions from cold to hot forming (up to 700°C) as well as for testing with water-based metalworking fluids. Finally, it will discuss how the

new tribological methodologies supported the industry to optimize the formulation of MWFs as well as made it possible to form high strength materials that are difficult to form. This will help to cope with the upcoming challenges such as lightweight design and improved fuel economy.

4:20 pm - 4:40 pm
4094439: Fluid Fusion- Enhancing Performance and Longevity with Hybridization Sustainable Metalworking Fluids
Jesse Ziobro, Stockton University, Houston, TX

This presentation outlines the forefront of sustainable metalworking utilizing modern hybridized formulary. The focus is on enhancing performance, stability and longevity of a metalworking fluid utilizing hybrid formulations. By merging traditional and sustainable technologies hybridized formulations mark a significant advancement in high performance machining. Through in-depth examination of key performance properties (e.g., 4 Ball EP and AW, Falex Pin and V block (elliptical), RTech cutting tribometer, PDSC, etc.) we will reveal the transformative new sustainable hybrid technology. The presentation will shed light on the impact sustainable formulations provide in advancing innovative and sustainable metalworking fluids.

4:40 pm - 5:00 pm - **Metalworking Fluids Business Meeting**

Session 8D — 101 E

Rolling Element Bearings III

Session Chair: Travis Shive, SKF USA Inc., Lansdale, PA
Session Vice Chair: Kushagra Singh, Purdue University, West Lafayette, IN

1:40 pm - 2:20 pm
4005653: Propagation of Surface-Initiated Fatigue Cracks and its Significance to Fatigue Life Predictions
Amir Kadiric, Pawel Rycerz, Bjoern Kunzelmann, Imperial College London, London, United Kingdom

This talk explores the propagation behavior of surface-initiated contact fatigue cracks using recent experimental and numerical results and discusses the significance of this in terms of our ability to better predict contact fatigue lifetimes. A method employing a triple disc fatigue machine in combination with a novel crack sensor, which allows us to generate and grow surface fatigue cracks and quantify their propagation rates, is first described. The results are shown to explore the influence of several parameters, including surface roughness, friction, type of steel and Hertz pressure on crack propagation rates. An accompanying LEFM crack model is used to study the evolution of stress intensity factors during crack over-rolling. The trends in crack propagation rates are then discussed in terms of our ability to predict the crack growth, and hence eventual failure, starting from an initial fault, in a manner that is commonly employed in structural fatigue.

2:20 pm - 2:40 pm
4000229: Automated Cage Optimization Using Machine Learning
Hannes Grillenberger, Schaeffler Technologies, Herzogenaurach, Germany

Cages are important components of rolling element bearings. Due to their high degree of freedom, they are subjected to dynamics which are influenced by many factors. Some simulation programs can capture the complex movements and effects, but typically they take a long time or use too many empirical assumptions to find a proper physical based design. To find an optimum design for all operation

conditions is too extensive by these physical simulations only. The presentation shows a workflow how to automatically optimize a cage design on the robustness against cage instability. By switching between physical and data driven machine learning models the optimization task can be fulfilled not only for one operating condition, but for all operating condition of the bearing. The approach reduces the simulation time needed by more than three orders of magnitude compared to a purely physical simulation – without essentially loosing quality and thus can be used in the design process.

2:40 pm - 3:00 pm
4002170: Bearing Rotor Housing System Modelling
Abbas Shafiee, Farshid Sadeghi, Purdue University, West Lafayette, IN; Matthew G. Wilmer, The Timken Company, North Canton, OH

Most traditional bearing models have conventionally assumed that the bearing inner race is fixed to a rigid shaft and the outer race is fixed to a rigid ground. In practical applications, bearings are often integral parts of rotating machinery, where the flexibility of rotor and housing components can introduce displacements and misalignments that exert a substantial impact on bearing performance. In order to address these shortcomings and improve on the versatility of bearing simulations, the previously developed ADAMS dynamic bearing model was integrated with flexible rotor and housing models. This combined bearing-rotor-housing system enables the exploration of how the housing and rotor flexibility influence bearing dynamics and provides valuable insights into the operation of the bearing and can lead to optimizing bearing system designs.

3:00 pm - 3:20 pm - **Break**

3:20 pm - 3:40 pm
4005450: Modeling Raw Material CO_2 Emissions to Reduce the Bearing Industry Carbon Footprint
Samantha Melnik, Bryan Allison, SKF, Falconer, NY; Paul Lynch, Penn State Behrend, Erie, PA

194 countries signed the Paris Agreement to make a concerted global effort to reduce climate change. Iron and steelmaking contribute approximately 7% of the worldwide CO_2 emissions. Rolling element bearings are primarily composed of high strength steel and a substantial portion of the emissions attributable to bearings are due to the manufacture of bearing steel including mining, ironmaking, and steelmaking operations. There are varying paths to producing steel, thus leading to varying emissions factors associated to the final product. Through the informed selection of raw materials and processes, the total emissions attributed to bearing manufacturing can be greatly decreased. In this presentation, a new method to estimate the emissions generated during steelmaking will be discussed.

3:40 pm - 4:00 pm
3980974: A Fast and Efficient Calculation Method for Pitch Bearing — Blade Assembly Subjected to External Loads
Rémy Duquesne, Daniel Nelias, Sébastien Morterolle, Contact and Structural Mechanics Laboratory (LaMCoS), Lyon, France

Pitch bearings are components used in wind turbines or airplane propellers to make the link between the hub and the blade. The excentric aerodynamic forces lead to high loads and overturning moments on the bearings. It is therefore important to use tools that can predict the level of stress that each rolling element will have to withstand. In our work, we propose an efficient bearing calculation method adapted to pitch bearings that will solve the equilibrium of a bearing assembly supporting a flexible blade. The interest of our method is that the external loads due to aerodynamic and centrifugal effects are prescribed on the blade, and then distributed between the bearings. In our approach, we suggest considering the governing equation of the blade bending, which will allow us to establish additional relations between the unknowns and then further solve the initially statically indeterminate problem with a classical Newton-Raphson algorithm.

4:00 pm - 4:20 pm
4001192: Frictional Torque Investigations of Radially Preloaded Cylindrical Roller Bearings
Tom Wittek, Leibniz University Hannover, Garbsen, Germany

By distributing the external load over a higher number of rolling elements, the maximum rolling element force can be reduced and thus the fatigue life increased. In addition, the unloaded zone is reduced, which reduces slip damage. The increase of the load zone can be realized by reducing the bearing clearance to negative values. Each additionally loaded rolling element worsens the efficiency due to additional frictional losses. The balance between maximum fatigue life and friction minimization can thus be adjusted as a function of the mounting clearance. To detect an ideal mounting clearance, the operating behavior of test bearings with different bearing clearances was reproduced theoretically and experimentally. Using the calculation model developed, it was found that an optimum mounting clearance exists. With the aid of this calculation method, bearing arrangements can be designed in a resource-efficient manner and thus contribute to the sustainable design of technical systems.

4:20 - 4:40 pm
4003498: Effect of Cage Wear on Lifetime of Cryogenic Bearing Under Various Load Conditions
Yeongdo Lee, University of Science and Technology, Seoul, Republic of Korea; Yunseok Ha, Yongbok Lee, Korea Institute of Science and Technology, Seoul, Republic of Korea

Cryogenic ball bearings are used in LNG pumps, and rocket turbopumps is a self-lubricating bearing. The appropriate thickness of transfer film on the ball and raceway surfaces is important for adequate lubrication and stable operation of the bearing. Excessive or too little cage wear can cause premature failure. However, the appropriate cage wear to ensure long life is unknown. In this research, accelerated life tests (ALT) of ball bearings were performed with 4 different stress levels. We analyzed the correlation between the cage wear and the life of cryogenic ball bearing. The analysis showed that the life of the bearing decreased as the wear of the cage increased. Test bearings with relatively long lives had a wear rate below a certain level. Additionally, it was found that the wear rate decreases as the dimensionless internal clearance increases.

Session 8E — 101 F

Environmentally Friendly Fluids III

Session Chair: Brajendra Sharma, USDA/ARS/NEA/ERRC, Wyndmoor, PA
Session Vice Chair: Selim Erhan, Process Oils, Inc., Trout Valley, IL

1:40 pm - 2:20 pm
3987440: Sustainable High-Performance Lubricants & Greases: Eliminating Hazards and Enhancing Performance Using New Technologies of Non-Hazardous Antiwear and Antioxidant Additives
Gregoire Herve, NYCO, Paris, France

Sustainability is increasingly vital in technological developments, with final users seeking nonhazardous materials that pose minimal environmental and safety risks. Evolving regulations are unveiling the true toxicity of various chemicals, particularly affecting performance additives, transcending industries. The quest for effective and safer additive chemistries remains a big challenge for the industry. Our work tackles this challenge head-on through an innovative approach: a holistic assessment integrating modeling and practical experiments on anti-wear and antioxidant additives. The result? Lubricants, greases included, that not only excel in performance but are also safer and risk-free. Finally, our thermal

and tribological evaluations demonstrate superiority over existing market lubricants. This research demonstrates the harmonious coexistence of sustainability and performance, aligning with industry and environmental needs.

2:20 pm - 2:40 pm
4026812: Lubricant Requirements for Low GWP Refrigerants in HVAC&R Applications.
Wasim Akram, Morgan Leehey, Trane Technologies, Bloomington, MN

Due to environmental regulations, HVAC&R (heating, ventilation, air conditioning, and refrigeration) equipment manufacturers are required to transition products to lower global warming potential (GWP) fluids. In general, HVAC&R systems have unique lubricant requirements, however new refrigerant chemistries are posing additional challenges. Hydrofluoroolefin (HFO) chemistries interact with existing lubricant chemistries differently than traditional hydrofluorocarbon (HFC) refrigerants, leading to lubrication challenges as well as potential concerns with chemical stability and material compatibility. As applications of these systems are expanded to higher temperature ranges, these challenges become more significant. This presentation will explore the requirements and test methods utilized to evaluate a lubricant for use in these systems.

2:40 pm - 3:00 pm
4002561: Sustainable Sourcing and Traceable Mass Balance: Unveiling the Path to Environmentally Friendly Fluids
Shubhamita Basu, Perstorp Polypls, Willoughby, OH; Elisa Swanson-Parbäck, Valentina Serra-Holm, Alisha Bloodworth, Dominic Petruccio, Perstorp AB, Malmö, Sweden, Sweden

The industry is experiencing a transformation driven by a shared commitment to high-performing lubricants and eco-conscious practices, leading to an increasing demand for environmentally friendly fluids. This paper explores the multifaceted concept, encompassing in-use performance and environmental attributes, with a particular focus on the selection of raw materials. In this context, transparency plays a pivotal role and is crucial to avoid 'greenwashing' and to establish trust in value chains. This paper underscores how the procurement of lubricant raw materials from recycled and renewable sources can profoundly influence sustainability metrics, aligning with environmental stewardship and substantiating a reduced carbon footprint. As environmental regulations evolve and consumer expectations rise, this paper emphasizes the importance of the adoption of certified traceable mass balance as a globally recognized approach that serves as the linchpin for a sustainable transition.

3:00 pm - 3:20 pm - **Break**

Session 8F — 101 G

AI and Machine Learning II

Session Chair: Max Marian, Pontificia Universidad Católica de Chile, Macul, Región Metropolitana, Chile
Session Vice Chair: Nikolay Garabedian, Karlsruhe Institute of Technology, Karlsruhe, Germany

1:40 pm - 2:20 pm
4027551: Navigating the Microscopic World: Autonomous Measurements Powered by Machine Learning
Yongtao Liu, Rama Vasudevan, Maxim Ziatdinov, Oak Ridge National Laboratory, Oak Ridge, TN; Sergei Kalinin, The University of Tennessee, Knoxville, TN

Here we developed ML-driven automated and autonomous scanning probe microscopy (SPM), enabling the automatic discovery of material functionalities and mechanisms. We demonstrate the application of active learning and hypothesis learning-driven SPM by investigating ferroelectric materials, including studies of domain wall dynamics, domain switching mechanisms, and the relationship between domain structure and local properties. Hypothesis learning empowers the microscope to autonomously deduce the physical laws governing material responses. While we applied these methodologies in a specific class of materials, they hold potential for broader applications across various characterization approaches and techniques, such as characterizing stiffness and adhesions via force-distance curves in SPM.
Acknowledgments: This work was performed at the Center for Nanophase Materials Sciences, a US Department of Energy Office of Science User Facility.

2:20 pm - 2:40 pm
4000725: Integrating AI and Machine Learning with Oil Analysis Data
Jorge Alarcon, Polaris Laboratories®, Indianapolis, IN

The industry has always been at the forefront of technological advancements, and the integration of artificial intelligence (AI) and machine learning (ML) with oil analysis data is a proof to its commitment to innovation. This synergy between AI, ML, and oil analysis has the potential to revolutionize the way the industry operates, enhancing efficiency, reducing costs, and improving safety. Oil Analysis is a critical component of predictive maintenance in the industry, providing insights into the condition of machinery and equipment. Traditionally, human experts analyze oil samples, but this process is time-consuming and prone to errors. AI and ML algorithms can process vast amounts of data quickly and accurately, identifying patterns and anomalies that might elude human analysts. This predictive capability enables early detection of equipment failures, minimizing downtime and preventing costly breakdowns.

2:40 pm - 3:00 pm
4004369: Application of Machine Learning to Pour Point Prediction of Transesterified Bio-oils for Biolubricant Production
Guillermo Díez Valbuena, Alejandro García Tuero, Jorge Diez Peláez, Eduardo Rodríguez Ordóñez, Antolín Estaeban Hernández Battez, University of Oviedo, Gijón, Asturias, Spain

The Sustainable Development Goals have raised awareness of the climatological situation of our planet, so a decarbonization process has begun to reduce the carbon impact of products such as fuels or lubricants. Some of the most demanding tribological properties for new biofuels and biolubricants are those that affect the cold flow of fluids. Pour point is the minimum temperature at which a fluid can flow and predicting this property can be used as a pre-screening step to filter out bio-oils as candidates for the biolubricant production. Machine learning techniques can help find complex correlations between feedstock composition and final product pour point. This work presents models for predicting pour point from the fatty acid methyl ester distribution of the feedstock oil, a study of the performance of the models using metrics such as mean absolute error and coefficient of determination, and a study of the importance of the different attributes in making the prediction.

3:00 pm - 3:20 pm - **Break**

Session 8K — 200 B

Wear II

Session Chair: Kora Farokhzadeh, DSM Engineering Materials, San Jose, CA
Session Vice Chair: Xue Han, Cummins, Inc., Columbus, IN

1:40 pm - 2:00 pm
4002989: Tribological Properties of Lubricating Oils Derived From Plastic Wastes Under Electrified Conditions
Seungjoo Lee, Ali Erdemir, Texas A&M University, College Station, TX; Leonardo Farfan-Cabrera, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico

Plastic pollution is a significant environmental issue that has led to global efforts to reduce its harmful effects. Here we present the tribological properties of a high-quality lubricant upcycled from plastic wastes. More specifically, using a ball on disk tribometer and a variety of surface and structure analytical techniques, we elucidate the friction and wear characteristics of such oil under normal and electrified conditions. The results confirmed that lubricant derived from plastic oil showed much superior wear performances than conventional oils due to the formation of a carbon-rich tribofilm. We also observed a very unique wear transition taking place with respect to the extent of electrical current passing through the contact interface suggesting that electricity can be used to control or manipulate the mode or mechanism of wear.

2:00 pm - 2:20 pm
4004031: Effect of High-Pressure Hydrogen Gas on the Friction and Wear of PTFE Composite
Kotaro Ishii, Hironori Shinmori, Yoshinori Sawae, Takehiro Morita, Kyushu University, Fukuoka, Japan; Hikaru Hashimoto, Ayako Aoyagi, Shigenobu Honda, NOK Corporation, Fujisawa, Kanagawa, Japan

In this study, a friction and wear test was conducted to evaluate the tribological property of PTFE composite under different hydrogen gas pressures. Pin-on-disk tribometers were installed into a high-purity hydrogen gas chamber and a high-pressure hydrogen gas environment chamber, and gas pressures were 0.1 and 40 MPa, respectively. PTFE composite containing bronze and carbon fiber was prepared as the pin, and SUS 316L was prepared as a disk. From the results, the constant friction coefficient was observed at 40 MPa gas pressure, while the friction coefficient gradually decreased and reached 0.05 at 0.1 MPa gas pressure. Raman and XPS analysis indicated carbon-based transfer film formed on the disk surface at 0.1 MPa. On the other hand, PTFE-based transfer film was formed on the disk at 40 MPa. Analysis data revealed that differences in the composition of the transfer film led to the difference in friction and wear behavior.

2:20 pm - 2:40 pm
4004248: Effects of Trace Moisture on Tribo-Film Formation, Friction and Wear of CF-filled PTFE in Hydrogen under High Contact Pressure Condition
Qian Chen, Takehiro Morita, Yoshinori Sawae, Kyushu University, Fukuoka, Fukuoka, Japan; Kanao Fukuda, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Carbon fiber (CF) filled polytetrafluoroethylene (PTFE) composites are widely used as sealing material for reciprocating gas compressors. This study aims to investigate the effects of trace moisture content in hydrogen gas on tribological behavior of CF-filled PTFE composites under high contact pressure condition. Sliding tests were carried out on pin-on-disk tribometer installed within an atmosphere-controlled chamber using a composite pin and a stainless-steel disk. The moisture content of the hydrogen gas environment was controlled from 200 to 1000 ppb while the contact pressure and sliding speed were set at 7 MPa and 2 m/s, respectively. The results showed tribological behavior was significantly affected by trace moisture content. Both specific wear rates of the composite pin and coefficient of friction tended to increase as the water content increased. Furthermore, transfer films with different chemical composition were observed atop the disk surfaces at different moisture levels.

2:40 pm - 3:00 pm
4004395: Effect of the Accelerated Cryogenic Ageing on Mechanical and Tribological Properties of PEEK and PI Composites
Maksim Nikonovich, Nazanin Emami, Luleå University of Technology, Luleå, Sweden; Amilcar Ramalho,

University of Coimbra, Coimbra, Portugal

Recent advances in energy and transport industries have increased the demand on extreme working environments like low-temperature vacuum and exposure to cryogenic liquids such as liquid nitrogen and hydrogen, increasing the need for materials capable to perform under extreme conditions. In this study, the mechanical and tribological behavior of commercial PEEK and PI composites was examined after cycling-aging in liquid nitrogen and at 40^{o}C in air. Results indicate that aging impacts mechanical and tribological performance of the tested composites. Samples weight, stiffness, and friction coefficients slightly changed. With increased number of cycles, fracture toughness and wear resistance of some materials showed significant decrease, 100% and 400%, respectively, caused by matrix embrittlement and/or thermal stresses at filler/matrix interface. While wear mechanisms were not significantly altered compared to non-aged materials, abrasive and fatigue wear became more pronounced.

3:00 pm - 3:20 pm - **Break**

3:20 pm - 3:40 pm
4000684: Study on the Friction Temperature Field and Wear Characteristics of Polymer Materials
Yichun Xia, Tsinghua University, Beijing, China

The friction and wear characteristics of polymer materials are significantly affected by the friction temperature. This study focuses on the surface contact friction process between three polymer materials and steel. Firstly, friction and wear experiments under different conditions were designed and the friction temperature was measured. Secondly, two models for simulating friction temperature have been developed: the constant heat partitioning model and the total heat flux model. Comparing the simulation and experimental results, it was found that the friction temperature and heat partitioning coefficient obtained by the total heat flux method are more consistent with the experimental results, and the heat partitioning coefficient is not a constant value during the friction process. Under different experimental conditions, the wear characteristics of the three polymer materials are different, and the friction temperature significantly affects the wear form of the polymer.

3:40 pm - 4:00 pm
4000274: A Strategy to Enhance the Wear Resistance of PTFE/Kevlar Fabric Liner via Oil-Containing Microcapsules
Weitang Xiong, Tsinghua University, Beijing, China

It has been an everlasting challenge to enhance the wear resistance of PTFE/Kevlar fabrics, facing demanding service conditions and reliability requirement of self-lubricating spherical plain bearings. Utilizing microcapsule technology, the liquid lubricants encapsulated by solid materials can be dispersed into fabric matrix, so a better lubricating effect is expected to achieve. In this work, an innovative strategy to prepare oil-containing microcapsules was reported. The prepared oil-containing hollow silicon microcapsules (Oil@SiO_2) and oil-containing hollow carbon nanocapsules (Oil@C) were used as additives to enhance the wear resistance of PTFE/Kevlar fabrics, respectively. The friction coefficient of modified fabrics decreased by 24%, while the service life increased by 127%, compared with that of pure fabrics. Besides, the transfer film on friction counterpart and morphology of wear scar were analyzed to reveal the enhancement mechanism and self-lubricating mechanism.

4:00 pm - 4:20 pm
3998295: The Impact Corrosion Has on the Particle Wear Emissions Generated From Different Brake Rotor Material
Ishmaeel Ghouri, University of Leeds, Rochdale, United Kingdom

The new Euro 7 standard is set to be in place by 2025, which will be the first legislation that will cap the emissions produced by a brake system. This has caused brake manufacturers to find alternative solutions to reduce the emissions generated from the conventional grey cast iron (GCI) friction brake system. With electric vehicles (EVs) becoming the future of the modern vehicle, their regenerative braking system will cause the friction brakes not to be used as frequently as for an internal engine combustion vehicle. This may lead to a build-up of corrosion on the brake rotor that may not only affect the performance and service life of the brakes but also increase particle wear emission when braking. Aluminum metal matrix composite (Al-MMC) and plasma electrolytic oxidation (PEO) coated rotors could be an alternative solution to reduce the risk of corrosion failure, possibly produce lower brake emissions and also improve the efficiency of the EV by reducing its un-sprung mass.

ECP — Exhibit Hall B

Early Career Posters

4004752: Effectiveness of India's Bharat Stage Mitigation Measures in Reducing Vehicular Emissions: Bharat State -IV and Beyond
Kamaraj Duraisamy, Adipro USA, New York, NY

In an effort to reduce the impact of vehicular emissions on air quality, India has set Bharat Stage emission standards since 2000 and the country has now shifted to BS-VI norms from April 2020 onwards. The impacts of different stages of BS emission standards in controlling pollutant emissions are analyzed. The results show that the CO, NMVOC, OC, and BC emissions have reduced by 7%, 9.7%, 20%, and 5%, respectively in 2021 when compared to 2017. The NOx emission levels have increased by 4.9% in 2021 with reference to 2017. The NOx emissions show a positive correlation with vehicular population under BS-VI norms. The findings indicate that though the advanced emission control measures are expected to effectively reduce the emissions, the penalty of emitting new pollutant species and increasing NOx levels. This paper will detail of review of the requirements in Bharat Stage IV identify the gaps in curtailing emissions and suggest future courses of action.

4000420: Tribological Behavior of Recycled Polyvinyl Butyral (rPVB) and Glass Fiber Reinforced Polyamide 6 (PAGF) Blends in Dry and Micro-Abrasive Contacts
Leonardo Farfan-Cabrera, Andys Hernandez Peña, Andrea Guevara Morales, Ulises Figueroa Lopez, Ariadna Carmona-Cervantes, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Juan Pascual-Francisco, Universidad Politecnica de Pachuca, Zempoala, Hidalgo, Mexico

Contributing with recycling of polymers in automotive industry, recycled polyvinyl butyral (rPVB) from automotive windshields is being explored as a solid lubricant reinforcement for improving lubricity of other engineering polymers. This work aims to evaluate the tribological behavior of recycled polyvinyl butyral (rPVB) and glass fiber reinforced polyamide 6 blends in two-body and three-body abrasion by dry and micro-abrasive wear tests. Different polymer blends were produced by adding recycled polyvinyl butyral (rPVB) into a matrix of either a commercial polyamide 6 (PA6) Ultramid B3S, and a commercial 30% glass-fiber reinforced polyamide 6 (PAGF) Ultramid B3ZG6 from BASF. The tribological tests were conducted in an instrumented micro-abrasion tester for generating wear and measuring friction coefficient. Overall, rPVB was found to be effective to reduce CoF up to 10% and 50% for both PA6 and PAGF in dry condition.

4091228: Effect of Commercial Tackifiers on Adhesion and Tackiness of Calcium Soap Grease
Taylor Hudson, Jacob Bonta, Valvoline Global Operations, Lexington, KY

The objective of this study aims to quantify how different concentrations of commercial tackifiers affect the inherent tackiness and adhesion of a calcium soap grease at room temperature. This was studied by employing indention-retraction sequences, which were measured with a Tackiness Adhesion Analyzer based on the ASTM Method currently under development.

GSP Exhibit Hall B

Graduate Student Posters

4088419: Frictional Properties of Catheters and the Implications for Medical Procedure Safety
Kevin Moreno-Ruiz, Samuel Leventini, Ashlie Martini, University of California, Merced, Merced, CA; Andrei Cumpanas, Brandon Camp, Ralph Clayman, University of California, Irvine, Irvine, CA

The frictional properties of catheters determine their effectiveness in medical procedures. This study focuses on the tribological interactions between catheters and tissues, particularly examining the coefficient of friction (CoF). A series of catheters were ex-vivo tested to simulate insertion and retraction cycles in ureter tissues. With this approach, the catheters could be ranked based on their CoF, revealing significant differences in their performance. The results demonstrate that certain catheters reduce tissue trauma due to their frictional performance. The insights gained from this research are pivotal in guiding the development of catheters that are safer, potentially leading to reduced complications in ureteral catheterization.

4096599: Urea-functionalized Hydrophilic MoS_2 Particles as Potential Additives for Grease
Mohammad Humaun Kabir, Darrius Dias, Kailash Arole, Hong Liang, Texas A&M University, College Station, TX

Molybdenum disulfide (MoS_2) is favored in lubricant formulations for its versatile surface chemistry, yet it lags in performance relative to alternative antiwear agents. This research studies the effects of MoS_2 on tribological performance of a lithium grease. The MoS_2 particles were functionalized with hydrophilic urea molecules. Tribotesting showed that urea-modified MoS_2 enabled 22% reduction in friction and an 85% decrease in wear. Analysis indicated that urea's presence on MoS_2 surfaces and between layers resulting hydrophilicity on the surface and reducing van der Waals forces between the layers. This work suggests using functionalized hydrophilic molecules for advanced lubricant additives.

4096756: Annealing $Ti_3C_2T_z$ MXenes to Control Surface Chemistry and Friction
Kailash Arole, Micah Green, Hong Liang, Texas A&M University, College Station, Bryan, TX

Although surface terminations on MXene nanosheets strongly influence their functional properties, synthesis of MXenes with desired types & distribution of those terminations is still challenging. Here, it is demonstrated that thermal annealing helps in removing much of the terminal groups of molten salt-etched MXenes. The chloride terminations of ML-$Ti_3C_2T_z$ were removed via thermal annealing & which created some bare sites available for further functionalization of $Ti_3C_2T_z$. The annealed ML-$Ti_3C_2T_z$ was refunctionalized by −OH groups and 3-aminopropyl triethoxysilane (APTES). The −OH and APTES surface-modified ML-$Ti_3C_2T_z$ are evaluated as a solid lubricant, exhibiting a 70.1 & 66.7% reduction in friction. This enhanced performance is attributed to the improved interaction or adhesion of functionalized ML-$Ti_3C_2T_z$ with the substrate material. This approach allows for the effective surface modification of MXenes and control of their functional properties.

4088769: Synergetic Tribological and Electrical Performance of Lubricants with $Ti_3C_2T_z$ MXene as Additives
Mohsen Tajedini, Kailash Arole, Micah Green, Hong Liang, Texas A&M University, College Station, TX

This research explores the impact of incorporating Multi-Layer (ML)-$Ti_3C_2T_z$ MXene into lubricants on their frictional performance and electrical properties. Through electrochemical impedance analysis, we studied the effects of concentrations of ML-$Ti_3C_2T_z$ MXene in light mineral oil on friction and electrical conductivity. Results revealed that the addition of ML-$Ti_3C_2T_z$ MXene reduced friction by up to 60% while simultaneously enhancing electrical conductivity. The outcome of this research opened opportunities for improving lubricants tailored for electric vehicles.

4089596: Advancements in Lubrication Systems: Gadolinium-Doped DLC Coatings and Phosphorus-Containing Ionic Liquids for Enhanced Wear Resistance and Friction Reduction
Takeru Omiya, Albano Cavaleiro, Fabio Ferreira, University of Coimbra, Coimbra, Portugal; Filippo Mangolini, The University of Texas at Austin, Austin, TX

Enhanced techniques in managing friction and wear could significantly lower greenhouse gas emissions. Diamond-like carbon (DLC) coatings are noted for their durability, while phosphorus-containing ionic liquids (ILs) are recognized for their ability to reduce friction. This research focuses on DLC coatings enhanced with gadolinium (Gd-DLC) through high-power impulse magnetron sputtering. The study examined the effectiveness of these coatings in conjunction with two distinct phosphorus-containing ILs, noting an 80% reduction in wear when gadolinium was incorporated. Further analysis of the wear tracks post-experiment was conducted using sophisticated instruments like XPS and ToF-SIMS, providing insights into the interactions between the ILs and Gd-DLC coatings. These findings pave the way for advancements in lubrication system designs.

4090127: Enhancing Tribological Properties of MoS_2 Using a Chromium Underlayer
Nihal Ahmed, Sujan Ghosh, University of Arkansas at Little Rock, Little Rock, AR

Lightweight metals like Aluminum are highly sought after in the vehicle and aviation sectors due to their impressive strength-to-weight ratio. Despite its favorable strength-to-weight ratio, Aluminum has high COF and wear rate, limiting its use in vehicles and aviation industry. MoS_2 coatings are examined to improve these properties but face challenges like low adhesion to Aluminum and oxidation in air. By integrating a chromium underlayer known for its corrosion resistance and adhesive qualities, this research aims to overcome these drawbacks. The layers were applied using Physical Vapor Deposition (Sputtering). Results showed a substantial COF reduction from 0.7 to 0.28 and a doubled lifespan of the MoS_2 coating, indicating the chromium's significant role in enhancing durability and adhesion without impacting the low COF. However, adding a chromium top layer did not improve the coating's durability or COF, highlighting the complexity of optimizing such composite coatings.

4093793: Computational Analysis of Low-Speed, High-Load Journal Bearing
Asmita Schinde, Nicholas Garafolo, The University of Akron, Akron, OH

A computational analysis is presented addressing the performance and reliability of a large, low-speed, high-load journal bearing for the rolling mills industry. A multiphysics model has been developed utilizing EHL techniques coupled with thermal analysis and Navier Stokes in the oil supply region. A parametric study has been carried out for different load and speed. The numerical results shows that dynamic load plays significant role on the overall performance of the Hydrodynamic journal bearing. The numerical results shows good agreement with the experimental referents.

4092916: Microscale Tribochemistry of Diamond-like Carbon Coatings
Hind Flaih, Maureen Bowen, Ana Colliton, Eskil Irgens, Lucas Kramarczuk, Griffin Rauber, Zachary Van Fossan, Jordan Vickers, Brian Borovsky, St. Olaf College, Northfield, MN; Seokhoon Jang, Seong Kim,

Pennsylvania State University, University Park, PA; Zhenbin Gong, Lanzhou Institute of Chemical Physics, Lanzhou, China; Zhe Chen, Zhejiang University, Hangzhou, China

We present a study of sliding friction on hydrogenated diamond-like carbon (H-DLC). We load a stainless-steel microsphere onto a H-DLC surface coated onto a quartz crystal microbalance (QCM). By resonating the QCM, we generate a 5 MHz reciprocating shear motion at the interface with track lengths of 1 to 100 nm. The QCM performs friction measurements with the normal load fixed between 5 μN and 1 mN. These measurements can be sustained even when a secondary lateral motion is superimposed using a piezo stage, with a track length of 20 μm at 40 Hz. We observe a substantial reduction in friction over time as long as the track length exceeds a threshold value near 15 nm. We associate this drop in friction with the "running-in" behavior of H-DLC and its shear plane chemistry. We report measurements of sliding shear stress as a function of pressure, both before and after run-in. Finally, we explore relationships between the sliding distance, contact size, and the tribochemistry of H-DLC.

4091916: Predicting Electric Vehicle Transmission Efficiency Using a Thermally Coupled Lubrication Model
Joseph Shore, Amir Kadiric, Imperial College London, London, United Kingdom; Ning Ren, VGP Holdings, LLC (Valvoline), Lexington, KY

A model for predicting EV transmission efficiency is presented. Incorporating an iterative scheme, measured oil rheology is accounted for when predicting gear meshing friction, allowing nominally identical fluids to be compared. Gear churning losses are predicted with a newly devised expression which accounts for the non-monotonic relationship between churning torque, speed, and viscosity by considering the dynamic oil surface profile during operation. Gear meshing and churning loss predictions are complemented by an existing semi-empirical bearing loss model. Transmission temperature evolution during operation is predicted with a thermal network approach. The model is applied to the transmission of a typical passenger EV and validated with in-situ temperature measurements in real-world road tests. Finally, oil parameter studies are used to assess the influence of various properties on efficiency. One such study shows that the optimal oil viscosity strongly depends on vehicle duty.

4091717: Flow Visualization of Surface Textured Mechanical Seals by Particle Tracking Velocimetry
So Makishima, Yuichiro Tokunaga, Iwa Ou, Eagle Industry Co., Ltd., Sakado-shi, Saitama-Ken, Japan; Kazuyuki Yagi, Kyushu University, Fukuoka, Japan

A developed textured mechanical face seal, which has a Rayleigh step for dynamic pressure and a reversed Rayleigh step to cause cavitation to prevent leakage, has superior sealing and lubricating performance. It also has deep grooves, tens to hundreds of microns in depth, which has an important role in supplying fluid into the Rayleigh steps. However, there is a lack of understanding of the flow in the grooves. In this study, tracer particles were used to visualize the flow within the deep grooves to gain a better understanding of the flow. Particle Tracking Velocimetry (PTV) was used to analyze the fluid flow and velocity. Computational Fluid Dynamic (CFD) analysis was also conducted for comparison. It was found that the fluid flow in the deep grooves varied significantly with groove depth. In the experiments, the phenomenon of air bubble accumulation in the deep grooves was observed with increasing depth, and the results for this condition differed from those of the CFD analysis.

4093797: PTFE Composites: Effect of PTFE Composite Filler Materials on Dry Sliding Wear Performance
Eliot Berberich, Mark Sidebottom, Miami University, Oxford, OH

Polyfluorotetraethylene (PTFE) and a number of PTFE composites were evaluated in dry conditions in a humidity-controlled laboratory air environment. All wear and friction testing was completed using a linear reciprocating flat-on-flat tribometer for 25 km of testing at experimental conditions of 50 mm/s and 6.3 MPa of pressure against polished 304 stainless steel. The results of the testing were extremely variable, with some composite samples unable to complete testing due to excess wear, and some

samples, like glass-filled PTFE, achieving ultra-low wear rates (K ≤ 5x10-7). Results from testing resulted in groups of polymer composites with high, moderate, and low wear regimes. Additional characterization on low materials will be used to identify if mechanisms within these composite systems align with those found in previous low wear PTFE composites.

4091258: Enhancing Tribological Properties of Ni-Cr Thin Film Coatings by Incorporating MAX Phase Ceramic.

Aaron McCollum, Nihal Ahmed, Sujan Ghosh, University of Arkansas at Little Rock, Little Rock, AR

Conventional Ni-Cr coatings are known for their substantial protection against wear and corrosion. However, their coefficient of friction (CoF) ranges between 0.5 and 0.55, which may not meet the requirements of applications demanding lower friction levels. The integration of MAX phase particles, celebrated for their unique blend of metallic and ceramic properties, into the Ni-Cr matrix, was aimed at overcoming this limitation. The presence of the MAX phase was confirmed using EDS. The topological study showed a very conformal Ni-Cr coating when MAX phase was added. The tribological performance was assessed using a linear ball-on-disk apparatus to mimic real-world friction scenarios. The incorporation of the MAX phase slightly reduced the CoF to 0.45-0.5. Furthermore, durability tests revealed an increase in wear life by 7 to 8 times compared to the unreinforced coatings. Findings demonstrate that including MAX phase particles in Ni-Cr coatings can effectively enhance wear resistance.

4090898: Unveiling the Potential of PEO-Chameleon Coatings on Titanium Alloys Across Varied Environments and Temperatures

Vanessa Montoya, Ali Zayaan Macknojia, Diana Berman, Andrey Voevodin, University of North Texas, Denton, TX

Dual-phase coatings, developed by combining plasma electrolytic oxidation (PEO)-modified substrates with solid lubricants such as graphite, MoS2, and BN, provide an efficient concept for the adaptation of materials under a wide range of conditions. The PEO layer enhances hardness and load support, while the solid lubricant powders minimize friction. Here, we evaluate the adaptation mechanism under different environments, temperature, and contact pressure conditions. In order to obtain and analyze the coating we conducted advanced characterization techniques, such as scanning electron microscopy (SEM/EDS) and Raman Spectroscopy. The ultra-low friction behavior of the composite coating was attributed to the low shear strength of solid lubricants, along with the effective adhesion and integration of the chameleon coating with the PEO sublayer under high contact pressures during sliding.

4071859: Exploring Line Contacts with Electrical Impedance Spectroscopy: A New Frontier in Film Thickness Assessment

Manjunath Manjunath, Patrick De Baets, Dieter Fauconnier, Ghent University, Ghent, Flanders, Belgium; Simon Hausner, André Heine, Flucon Fluid Control GmbH, Wistobastraße, Germany

This article focuses on utilizing electrical impedance spectroscopy (EIS) to assess global and contact impedances in roller bearings. The primary goal is to quantitatively predict lubricant film thickness in EHL and investigate impedance transitions from ohmic to capacitive behavior during the shift from boundary lubrication to EHL. Measurements of electrical impedance, bearing and oil temperature, and frictional torque are conducted on a CRT bearing under pure axial loading at various rotational speeds and supply oil temperatures. The impedance data is analyzed to measure lubricant film thickness using impedance and capacitance methods. The translation of impedance values to film thickness is compared with analytically estimated values using the Moes correlation, showing robust agreement within 2% for EHL film thickness. Monitoring bearing resistance and capacitance via EIS reveals clear transitions from boundary to mixed lubrication and from mixed lubrication to EHL.

4078320: The Role of Tribology in the Circular Economy: Effect of Shaft Misalignment on Energy Consumption and CO_2 Emissions
Mkpe Kekung, Lulea University of Technology, Luleå, Sweden

This study investigates the impact of shaft misalignment on energy consumption and CO_2 emissions within the context of tribology and the circular economy. It aims to evaluate the energy and CO2 emission consequences of varying degrees of misalignment in industrial machinery and to formulate practical recommendations for improvement. A combined experimental and theoretical approach was used to analyze the impact of shaft misalignment in operational inefficiency, energy loss, and increased CO_2 emissions. Key findings from the experimental study demonstrate that even minor misalignment can significantly affect energy consumption and emissions, which emphases the need for proper alignment in industrial machinery. The study highlights the necessity of incorporating tribological principles in the design and maintenance of mechanical systems to achieve better environmental outcomes, such as enhanced component longevity, decreased energy consumption, and reduced CO_2 emissions.

4082233: Evaluating Grease Behavior Under a Simulated Space Environment
Michelle Padilla, Jose Morales, Ashlie Martini, University of California, Merced, Merced, CA; Sara Cantonwine, Juan Flores Preciado, SpaceX, Hawthorne, CA

Mechanical components that operate in space need high-performance greases to decrease wear and increase operating duration. To evaluate the tribological behavior of such greases, it is necessary to test and analyze the behavior under space conditions. Here, a series of tests was conducted on various Perfluoropolyether (PFPE), Multiply alkylated cyclopentanes (MAC), and Polyalphaolefin (PAO) greases. The tests included ball-on-disk tests and four-ball tests under both typical air conditions and nitrogen conditions. Nitrogen was used to simulate space conditions as it is relatively unreactive and can create a low oxygen environment. After completing the comprehensive testing and comparisons, it was observed that environmental conditions play a significant role in the grease performance.

4083649: Improved Lubricating Performance of Nanodiamonds with Organic Friction Modifier
Afrina Khan Piya, Liuquan Yang, Ardian Morina, University of Leeds, Leeds, West Yorkshire, United Kingdom; Nazanin Emami, Lulea University of Technology, Lulea, Sweden

The frictional performance of a newly developed nano-lubricant, comprising PAO oil, GMO, ZDDP, and nanodiamonds, was analyzed using a reciprocating tribometer. The addition of 0.05 wt% nanodiamonds resulted in a 60% reduction in the coefficient of friction (COF) at 80°C. The synergistic effect of the nanolubricant significantly influenced frictional performance by facilitating the formation of chemically reactive additive layers that mechanically interlocked the nanodiamonds. From both commercial and environmental perspectives, this study offers a promising approach to reducing harmful concentrations of sulfur and phosphorus by incorporating small concentrations of nanodiamonds without compromising the protective performance level of contacting surfaces. Further exploration of the synergy between nanolubricant additives could lead to their broader application in the lubricant and automotive industries.

3985334: Accelerating the Calculation of Lubrication Systems Using AI Methods
Zhaoyang Guo, Jiabei Wang, Jiusheng Li, Shanghai Advanced Research Institute, Shanghai, China

Reliability prediction for equipment is a key issue in the industrial and maintenance sectors, as it helps in early identification of potential failures and taking appropriate maintenance measures to reduce production time and repair costs. In recent years, with the improvement in data collection techniques and computational capabilities, data-driven methods and advanced prediction technologies have started to lead the development of reliability engineering. However, this approach has inherent limitations and cannot meet the requirements of modern industry. In this article, we addressed the challenges posed by

the diversity and complexity of lubricating grease systems, utilizing accelerated algorithms, and enhanced the computational capabilities and precision data for the microstructure of lubricating greases to establish a predictive model for the properties and formulations of future lubricating greases.

3981379: Decoupling Activation Volume via Dynamic Electron Transfer in Stress-Driven Chemical Reactions

Yilong Jiang, Southwest Jiaotong University, Chengdu, China

Density functional theory calculations are used to investigate the general rules of charge transfer underlying activation volume in controlling typically mechanochemical reactions process. It is found that the activation volume could be decoupled into the electronic contributions from interface chemistry and bulk physical deformation, which are commonly linear dependent with the contact pressure. Therefore, the activation volume may be indeed derived from the stress-driven charge transfer underlying cooperative competition between interfacial chemistry and bulk region. This competition is related to the stiffness change from bulk to slab. The magnitude of stiffness change represents the degree to which the interface atoms modify the bulk properties, which is directly related to the contribution of different regions to the activation volume.

3982324: Investigating the Friction and Wear Properties of Polymer Laser Sintered Components

Kieran Nar, The University of Sheffield, Sheffield, United Kingdom

Today, Additive Manufacturing (AM) is ubiquitous within industry. Laser Sintering (LS) in particular is one of the most well-established polymer AM processing techniques due its capability of producing geometrically complex and functional components. However, despite this the adoption of laser sintered components for end-use applications remains hindered due to an incomplete understanding of their in-service behaviors, particularly when subject to dynamic contact. Therefore, this work gives an overview of the pertinent sliding phenomena discovered whilst investigating the friction and wear properties of laser sintered Nylon-12 components. More specifically, ball-on-flat, pin-on-disk, dry sliding tests were performed in accordance with a design of experiments to highlight the individual and compound influence normal load, sliding velocity and contact configuration had on the coefficient of friction and wear rate of sample surfaces examined.

4000831: A Novel Multiphase CFD Model for Investigating the Flow Dynamics of Aerated Bubbles in Bearing Lubrication

Ujjawal Arya, Farshid Sadeghi, Purdue University, West Lafayette, IN

This study delves into the intricate flow dynamics of aerated bubbles within lubricating oil during bearing operation. To achieve this objective, a novel Computational Fluid Dynamics (CFD) model was prepared in Ansys Fluent, which simulates the movement of these bubbles within the bearing chamber. This model utilizes a coupled solver that incorporates a two-way transition algorithm between the Discrete Phase Model (DPM) approach, which was used to model bubble dynamics, and the Volume of Fluid (VOF) approach, which was used to depict oil starvation inside the cage pocket. Results from this CFD model were validated with the experimental observations for the bubble motion from the Counter Rotating Angular Contact ball bearing Test Rig (CRACTR). This coupled CFD model demonstrates an efficient and thoroughly validated modeling approach to examine the complex phenomenon of multiphase oil flow in bearing lubrication, adeptly accounting for the impact of both aeration and oil starvation.

4002330: Observation of Crack Propagation Process Initiated From Rolling Sliding Contact Under Lubrication with Fully Formulated Lubricant

Kaito Yoshioka, Hayato Monzen, Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan; Takuto Kunii, Ryotaro Ohashi, Graduate School of Tokyo University of Science, Katsushika, Tokyo, Japan

In recent years, the popularity of electric vehicles (EVs) has significantly increased to reduce energy consumption. To improve power efficiency of electric vehicle, it is required to improving fatigue wear resistance inside gear boxes due to the high rotational speed of motors. Lubricants are being made lower in viscosity to reduce energy loss and are expected to operate under more severe lubrication conditions. However, the occurrence mechanism of pitting, a type of surface fatigue damage, is not fully understood. In this study, to investigate the mechanism of propagation of fatigue damage under tribofilm formation, triple-contact friction tests were performed with a fully formulated lubricant depending on sliding cycles. Xray photo was used to measure the chemical bonding and thickness of the tribofilms. Crack were observed using white light interferometry and scanning electron microscopy by investigating cross sectional images of micropitting.

4002331: Effects of the Heat Treatment on Fatigue Wear of Gear Steel under Rolling/Sliding Contact Conditions

Hayato Monzen, Tokyo University of Science, Katsushika, Tokyo, Japan; Takuto Kunii, Kaito Yoshioka, Ryotaro Ohashi, Kaisei Sato, Shinya Sasaki, Graduate School of Tokyo University of Science, Katsushika, Tokyo, Japan

In recent years, as electric vehicles (EVs) become more widely used, it is important to suppress fatigue wear of reduction gears, which is caused by the high rotation speed of motors. However, fatigue wear is influenced by many factors, and its mechanism is not fully understood. This study focused on the effects of surface heat treatments (carburizing and quenching and gas soft nitriding) on gear steel. The experiment used a triple-contacts friction tester to investigate the effects of varying the surface pressure and slip rate in a full-formulation lubricant. Wear damage was evaluated by observing the roller surfaces using white light interferometer and confocal laser microscope. Moreover, to clarify the damage mechanism, microstructural changes in the cross section and the depth of damage were evaluated by scanning electron microscopy (SEM). In this presentation, we report the results of these studies.

4003896: Understanding the Additive Compatibility and Tribological Properties of Regular and High Oleic Soybean Oil Lubricants

Piash Bhowmik, Yachao Wang, Clement Tang, University of North Dakota, Grand Forks, ND; Brajendra Sharma, Majher Sarker, USDA/ARS/NEA/ERRC, Wyndmoor, PA; Sougata Roy, Iowa State University, Ames, IA

With the increasing demand for biobased lubricating oils in research, there's a growing emphasis on the exploration of various oil varieties. Especially there is rising interest in high oleic oils, known for their higher stability compared to conventional oils. This investigation is focused on revealing the compatibility of both regular and high oleic soybean oils with select antiwear and antioxidant additives along with a comparative performance analysis of these additives. Reciprocating friction, wear and electrical contact resistance-based analyses were conducted to evaluate additive compatibility and wear mechanisms at room temperature lubrication conditions. Interestingly, regular soybean oil with additives exhibited a 28% improvement in wear resistance, whereas high oleic soybean oil with additives demonstrated only an 8% increase. SEM-EDS analysis was conducted to uncover the underlying scientific factors responsible for the distinct properties of additized lubricants.

4005030: Exploring the Tribological Behavior of Additively Manufactured Al-6061 Alloy for Space Application

Pial Das, Iowa State University, Ames, IA; Matthew Mazurkivich, Sara Rengifo, Marshall Space Flight Center NASA, Huntsville, AL; Sougata Roy, Iowa State University, Ames, IA

For a prolonged space mission, the frictional energy loss accumulates and becomes substantial with limited lubrication scope. Al6061 has been a promising candidate for space applications due to several advantages like corrosion resistance, strength-to-weight ratio, formability, and insensitivity to the

extraterrestrial environment, while additive manufacturability of this alloy can give true freedom of fabrication. The tribological performance of additively manufactured Al6061 parts has yet to be widely investigated. In this study, we investigated the additive manufacturability and tribological performance of Al6061 fabricated through Wire Arc Additive Manufacturing (WAAM) and Laser-Powered Direct Energy Deposition (LP-DED). Additional investigations on TiC-reinforced Metal Matrix Composite (MMC) were also performed. Post fabrication, detailed microstructural characterization, and tribological behavior in vacuum were conducted with detailed analyses of dominant wear mechanisms.

Participants Index 2024

Includes technical program authors, Commercial Marketing Forum (CMF) presenters, Early Career Poster (ECP) and Student Poster (SP) authors.

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