Electric Vehicles III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3644979: The Impact of Bearing Currents on the Failure Modes of Motor Bearings in Electric Vehicles
Duncan Nicoll, University of Southampton, Portsmouth, Hampshire, United Kingdom

The rate of growth of the electric vehicle (EV) industry is increasing, with current predictions estimating that by 2030 EVs will account for 69% of UK passenger car sales. Approximately 5% of electric motor failures result from rolling contact fatigue linked to electric currents across the bearings [2]. These “bearing currents” include leakage and induced electrical currents that flow through motor bearings. Bearing currents result in damage to the motor bearings due to a build-up of capacitance across the insulated gap between the roller element and raceway leading to a breakdown of the insulating lubricant film resulting in r arcing between the two surfaces. This discharge results in localised heating of the surface and the displacement of material. This study focuses on understand the range of electric currents and their frequencies found in motor bearings within the electric vehicle industry and their impact on the bearing failure modes and reduced operation life of the bearing.

8:30 - 9 am
3648072: An Experimental Study of Load-Independent Power Losses in an Electric Vehicle Gearbox at High Speeds
Alexander MacLaren, Amir Kadiric, Imperial College London, London, United Kingdom

Lubrication systems in Electric Vehicles (EVs) must balance the competing requirements of mitigating tribological damage and maximizing transmission efficiency over a very wide speed range. At low speeds, high lubricant viscosity is required to prevent surface damage to gears and bearings, whereas at high speeds, lubricant churning losses limit transmission efficiency, and low-viscosity lubricants are desirable. EV motor speeds considerably exceed the limits of validity of existing churning loss models, necessitating further investigation in-situ at high speeds to inform transmission design and lubricant optimization. In this study, load-independent power losses in a two-stage, single speed reduction gearbox from a popular passenger EV are evaluated using a newly developed test rig. The contribution of each source of loss is compared to that predicted by a number of empirical and semi-analytical models, and implications for future modelling and design of EV transmissions are discussed.

9 - 9:30 am
3645195: Investigation of the Voltage Induced Fluting Pattern Progression in Thrust Ball Bearings
André Harder, Steffen Puchtler, Eckhard Kirchner, TU Darmstadt, Darmstadt, Germany

Voltage induces bearing damage is a well-known phenomenon in electric drives. The potential difference between the rotor and the stator of the drive can lead to an EDM current through the bearing, which damages the raceways and the lubricant. Although this phenomenon has been known for several years, there is no established method to estimate the lifetime of a bearing under damaging electrical current. This work presents an approach to quantify the extent of the bearing damage by measuring the geometric changes of the rolling surface over time. Therefore, experimental results show the damage progress on the raceways of thrust ball bearings, which are inspected with a white light interferometer. The thereby quantified geometry change is correlated with the condition monitoring data like acceleration and impedance measurement for various loads, enabling the synthesis of an empirical calculation model for electrical bearing damage.

9:30 - 10 am
3688134: Innovative design of electrical lubricants test rig for e-grease and e-fluids
Deepak Halenahally Veeregowda, Debdutt Patro, Ducom Instruments, Bangalore, India

A new generation of component test rigs relevant to electric vehicles have become essential for lubricants industry. In this talk, we will describe our innovative product design of Electrical Lubricants Test Rig with a two stage lubricated bearings that can be tested up to 30,000 rpm and at load up to 15 kN. Bearings can be lubricated with grease or oils, that can be heated up to 150 deg C using our proprietary heat exchanger. Rotor dynamics and cooling system are key techniques to reduce its downtime and improve safety of the operator. Each bearing station is embedded with smart sensors that captures the vibration, noise, bearing friction and temperature of the lubricated system. The sensor system automates the process of data collection, cloud storage, analytics, and reporting. We will share a case study that describes the performance of few electrical lubricants widely used in electric motor and electric wheel hubs of battery powered EV's.

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

10:30 - 11 am
3663058: Electrified Driveline Fluid Durability Testing and Profiling
Marshall Hudson, Southwest Research Institute, San Antonio, TX

Electrified vehicles are growing in market share and complexity and the driveline lubricants are required to perform in unique environments, often for the life of the vehicle without fluid change. Despite this, many manufacturers are specifying driveline fluids originally formulated for conventional axles or automatic transmissions. This means opportunities to optimize and/or improve the fluids for an electrified driveline exist if more was known about the manner in which these fluids age and their useful life. A selection of electrified vehicles have been heavily instrumented and run for 100,000 miles on a chassis dyno using a unique drive cycle. Changes in the fluids' bulk properties, oxidation, conductivity, electro-rheology, and aeration performance were observed over the life of the fluid, and the change in overall vehicle efficiency attributable to the fluid aging was quantified.

11 - 11:30 am
3669349: Electrification Effects on the Tribological Behavior of Electric Vehicles Drivetrain Gear Materials
Leonardo Farfan-Cabrera, Julio Cao-Romero-Gallegos, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Ali Erdemir, Texas A&M University, College Station, TX

Electrification of electric vehicles' drivetrains can give rise to damaging shaft voltages/currents that can impair the long term tribological performance of critical components (i.e. bearings, gears, etc.) resulting from electrical discharges at sliding interfaces. Particularly, gears are used in drivetrain architectures comprising electric motor coupled to single-speed or multi-speed transmissions which could be very vulnerable to such problems. Thus, shaft voltage/currents can interfere with the contact interfaces of bearings and gears thus altering their normal tribological behavior. This research focuses on investigating the electrification effects caused by different ranges of shaft currents (DC) on the tribological behavior of common gear materials in pin-on-disc testing under lubricated conditions. The differences in electrical contact resistance, CoF, wear rates and underlying mechanisms triggered by electrified sliding contacts are examined in detail and presented.

11:30 am - 12 pm
3663243: Importance and Challenges of Greases in Electrical Vehicles – ICE vs EV Testing Requirements
Richard Baker, TriboTonic Ltd, London, United Kingdom

Today, all moving components on an automobile are investigated for friction and energy losses. Passenger cars and light trucks are major grease users, and a typical light vehicle may use up to 50 different greases to lubricate components. However, only a handful of these impact energy efficiency.

This projected uptake in EV's, and hence electric motors, will increase grease volumes in a vehicle. A modern, high-end vehicle, could employ upwards of 40. Combined grease volumes could equate to approximately two kilograms per vehicle, and Lubrizol estimates 5,000 tons of grease could be required simply to lubricate electric motors in new vehicles each year[1] This presentation will highlight the challenges on future grease formulations – where they will (and won't) be required for EV's and how the industry is currently going about testing and qualifying greases for EV applications. 1 F+L Magazine, October 9, 2018

3B Southern Hemisphere II

Lubrication Fundamentals III - Stability

Session Chair: Brendan Miller, Chevron Oronite Company, Richmond, CA
Session Vice Chair: TBD

8 - 8:30 am
3645610: Antioxidants for Next Generation Automotive Lubricants
Jun Dong, Songwon Industrial Group, Glen Allen, VA

To help maintain designed performance and service life, antioxidants have been a vital component in nearly all types of lubricants. As the lubricant industry is embarking on next generation engine oils and new types of lubricants suitable for electrical vehicles (EVs), the demands for antioxidants especially high performance antioxidants will increase. In our view, the traditional amine and phenolic types will continue to be the preferred antioxidants of choice. New classes of antioxidants, however, could become sought after if they can overcome some of the performance barriers associated with the traditional antioxidants while offering formulation simplicity and cost-effectiveness. This presentation outlines some of the oxidation-related challenges in the development of next generation automotive lubricants and discuss solutions being developed.

8:30 - 9 am
3647545: Development of Liquid Aminic Additives as Effective Antioxidants
Kevin Sterling, Brian Casey, Vincent Gatto, Vanderbilt Chemicals LLC, Norwalk, CT

Antioxidants are essential components in lubricant formulations to ensure robust and reliable performance. Recent potential toxicity issues are creating concerns regarding the long-term viability of low molecular weight aminic antioxidants. New antioxidant technologies are needed to meet future demands in terms of improved safety, ease of handling, and performance. Low volatility and high molecular weight liquid aminic antioxidants have been developed and compared to the traditional, and more volatile solid aminic antioxidants. The impact of alkyl chain length and branching on the physical properties and high temperature performance profiles was evaluated. Additional bench testing assessed potential synergies between the antioxidants and other traditional lubricant additives. The results indicate that these liquid aminic additives are potent antioxidants capable of meeting or surpassing the performance of traditional antioxidants particularly in high temperature oxidation tests.

9 - 9:30 am
3640725: Which Lubrication Certification is Right For Me?
Michael Holloway, 5th Order Industry, Highland Village, TX

There are thousands of professional certifications for seemingly all disciplines. In the world of maintenance and reliability there are at least ten (10) for lubrication alone. With such an offering, it can be confusing (and argumentative) as to which certification is best suited for a position. The intent of this session is to provide a structure to the offerings and align with job functions.

9:30 - 10 am
3643544: Varnish Resistance Prediction Indicator (VRPI) for Group I-IV Lubricants
Joseph Fotue, TotalEnergies Cameroon, Douala, Cameroon

In recent years, industries have witnessed an increase in varnish - related problems. Varnish is one of the most harmful contaminants impacting lubrication systems severely and leading to component failures, unplanned shutdown, and costly downtime. Varnish precipitation in a system is affected by operating conditions, lubricant, and the environment. Responding to varnish with a suitable solution is critical and helpful. Many solutions exist to mitigate varnish in a system. However, since prevention is better than cure, the first line of defense is choosing an excellent varnish resistance lubricant. Is there a single indicator that can show the lubricant's varnish resistance? If yes, this indicator should depend on oxidation resistance and product solvency. In this presentation, we are proposing the VRPI (Varnish Resistance Prediction Indicator) to help users easily evaluate different formulations and to make better purchasing decisions.

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

10:30 - 11 am
3669107: Mechanism of Antioxidant Action of Fullerenes in Lubricating Oil
Daiki Takasaki, Tomomi Honda, University of Fukui, Fukui, Japan

In recent years, the sliding condition of machine elements has changed to higher speed and contact pressure. ZnDTP has been subjected to severe operating environments, where it quickly turns into sludge and causes various problems. Therefore, there is a need for a new additive to replace ZnDTP, and fullerenes are attracting attention. Fullerenes are expected to be used as antioxidants in lubricants because of their radical trapping ability. In this study, in order to elucidate the antioxidant mechanism of fullerenes with radical trapping effect, fullerene containing oils with different amounts of fullerenes were prepared, and oxidized by electric discharge in the oil, and the relationship between the amount of fullerene contained and the radical trapping property was investigated. As a result, it was found that there was a difference in the radical trapping characteristics depending on the fullerene content, indicating that the fullerene undergoes a structural change.

11 - 11:30 am
3669459: About the Nature of Precursors to Oil Varnish
Nicole Doerr, Christoph Schneidhofer, Krisztian Dubek, AC2T research GmbH, Wiener Neustadt, Austria

The harmful potential of oil varnish is well known, which can cause serious damage in components such as bearings, valves, filters and cooling units. This work focused on the morphological and chemical characteristics of precursors to oil varnish. To capture such particles, a sensor based on a mechanically oscillating micro electromechanical system (MEMS) cantilever was utilized, which selectively accumulated the particles on the sensor surface. Exemplarily, artificial alteration of a turbine oil revealed spherical precursors with a diameter of about 1 µm arranged in chains. The most abundant elements found were carbon and oxygen, attributed to products of base oil oxidation. Another feature was the occurrence of phosphorus, which derived from anti-wear additive.

11:30 am - 12 pm
3653667: Multiscale Molecular Modeling of Deposit Control
Anil Agiral, Binbin Guo, Lubrizol Corporation, Wickliffe, OH; Esra Kan, Erol Yildirim, Middle East Technical University, Ankara, Turkey

Preventing deposit formation is a critical performance property for engine oils. In this study, we investigated the complex mechanisms of deposit control by bringing experimental colloids science and multiscale molecular modeling to present a unified approach. We started from first principles quantum chemistry calculations of exact electronic structures and interactions between base oil-dispersant-detergent and insoluble particles that cause deposit formation. After quantum chemistry calculations, we carried out molecular dynamics simulations where we modeled up to 5 nm scale to understand solvation

and mixing mechanisms. Finally, coarse-grained simulations were performed to observe system behavior under 50 nm, to explain experimental observations, and elucidate deposit control mechanisms of detergent and dispersant additives on a larger scale. We will discuss molecular level, mesoscale, and microscale mechanisms of controlling the rate and extent of aggregation and deposit formation.

3C Southern Hemisphere III

Commercial Marketing Forum III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am - **Open Slot**

8:30 - 9 am
Lubrication Specialties, Inc.

9 - 9:30 am
3647752: Biosynthetic Technologies: Biocea(TM) – Sustainable, Safe and Performance-driven Metalworking Fluid Additives for Real World Formulations
Jeffrey Mackey, Biosynthetic Technologies, Indianapolis, IN

Biosynthetic® Technologies has developed a revolutionary new class of high-performance bio-based additives for metalworking fluids, called Biocea™. These novel sustainable additives use the patented estolide technology and are biobased, biodegradable, non-bioaccumulative, and non-toxic. Biocea additives deliver superior lubricity, film strength, biostability, hydrolytic stability, oxidation stability, and increased polarity on both ferrous and non-ferrous alloys. They are derived from natural oils and improve the overall quality of formulated metalworking fluid. Biocea additives can result in increased productivity, reduced waste and down time, and lower cost in your overall manufacturing operation. This 30 minute session will be a MUST for anybody looking to develop a sustainable and safe metalworking fluids.

9:30 - 10 am
Munzing

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

10:30 - 11 am
Colonial Chemical Company

11 - 11:30 am
The Lubrizol Corporation

11:30 am - 12 pm
BASF Corporation

Tribotesting III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3666623: Finite Element Analysis of Dynamic Contact Pressure on Rotary Shear Biomass Comminution System
Lianshan Lin, Jim Keiser, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; David Lanning, Forest Concepts, Auburn, Washington, Åland Islands

Size reduction is a key processing step for biomass-fuel conversion. Traditional methods such as hammer mills, grinders, and chippers are limited to producing larger particles or particle sizes distributed over a wide range causing poor flowability and a large amount of fines that cannot be used in conversion. The Crumbler® rotary shear has been developed to process woodchips into more uniform particles for improved flowability and higher thermochemical yields. However, this milling unit experiences significant abrasive wear on its feeding teeth and cutters when processing debris-contaminated feedstocks. Comprehensive dynamic finite element analysis was used to study the variations in contact pressure between the woodchips and cutters with different tooth designs, including various tooth shapes, heights and edge angles. Contact analysis of woodchips on the clearing plate provided insights in tailoring the edge profile to reduce the pressure at contact regions and improve woodchip flow.

8:30 - 9 am
3647499: In-Situ Digital Holographic Microscopy for Polymer Transfer Film Characterization
Kian Kun Yap, Marc Masen, Imperial College London, London, United Kingdom; Pushkar Deshpande, Kilian Wasmer, Swiss Federal Laboratories for Materials Science and Technology, Thun, Switzerland; Jennifer Vail, DuPont, Wilmington, DE

Polymers are often referred to as self-lubricating materials due to the friction-reducing transfer films that form when they slide against metals. A common way to study the films is to analyze the surfaces post-test when they are fully-developed. This overlooks their evolution which is crucial for understanding the system. We investigate the development of transfer films using an in-situ pin-on-disc tribometer which is equipped with a digital holographic microscope. This microscope enables real-time surface profile measurement of the worn disc surface in motion. Our research focuses on the sliding of PTFE against AISI 304. Two distinctive wear mechanisms are found. Mild wear is characterized by the formation of oxide protective layers on the PTFE surface, while severe wear is indicated by the formation of highly mobile PTFE transfer lumps on the steel. These results allow us to better understand the transfer mechanisms of polymers and their roles in governing friction and wear.

9 - 9:30 am
3662733: New Methodologies Indicating Adhesive Wear in SRV Load Step Tests
Gregor Patzer, Optimol Instruments GmbH, Munich, Bavaria, Germany; Mathias Woydt, Matrilub, Berlin, Germany

When looking in detail at analyses of the tribological load-carrying capacity of lubricants, it becomes apparent that an exclusive evaluation of the evolution of the coefficient of friction alone cannot provide any sufficient criteria for determining the occurrence of adhesive failure. Extending the knowledge base by combining several criteria in order to draw a clearer picture of adhesive wear mechanisms is urgently required. Due to the specific characteristic of the linear actuator of SRV, the evolution of coefficient of friction can be combined with stroke signals and/or the electrical contact resistance and/or contact temperature and/or acoustic emission and/or stroke zero position, frictional power input and further derived parameters.

9:30 - 10 am
3665014: Development of a 2-Body Abrasion Test for Cemented Carbides (Hardmetals)
Kenneth Budinski, Bud Labs, Rochester, NY

ASTM B611 has been the gold standard for 3-body abrasion testing of cemented carbides for decades. However, this test does not apply to metals and ceramics because of adhesive interactions with the steel wheel used in the test to force loose abrasive against the test specimen. This paper describes a two-body abrasion test that can be used to rank cemented carbides with other material systems (metals, ceramics, coatings etc.). It is a modification of the ASTM G174 abrasive loop test using a more aggressive alumina belt as the abradant. The loose abrasive particles and steel contacting wheel in the ASTM B611 test are replaced by line contact of a test specimen with a fixed abrasive belt over a drive spindle. The test details and its development are described.

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

10:30 - 11 am
3667828: Designing a Simple Test to Measure and Rate Lubricant Controlled Friction Reduction
Marc Ingram, Ingram Tribology Ltd, Carmarthen, United Kingdom; Izzy Roots, Thomas Welham, Clive Hamer, PCS Instruments, London, United Kingdom

The ability of a lubricant to reduce friction and increase machine efficiency is one of its main functions. However, a standardized test to measure lubricant controlled friction reduction does not exist. In this work we take a common tribometer and design a test sequence to allow the friction reduction of any lubricant to be measured and rated, quickly and accurately. The viscosity of the lubricant is used to calculate appropriate entrainment speeds to maintain a constant test severity. A set sliding distance is determined experimentally to ensure that a stable tribofilm is formed. The lubricants are then rated in terms of their ability to maintain low friction in the boundary, mixed and full film regimes, using data from the normalized Stribeck curves. The proposed method has been designed to ensure good repeatability, across a range of lubricants (engine oils, transmission fluids, hydraulic fluids, gear oils).

11 - 11:30 am
3667558: Digitalization & Tribology: Advances in Tribofilm Image Processing
Oluwaseyi Ogunsola, Shell Global Solutions (US) Inc., Houston, TX; Chaitanya Pradhan, Aarthi Thyagarajan, Vishal Ahuja, Nitish Nair, Shell India Markets Pvt. Ltd, Bangalore, India

Tribofilm formation capabilities and enhanced wear protection continues to be a relevant topic for lubricants across a wide range of applications. Recently, Shell developed the Lubricant Uniformity Predictor via Image Treatment and Analysis tool, a digital toolkit to process Mini Traction Machine (MTM) Tribofilm images generated anytime, globally. By leveraging digitalization for image processing, several previously un-investigated, un-unidentified Tribofilm image features were developed and analyzed for historical Tribofilm images. This presentation will showcase further advancements of Tribofilm image extraction that is achievable by automation and batch-processing. Examples of Tribofilm image processing and findings for MTM experiments over a wide range of tribological conditions will be presented to demonstrate how digitalization is advancing tribology in experiments. Extracting more value from Tribofilm images is crucial to develop lubricants with enhanced protection capabilities.

11:30 am - 12 pm
3667852: Maintaining Safe and Quiet Railways with “Top of Rail Materials”
Marc Ingram, Ingram Tribology Ltd, Carmarthen, United Kingdom; Matthew Smeeth, PCS Instruments, London, United Kingdom; Anup Chalisey, Rail Safety and Standards Board, London, United Kingdom

Lubricants are used on the rail/wheel interface to control friction, reduce wear and fatigue along with reducing noise. As a train proceeds around a curve its wheels (which are fixed) travel different distances and thus some sliding between the wheel and the rail is inevitable. This sliding can cause an unpleasant high pitched noise. The noise is generated by an unsteady dynamic where the sliding wheel alternates rapidly between two sliding speeds. This unsteady dynamic can be suppressed by lubricants added

directly to the rail or wheel. To reduce noise the friction between the wheel and rail should increase as the percentage of slip (creep) increases. This friction characteristics can be evaluated using “creep curves” in controlled test machines. A test method has been developed which can generate creep curves under realistic conditions of speed and contact pressure. This method was found to differentiate 11 different railway products.

3E Southern Hemisphere V

Surface Engineering III

Session Chair: Suvrat Bhargava, TE Connectivity, Middletown, PA
Session Vice Chair: Kora Farokhzadeh, Bruker Nano Surfaces, San Jose, CA

8 - 8:30 am
3640374: Surface Functionality Prediction via Curvature Analysis
Mark Malburg, Digital Metrology Solutions, Columbus, IN

Traditional, surface descriptions (height, curvature, etc.) do not adequately model the surface features which are important in contacting applications. Unfortunately, most researchers use traditional parameters based on availability and past research. However, in nearly every case, these parameters are mere approximations of the actual feature geometries of interest. In recent years, morphological operations have been applied to surface topography data as a means of extracting and describing surface features of interest. Instead of being “height or length” based - these operations are curvature based and thus, they provide many new and powerful opportunities for better describing surface features as they relate to wear, contact phenomena and even stress concentrations. This talk will present the underlying concepts of morphological characterization along with several case studies in which these methods have solved industrial surface functionality problems.

8:30 - 9 am
3669032: Effect of Surface Texture on Lubricant Film Thickness and Frictional Behavior at EHL to Boundary Lubrication Regime
Yuji Yuhara, Graduate School of Tokyo University of Science, Higashikanamachi, Katsushika-ku, Tokyo, Japan; Seiya Watanabe, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

The effect of surface texture on the frictional property at EHL to boundary lubrication conditions has been widely studied. However, the effect of surface texture on lubrication was examined for respective frictional conditions and therefore the theory which inclusively explains the effect at lubrication conditions from EHL to boundary has not been established. To evaluate the effect of surface texture, simultaneous measurement of frictional properties and lubricant film thickness is required. In this study, we developed a ball on disk apparatus which enables us to simultaneously measure friction coefficient and lubricant film thickness with a wide sliding speed range and investigated the effect of surface texture on frictional behavior and lubricant film thickness from EHL to boundary lubrication. In this presentation, we report the results of dimple and groove surface texture on frictional behavior and lubricant film thickness.

9 - 9:30 am
3665854: Effect of Surface Texture Pattern on Friction Anisotropy Under Insufficient Lubrication
Atsuta Harada, Kaisei Sato, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Seiya Watanabe, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

A belt-type continuously variable transmission (CVT) is a type of transmission that enables highly efficient driving for automobiles. Since the CVT transmits torque by frictional force, high friction is required in the circumferential direction of the pulley. However, lower is required in in the radial direction to reduce friction loss. Therefore, it is important to generate friction anisotropy that satisfies both friction properties.

Surface texturing is one of the effective techniques to generate friction anisotropy. In this study, various patterns of surface textures were applied to the actual CVT pulley, and friction tests were conducted under insufficient lubrication. In this presentation, we will report the results of the friction test and explain the effect of surface texture patterns on the generation of friction anisotropy.

9:30 - 10 am
3669368: Surface Textures: Design Principle and Applications
Stephen Hsu, George Washington University, Germantown, MD

Surface textures have been increasingly used to enhance surface properties to meet a wide variety of demands. The primary constraint is the cost of fabrication and quantification of benefits achievable in various applications. Many size and shape designs have emerged on a large variety of surface materials. Many of these textures, when tested in bench tests yield significant benefits, but when put to practice, the benefits often are difficult to quantify or marginal. This paper discusses the general principles of surface texture design and suggests ways to enhance performance by avoiding potential pitfalls.

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

10:30 - 11 am
3645120: Concurrent Design of Nanostructured Surfaces with Quasi-Random Geometries for Adhesion Optimization
Chengiao Yu, Hebei University of Technology, Tianjin, China; Shuangcheng Yu, Xingyi Metal Group, Haining, China

Various engineering applications require flexible grasping and manipulation, where adhesion is desired to be optimized. Surface nanostructures largely determines the adhesion. While surfaces with periodic patterns usually require time consuming processing, quasi-random nanostructures (QRNS) can be self-assembled for scalable manufacturing. However, conventional real-space design methods are not suitable for such stochastic nanostructures. We integrated scalable nanomanufacturing with concurrent design to achieve functional QRNS surface with optimized adhesion. We have accomplished the reconstruction of real space QRNS with strong adhesion of ~100kPa by using Gaussian random field modeling. We represented the QRNS topology by Fourier spectral density functions (SDFs) that could bridge the processing–structure and structure–performance relations. Iterative search of the optimal structure via the SDF representation enabled concurrent design of nanostructures and their processing.

11 - 11:30 am
3647434: Tribological Properties of Fingerprint-Like Texture on Soft Surface
Tianze Hao, Huaping Xiao, Shuhai Liu, China University of Petroleum, Beijing, China

Different human fingerprints have different stretching deformation when grasping. By imitating the three basic shapes of fingerprint patterns—whorl, loop, and arch, three types of fingerprint-inspired texture were manufactured on silicone rubber surface through mold casting. Tribological experiments were performed with silicone rubber surface rubbing against glass under dry condition. Experimental results demonstrates that coefficient of friction (COF) of the contact strongly depends on the patterns of fingerprint. The whorl type exhibits the largest COF, and then the loop and the arch type. The maximum stress, displacement and recoverable strain energy can explain the relationship among COFs of three fingerprints through finite element analysis. By assembling the fingerprints on the soft fingers, the soft robotic hand shows better grasping performance especially in accurate grasping actions. This work presents a new method to enhance the grasping performance of artificial hands.

11:30 am - 12 pm
3691739: Enhancing DLC Coating Adhesion and Durability by Using Polydopamine + SiO_2 Nanoparticle Underlayer
Min Zou, Dipankar Choudhury, Mourad Benamara, University of Arkansas, Fayetteville, AR; Christopher Rincon, Ronghua Wei, Southwest Research Institute, San Antonio, TX

Diamond-like carbon (DLC) coatings show high hardness, low friction, and excellent scratch and corrosion resistance and thus are desirable for many applications. However, DLC coatings can have significant drawbacks, such as crack initiation and propagation, which could lead to coating delamination and premature failure. We have developed a novel adhesive underlayer that consists of polydopamine (PDA) and SiO_2 nanoparticles to improve DLC coating scratch and wear resistance. Compared to DLC coatings with a commonly used adhesion underlayer, trimethylsilane [$(CH_3)_3SiH$] (TMS), the PDA + SiO_2/DLC coating markedly increased the coating resistance to crack propagation and coating delamination during scratch tests. The cross-sectional area of the wear track from the reciprocating wear tests was also reduced 2.5 times and the average crack size was reduced 40 times. Therefore, the PDA + SiO_2/DLC coating shows great promise for practical applications.

Seals III: Hydraulic and Two-phase Seals

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3668666: Analysis of Sealing Performance of Elasto-hydrodynamic Seal for sCO_2
Jing Tang, Hanping Xu, Ultool LLC, Duluth, GA; Sevki Cesmeci, Ikenna Ejiogu, Georgia Southern University, Statesboro, GA; Jordan (Shuangbiao) Liu, Northwestern University, Evanston, IL

An Elasto-hydrodynamic (EHD) seal for supercritical CO_2 (sCO_2) power cycle is analyzed in a simple and quick parametric simulation model. Seal clearances, pressure distributions, flow rates and fluid densities are calculated in the dimensionless and dimensional form. A simplified function of boundary conditions is added to the calculation of the seal clearance, which significantly improves the simulation accuracy and has a better correlation with the fluid-structure coupled COMSOL Multiphysics model. Parametric analysis is conducted at speed to study the general impact of key parameters and optimize EHD seal performance. The results show that the dynamic throttle formed downstream of the EHD seal can sufficiently reduce the leakage flow rate while maintaining the minimum gap, thereby creating a non-contact, low-leakage, and energy-efficient sealing mechanism to support the rotating shaft in the sCo2 power cycle.

8:30 - 9 am
3645190: Simulation of Transient Processes of a Hydraulic Seal with Elastohydrodynamic Lubrication
Arne Leenders, Institute of Dynamics and Vibration Research, Garbsen, Germany

Hydraulic seals are used for processes, when high operating pressure is present and the tightness of the mechanical system has to be guaranteed. The lubrication between the seal and the shaft varies in time and depends on ambient and operating conditions and also on the used material for the seal and the lubricant. Transient excitations like starting processes and changing operating pressures affect the system's dynamics. One focus of fluid simulations is on the influence of transient effects on the system's lubrication and friction behavior inside the lubricating gap in due consideration of the interaction of the structure (seal) and the fluid (lubricant). We will describe a simulation of a hydraulic seal with elastohydrodynamic lubrication for viscoelastic material behavior of the seal and Newtonian fluid. The model is able to concern roughness of the shaft and the seal and wall slip for transient excitations like movements of the shaft or rise of the operating pressure.

9 - 9:30 am
3647339: A Grooved Rotor-Smooth Surface Stator Seal vs. a Smooth Surface Rotor-Grooved Stator Seal: Comparison of Measured Leakage and Effective Force Coefficients
Jing Yang, Luis San Andres, Dara Childs, Texas A&M University, College Station, TX

Submersible electric pumps handling particulates feature annular seals made by a grooved rotor and a smooth surface stator (GR-SS). A seal made of a smooth surface rotor and a grooved stator (SR-GS), on the other hand, offers better dynamic stability. The presentation details measured leakage and effective direct stiffness (K_{eff}) and damping (C_{eff}) coefficients for a GR-SS seal vs. a SR-GS seal. The seals' dimensions and operating conditions are typical of inter-stage seals: clearance/diameter=0.002, pressure drop =0.2 to 0.8 MPa, and shaft speed =2 to 8 krpm. Supplied with an ISO-VG2 fluid and a null inlet pre-swirl, the GR-SS seal leaks 10% less than the SR-GS seal. K_{eff}'s for the two seals are comparable in magnitude and decrease quickly with shaft speed. The SR-GS seal offers twice C_{eff}'s than the GR-SS seal, and not decaying as shaft speed increases. The experimental results demonstrate the SR-GS seal is preferable for its larger damping albeit imposing a minor penalty in leakage.

9:30 - 10 am
3652885: Fretting Wear and Tightness Assessment of Natural Gas Flange Sealing
Zheng Zhang, Deguo Wang, Yanbao Guo, China University of Petroleum, Beijing, China

Bolt-gasket-flange connection (BGFC) is the most important connection method in natural gas gathering and transportation systems. However, due to the large number of it, slight leakage caused by fretting may lead to serious consequences. In this study, micro-leakage risk analysis, fretting wear of gasket sealing interface, and tightness assessment of BGFC were carried out successively. In order to solve the problem of insufficient field data collection, a fuzzy fault tree method based on Noise Or gate was proposed. GeNIe software was used to calculate the corresponding minimum cut set and the highest risk factor. Then, fretting wear tests and mechanism studies on the interface between commonly used spiral wound gaskets and flange seals were carried out. According to the data on fretting wear, we proposed a leakage path model and tightness assessment method to provide theoretical guidance for oil and gas industry safety production and maintenance.

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

3G — Northern Hemisphere A2

Grease III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3669200: Performance Enhancement of Hybrid Bearings at Grease Lubrication
Daniel Merk, Schaeffler Technologies AG & CO. KG, Schweinfurt, Germany

The advantage of hybrid bearings to optimize the speed suitability of rolling bearings or to isolate them against electrical current are known and were often discussed in the literature. Furthermore, hybrid bearings show several characteristics which extend the grease operating life, compared to all-steel bearings. Based on extensive investigations, it was proved why hybrid bearings reach the rate of increase of the grease operating life. These investigations concentrated on comparison experiments between different ball bearing types in different systems, each with hybrid bearings against all-steel bearings.

8:30 - 9 am
3669341: Thermal Stability and Spectroscopic Studies of Grease Formulations Using Isothermal and Variable Heating Methods
Keith Schomburg, PerkinElmer, Magnolia, TX

Lubricants and greases in industrial equipment exist to provide lubricity to vital mechanical parts and to reduce heat and stress. To evaluate lubricant and grease thermal properties thermo-analytical techniques can be utilized. There exist several applications within the ASTM literature describing the use of Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) techniques that can be used for grease analysis. TGA techniques can be used to determine the compositional analysis of a grease including the inorganic content and is routinely used to evaluate evaporative and degradation parameters. DSC techniques have been used to evaluate the thermal stability of lubricants. In this presentation the thermal stability of several grease formulations is investigated. The resulting products are then tested using spectroscopic techniques to evaluate the grease formulations.

9 - 9:30 am
3669351: Fully Loaded: A Study of Additive Response in Meeting NLGI's New HPM + HL Grease Specification
Joe Kaperick, Shawne Edwards-Zollar, Amanda Stone, Afton Chemical Corp., Richmond, VA

NLGI's new set of industry specifications for High Performance Multiuse (HPM) greases includes a category aimed at applications needing additional performance under High Load (+HL). This category targets higher performance in standard measurements such as the 4 Ball EP and Wear tests but also introduces two relatively new methods for grease evaluation using the SRV instrument. These new tests are both ASTM standards and evaluate greases for extreme pressure performance (ASTM D5706) and fretting wear protection (ASTM D7594). A study was carried out in lithium complex grease to understand the appetite of these two oscillating, ball-on-disc tests for additive componentry and to optimize the performance of a grease to meet all four of the "+HL" tests. The work was carried out using advanced statistical techniques to optimize time and resources in this project. Discussion of the approach, process and conclusions will be presented.

9:30 - 10 am
3669435: Extreme Tribology (II): How to Apply to Preform Chemistry in Grease
Liwen Wei, Novitas Chem Solutions, Houston, TX

This study is an extension of the ET (extreme Tribology) study presented in 2021. In this study we apply ET additives to polyurea and lithium complex grease made with pre-form thickeners. These additives compared to traditional S/P/metal additives are unique as they exhibit a superior balance of load carrying and antiwear performance without corrosivity. Through extensive and a combination of tribological/rheological testing under thermal/mechanical stress these ET additives are shown to outperform traditional S/P/metal additives.

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

10:30 - 11 am
3688165: Evaluation of Railway Greases in Four Ball Tester Under Purpose-Specific Test Protocols
Fabio Alemanno, Deepak Halenahally Veeregowda, Ducom Instruments, Groningen, Netherlands

Railway greases for the wheel/flange interface and the top of the rail are still mostly chosen and differentiated after expensive and time-consuming field tests that lack repeatability and reproducibility. In this study, a new thorough analysis of railways greases is proposed. Five railway greases were tested in a Four Ball Tester: wheel/flange greases were tested according to ASTM D2596 to determine their weld load and load-wear index. Top of the rail greases were tested according to ASTM D2266 to evaluate their friction coefficient during a low wear test. Lastly, all the greases were tested according to an inverse Stribeck-like curve protocol, The analysis of the test results obtained with the Four Ball Tester under

tailored test protocols allowed the benchmarking of the tested greases for different applications and was revealed to be an effective method to select the proper product for the wheel/flange interface and the top of the rail.

11 - 11:30 am
3687373: Role of the Grease Components on the Overall Frictional Response of a Greased Contact Subjected to Low-sliding Velocity Conditions.
Ilaria Ghezzi, Davide Tonazzi, Francesco Massi, Sapienza Università di Roma, Rome, Lazio, Italy; Michael Rovere, Cédric Le Coeur, Jeremy Chorier, SOMFY SAS, Cluses, France; Yves Berthier, Univ Lyon, INSA-Lyon, CNRS, Villeurbanne, France

Despite the use of lubricants is promoted to reduce friction and wear, the frictional response of lubricated contacts at low relative velocities can bring to several issues, such as dynamic instabilities. The presence of a lubricant can introduce in fact a non-trivial frictional response, with an overall friction-velocity characteristic that can destabilize the system dynamics. In the case of grease lubrication, the complex rheology at the interface, due to its different components (thickener, additives and oil), becomes a key factor, specially at low velocities. Aiming to understand the role played by the different grease components, the frictional response has been then investigated by testing different types of lubrication conditions, corresponding to dry contact, oil lubrication and greased contact (with and without additives). The results highlighted an unexpected trend of the frictional response at low contact velocities, driven mainly by the grease thickener and additives.

11:30 am - 12 pm
3669786: Comparative Study of the Behavior Solid Lubricants in Various Type of Lubricating Greases
Mehdi Fathi-Najafi, Jinxia Li, Nynas AB, Gothenburg, Sweden; George Diloyan, Nanotech Industrial Solutions Inc, New Jersey, NJ

Proper lubrication is one of the core parts for equipment protection and service life. To meet industry demands, grease manufacturers continuously improve the performance of the lubricating greases. The vital parameters such as extreme pressure, shock, wear, friction, shear, temperature, and presence of water are affecting the performance of the grease and subsequently the life of the tools and the productivity.
The aim of this study is to investigate the possibilities of developing a high-performance grease preferably for heavy load applications by using solid lubricants such as MoS_2 and IF-WS_2 . One of the motivations for the choice of solid lubricants instead for chemically active Anti-wear and extreme pressure is that an extrapolation of the laboratory test results could be more justified if the risk of the side-effects of the additives are eliminated.
Reference: H. Zhang, S.B.Lu, J. Zheng, J.Du, S.C.Wen, D.Y.Tang, and K.P.Loh, Optics Express, 22 (6), (2014), 7249

3H — Northern Hemisphere A3

Tribochemistry II

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3640146: Understanding the Effect of Forces on Tribochemical Reaction Rates
Wilfred Tysoe, UW Milwaukee, Milwaukee, WI

The effect of applied stress σ on the rates of tribochemical reactions is described using the Bell model, where the rate varies as $\exp(\sigma\Delta V^{\ddagger}/k_BT)$, where $\Delta V^{\ddagger}$ is the activation volume. Strategies for measuring reaction pathways are illustrated using the gas-phase lubrication of copper by dimethyl disulfide (DMDS) where the rate of reaction of on a Cu(100) single crystal substrate is measured by exerting the force using an atomic force microscopy tip. The measured angular dependence of the methyl thiolate decomposition rate suggests that the kinetics can be analyzed using quantum mechanical methods that are used to analyze thermal reaction rates and is confirmed by measuring the effect of a normal stress on the reaction rate which is excellent agreement with values calculated using quantum theory. This approach is extended to studying shear-induced methyl thiolate decomposition which occur more rapidly and on investigating the tribochemical decomposition of carboxylates on Cu(100).

8:30 - 9 am
3663351: Tribocatalysis for In-Situ Formation of Zero-Friction and Zero-Wear Lubricating Carbon Films
Diana Berman, Asghar Shirani, Kelly Jacques, University of North Texas, Denton, TX; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

High contact pressure and shear during sliding provide the unique capability of local heating and shear- and load-induced compression of the materials in contact. For a correct combination of materials, these conditions may induce tribomechanically or tribochemically-activated transformations of the surfaces into protective tribofilms that are capable of significantly minimizing friction and wear of the sliding systems. Here, we demonstrate the tribo-assisted transformation of hydrocarbon sources, such as fuels and alcohols, into adaptive and self-replenishing low friction and wear coatings. The transformation is activated by presence of catalytic metals, such as copper and platinum, in the sliding interfaces. The characterization analysis revealed the onset of the hydrocarbon decomposition and reconstruction correlating with applied load and temperature conditions. We show that the process allows to significantly reduce the wear of the surfaces and extend the lifetime of the systems.

9 - 9:30 am
3664579: Tribo-Catalytic Coatings with Self-rRpair Behavior in Alkane Environment
Asghar Shirani, Yuzhe Li, Diana Berman, University of North Texas, Denton, TX; Osman Eryilmazb Eryilmazb, Argonne National Laboratory, Lemont, IL

Minimizing the wear of the surfaces exposed to high shear contact stresses is the key factor to maximizing the service life of rotary mechanical parts. In this study, we have discovered the anti-wear capability of a group of metal nitride-copper nanocomposite coatings exposed to sliding in a liquid hydrocarbon-based environment. Study of the wear tracks shows the formation of carbon-based protective films directly at the sliding interface during the tribological experiments. Further analysis of the MoN-Cu coating that provides the most promising results as a function of load and temperature was performed in three alkane solutions, decane, dodecane, and hexadecane. The Raman spectroscopy and elemental energy dispersive x-ray spectroscopy analysis revealed the amorphous carbon nature of the formed tribo-film that helps easy shearing at the contact interface. These findings deliver new perceptions into the tribo-catalysis mechanism that enables the formation of zero-wear coatings.

9:30 - 10 am
3668938: In-Situ Formation of Carbon Tribofilms During Relative Motion of Steels in Boundary Lubrication
Tobias Martin, Arman Khan, Jannat Ahmed, Harry Wise, Shuangbiao Liu, Q Jane Wang, Yip-wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

Tribochemical reactions induced in boundary lubrication conditions at the interface of steel surfaces provide the opportunity to form carbon tribofilms in-situ. The effectiveness of the tribofilm in decreasing friction and wear is influenced by the composition of the surfaces in contact and the properties of the lubricant. The tribofilm formation was evaluated with reciprocating pin-on-disk tribotests, Raman spectroscopy of the tribofilm deposit, and confocal microscopy characterization of the wear scars. The

mixed elastohydrodynamic lubrication film thickness was analyzed to determine the interfacial condition of the cases studied, and molecular dynamics simulations were conducted to understand the mechanism of film formation. The catalytic activity of alloying elements was evaluated experimentally by comparing 52100 steel with other steel compositions. We determined that certain alloying elements affect the tribological performance of steel when the testing conditions are maintained.

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

10:30 - 11 am
3675933: Effects of Cyclopropanecarboxylic Acid and Chromium on In-Situ Formation of Tribofilms on Steel Interfaces
Harry Wise, Tobias Martin, Jannat Ahmed, Arman Khan, Shuangbiao Liu, Q Jane Wang, Yip-wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US DEVCOM ARL, Aberdeen, MD

To mitigate high friction and high wear under boundary lubrication conditions, we have been exploring the in-situ formation of tribopolymers from hydrocarbon additives and lubricants. When used as an additive at low concentrations, cyclopropanecarboxylic acid (CPCa) was found to form tribopolymer films rapidly, leading to significant improvements in friction and wear in rotating pin-on-disk tribotesting experiments. In addition, we compared tribopolymerization processes occurring on D2 and 52100 steels as well as their respective lubricated tribological performance under identical thermal and tribotesting conditions. D2 contains ten times more chromium than 52100 and was heat-treated to give the same hardness as 52100. Such comparison gives us an insight into the role of chromium in accelerating tribopolymerization and in affecting tribological performance.

11 - 11:30 am
3669939: What Stress Components Drive Tribofilm Formation? A Study with ZDDP
Lu Fang, Martin Webster, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Spyridon Korres, ExxonMobil Research and Engineering, Clinton, NJ

Zinc dialkyldithiophosphate (ZDDP), the most widely used antiwear additive in engine oils, has been extensively studied over the last few decades. It forms tribofilms at sliding contacts to prevent wear. Recent studies reveal that mechanochemical reactions drive tribofilm growth via stress and temperature. However, the individual effects of shear, compressive stress, and temperature on film growth are not yet fully understood. In this study, these driving factors were studied separately by using different compositions of a high-viscosity, high-EHL-traction fluid mixed with a polyalphaolefin basestock. Films were generated with a ball-on-disc tribometer in the elastohydrodynamic lubrication (EHL) regime for tungsten carbide (WC)/WC contacts with mixed sliding-rolling conditions. Shear stress and temperature were found to promote film growth exponentially. However, compressive stress had the opposite effect, slowing tribofilm growth. Mechanisms to explain these results will be discussed.

11:30 am - 12 pm
3669356: Reactive Molecular Dynamics Simulations of Thermal and Shear Driven Tribopolymerization
Fakhrul Hasan Bhuiyan, Ashlie Martini, University of California Merced, Merced, CA; Seong Han Kim, Pennsylvania State University, University Park, PA

Tribofilm formation from antiwear additives is known to be a mechanochemical process. However, such reactions are not fully understood since the reactant species are subject to frictional heating and mechanical stress simultaneously in sliding contact. Here, reaction pathways driven by heat, normal stress, and shear stress were investigated using reactive molecular dynamics simulations of mechanochemical association reactions of alpha-pinene molecules on silica. Results identified shear stress as the key driver of association reactions, which are the first step towards tribopolymerization. Further, analysis of the reaction pathways showed shear could activate multiple reaction mechanisms not accessible thermally. The findings from the simulations provide critical insights into the activation mechanisms underlying tribopolymerization reactions that can guide the design of antiwear additives and

mechanochemical processes with optimized and potentially tunable shear-induced reactions.

3I Northern Hemisphere A4

Biotribology III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3669318: Fragile Biological Interfaces
Angela Pitenis, Dixon Atkins, Jonah Rosas, Allison Chau, Yen-Tsung Chen, University of California Santa Barbara, Santa Barbara, CA

Aqueous biopolymer networks protect epithelial cell monolayers by functioning as mechanical fuses of frictional shear stress during normal physiological motions including blinking and walking. In the event of injury or disease, these networks may be damaged or depleted, which can lead to a cascade of pro-inflammatory cytokine signaling, tissue degradation, and eventually loss of function. In this study, corneal epithelial cells were grown in a variety of insulin concentrations to simulate healthy and diabetic ocular surfaces and were slid against hydrogel probes with similar stiffness as commercially-available contact lenses. The lower the insulin concentrations in the growth media, the lower the quantity of mucin expression on the apical surfaces of the epithelial cells, and the higher the frictional shear stresses across the sliding interface. This work highlights the importance of fragile biological networks in sustaining lubricity.

8:30 - 9 am
3645834: Tuning Polymer Architecture at the Hydrogel Surface to Impact Lubricity
Allison Chau, Patrick Getty, Christopher Bates, Craig Hawker, Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

Biology is full of systems comprised of compliant substrates with lubricating surface layers (e.g. cartilage and corneal epithelial cells). Recent work has demonstrated that the friction coefficient of a hydrogel can be reduced using the same design principles found in biology by grafting polymer chains from the surface to create a low friction, brushy layer. However, the effects of polymer architecture coupled with a compliant substrate on the tribological properties of a surface have yet to be thoroughly explored. To this end, synthetic polymer chains with controlled molecular weight and architecture were grafted to a hydrogel surface with varying grafting densities to observe the resulting tribological changes.

9 - 9:30 am
3667643: Biomimicking Hydrogel 'Skin' Layer Dimensions Controlled by Composition
Alison Dunn, Christopher Johnson, Md Mahmudul Hasan, University of Illinois, Urbana, IL

Swollen gels with water content >85% by mass tend to form softer surface layers at their boundary with an open bath. These soft layers alter the contact mechanics, contact area, and slip of interfaces that they form. However, the layers can have thickness ranging from the polymer scale up to tens of micrometers, and as such are difficult to characterize in terms of their dimensions and character. In this work we use probe-based techniques and progressive contact models to characterize the thickness of these skin layers, as well as show how these dimensions control sliding friction. We use polyacrylamide samples of polymer content 5-15% by mass and crosslinker content 0.03-0.5%. We find that the skin layer thickness is inversely related to the bulk stiffness, and thicker skin layers produce a more consistent shear response for variations in normal load and sliding speed. This allows design of hydrogels incorporating skin layers for separately tunable frictional and bulk properties.

9:30 - 10 am
3663679: Superficial Modulus, Water Content, and Mesh-Size at Hydrogel Surfaces
W. Gregory Sawyer, Research Institute of Industrial Science and Technology, Gainesville, FL; Brent Sumerlin, University of Florida, Gainesville, FL

The most distal surfaces of lubricious high-water content aqueous gels may have decreasing concentrations and gradients of macromolecular chains on the surface that emanate outward into the environment. This superficial zone of extended polymer chains has a water content that approaches 100% over the final few hundred nanometers, and the superficial modulus is the elastic modulus of this superficial surface. Micro-rheology using high-speed microscopy with fluorescent nanospheres enabled measurements of both the storage modulus G' and the loss modulus G'' over a frequency range of 0.4 1/s – 50 1/s. This interfacial microrheological measurement method was further used to quantify the superficial modulus and water content of two commercial contact lens materials that have water gradient gels on their surfaces: delefilcon A (E = 48 ± 11 Pa, > 99.6 % water) and lehfilcon A (E = 10 ± 8 Pa, > 99.7 % water), facilitating measurements of the most distal superficial zone of aqueous gels.

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

10:30 - 11 am
3667573: The Role of Surface Roughness in Mediating Tissue Homeostasis
Jonah Rosas, Yen-Tsung Chen, Ricardo Espinosa-Lima, Rachel Bae, Allison Chau, Dixon Atkins, Samantha Chan, Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

Cells employ complex strategies to transduce information at epithelial cell sliding interfaces, and changes to the composition of these interfaces can have consequences for tissue function. When native cell-cell interfaces are replaced with cell-implant interfaces (e.g. silicone elastomer implants during surgical implantation), healthy cell lubrication is disrupted, resulting in transient or potentially chronic tissue irritation. The average surface roughness (R_a) of a material has been reported to correlate with its ability to disrupt healthy cell morphology in vitro and initiate pro-inflammatory responses in vivo. Our work will employ a novel implant-membrane probe design and healthy cell monolayers to better study the tribological conditions at cell-implant interfaces. Coupled with confocal microscopy, we seek to develop a temporal map of the cellular stress-response mechanisms employed by healthy cells to adapt to and re-engineer these unfavorable cell sliding interfaces.

11 - 11:30 am
3667604: Transcriptomics Analysis of Breast Epithelia in the Tissue-Implant Interface
Dixon Atkins, Angela Pitenis, Jonah Rosas, Allison Chau, Yen-Tsung Chen, Samantha Chan, Rachel Bae, Daniela Semaan, University of California Santa Barbara, Santa Barbara, CA

Implantable medical and cosmetic devices are becoming increasingly common, and with the rise in application of these devices comes an increase in complications associated with inflammatory reactions to frictional shear stress. Distinct cellular mechanisms at the tissue-implant interface are characterized as a change in the transcriptome. We use custom biotribometers to evaluate the interface between healthy breast epithelial cells (MCF10A) and silicone breast implants. We leverage high-throughput sequencing techniques to create differential gene expression profiles associated with biotribological shear stresses and chronic inflammation. Lowering shear stresses is correlated with fewer upregulated genes associated with inflammatory response.

11:30 am - 12 pm
3668797: Investigating the Mechanical Properties of Unilamellar Vesicles Using NSE and SANS
Tooba Shoaib, Ronger Huang, Changwoo Do, Wei-Ren Chen, Oak Ridge National Lab, Knoxville, TN

Phospholipids are a crucial component in biotribology, especially when attached as boundary layers, in the form of vesicles to provide boundary lubrication. However, the response of the liposomes or lipid vesicles under shear is not very well studied. For instance, in vivo, during articulation, vesicles might be subjected to shear rates as low as 0.001 s^{-1} or as high as 10^6 s^{-1}. Because of their deformation energy,

size , and the transient viscosity of synovial fluid, significant structural distortion of vesicles can occur in this range. Understanding how this conformational variation impacts the stability and the efficiency of the vesicles as a boundary lubricant is thereby of significant importance. Yet, studies of non-equilibrium structure are scarce so far. Here by synergistically combining NSE and SANS the micromechanical and conformational characteristics of unilamellar vesicles subjected to steady shear with flow rates comparable to those of in vivo conditions will be studied.

3J — Northern Hemisphere E1

Wear III

Session Chair: Kora Farokhzadeh, Bruker Nano Surfaces, San Jose, CA
Session Vice Chair: John Bomidi, Baker Hughes, The Woodlands, TX

Session Starts at 8:30 am

8:30 - 9 am
3645819: Investigate Wear Transition of CoCrMo Alloy after the Heat Treatment
Jiahui Qi, The University of Sheffield, Sheffield, United Kingdom

This study reports that the wear rate of the heat-treated CoCrMo alloy shows a sudden wear transition of more than 5-fold when the load/contact pressure increases from 45N (3.591GPa) to 50N (3.717GPa). The structure of the commercially available CoCrMo has changed from the initial face-centred cubic (fcc) γ-Co with a small amount of hexagonal close-packed (hcp) ε-Co to hcp ε-phase dominant alloy with uniformly dispersed nanoscale precipitates of ��-phase after the heat-treatment. High-resolution transmission electron microscopy (TEM), scanning transmission electron microscope (STEM), energy-dispersive X-ray spectroscopy (EDX) have been used to characterise the structure and chemical composition of the worn surface and tribofilm. A detailed and quantitative analysis of surface deformation was undertaken using precession electron diffraction (PET) integrated with the TEM.

9 - 9:30 am
3665129: Tribological Behavior of Electrical Connector Coatings Under Reciprocating Motion
Na Tyrer, Gary Barber, Fan Yang, Bingxu Wang, Bo Pang, Oakland University, Birmingham, MI

With the surge in demand for electronic devices, more and more researchers focus on the wear resistance of the electrical coatings on connectors to ensure the functionality of these devices. An electrical circuit has been developed to be used with a reciprocating wear test machine to study the tribological performance of various coatings to reduce metal oxidation of electrical connectors. This research considers the effect of tin and copper layer thickness, including the lack of a tin layer, on the tribological behavior.

9:30 - 10 am
3669504: Modeling the Abrasive Wear Using Discrete Element Method
Muhammad Sameer, C. Fred Higgs III, Rice University, Houston, TX

Developing a computational modeling simulation to predict the abrasive wear behavior of solids requires a method that can handle the continuum nature of bulk solids along with the discrete nature of the wear debris during the wear process. The abrasive particles responsible for this wear are discrete in nature and modeling them requires a treatment for the interactions between these particles and the continuum bulk solid. So instead of modeling bulk material using continuum methods, it has been discretized into small particles. These particles are connected together with bonds that exhibit elastic and plastic deformation behavior similar to what is observed in the real material. This collection of bonded particles acts like a continuum material, but this material can be broken into discrete particles if the bonds connecting them

are broken. The particles detached from the main body due to the broken bonds are considered wear particles and are thus accounted for the wear prediction.

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

10:30 - 11 am
3668913: Tribological Behavior of PEEK and PLA Based Composites in Different Tribological Environments
Surojit Gupta, Sabah Javaid, Caleb Matzke, University of North Dakota, Grand Forks, ND

In this talk, we will present fundamental research in design of novel polymeric composites for biomedical and other demanding applications. During the first part of the presentation, the processing and microstructure of novel PEEK and PLA based composites will be presented. These results will be correlated with thermal properties. During the second part, detailed tribological behavior in different fluids like Simulated Body Fluids (SBF) will presented. Fundamental mechanisms of the tribological behavior will be presented. It is expected that these composites can be used in biomedical and other demanding applications.

11 - 11:30 am
3652075: Stress Activates Wear at Multi-Asperity Interfaces
Cyrian Leriche, Bart Weber, Steve Franklin, ARCNL, Diemen, Noord-Holland, Netherlands

Wear causes surfaces to be irreversibly damaged, thereby incurring significant economic cost. For single asperity contact between Si based material, depending on the precise contact conditions, atomic attrition, gradual removal and fracture have been identified as the main wear mechanisms. To understand to which extent these three mechanisms control the wear behavior of, industrially more relevant, SiN-on-Si multi-asperity interfaces, improvements are required in our ability to quantify and track wear across the micro-to nanometer scale. In this work, we used the topography difference method on large AFM measurements with a post-test realignment error smaller than 1 pixel, enabling us to detect wear volumes as small as 3.09*10^-15 mm^3. We studied non-repeated SiN-on-Si friction and found that the wear rate of the SiN increases exponentially with the local contact pressure. This result suggests that a stress-augmented thermally activated process is the driving wear mechanism.

11:30 am - 12 pm
3648353: Elevated Temperature Fretting Wear Study of Additively Manufactured 17-4 PH Stainless Steel
Manisha Tripathy, Ali Beheshti, George Mason University, Fairfax, VA; Pooriya Nezhadfar, Nima Shamsaei, Auburn University, Auburn, AL; Keivan Davami, The University of Alabama, Tuscaloosa, AL

Additive Manufacturing is a novel manufacturing process only a few decades old with great potential to carve out better and more efficient manufacturing techniques. While investigations on mechanical properties such as strength, fatigue, and to some extent corrosion are abundant in the literature, friction and wear studies of additively manufactured materials are scarce especially for metals at high temperatures. This presentation reports the fretting friction and wear properties of traditionally and additively manufactured 17-4 PH from room temperature up to 700°C for less than 1mm stroke length. The samples are manufactured using laser powder bed fusion process at different orientations prior to fretting tests. SEM/EDS analysis is also performed to further investigate the wear and friction behaviors. At higher temperatures, lower friction coefficient and higher wear volume are observed with a significant deviation between the additively manufactured and wrought samples.

Contact Mechanics I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3705999: Radial Load Distribution Comparison in Rolling Element Bearings
Mário Ricci, INPE, São José dos Campos, Brazil

The application of a radial load to the shaft of a rolling element bearing causes a displacement between the rings, which causes deformation of the rolling elements (balls or rollers) and elimination of the clearance along an arc of $2\psi_l$. For static balance, the applied load must be equal to the sum of the components of the rolling elements loads parallel to the direction of the applied load. In this work the results of the load distribution obtained by three methods are compared for a range of applied radial load.

8:30 - 9 am
3669135: Energy Dissipation as a Tool to Quantify Three Different Friction Models
Iyabo Lawal, The University of Texas at Austin, Austin, TX; Matthew Brake, William Marsh Rice University, Houston, TX

The effect of three different frictional interface models on an elastic, perfectly plastic half-space is presented. For the three models studied: Coulomb, Soil-Concrete Interface and Bouc-Wen, a computational mechanics framework is used to develop the contact mechanics that result from reciprocating sliding using an elasto-plastic friction algorithmic method that captures energy dissipation and hysteresis due to friction sliding. This framework can also be used to quantify wear on interfaces subject to friction loading. Additionally, the use of the 4-parameter Bouc-Wen model represents a new development in contact mechanics that allows microslip of the contact interface to be modeled.

9 - 9:30 am
3669362: Plane Elastic Cylindrical Line Contact Theory and Comparison to Finite Element Predictions
Chiraag Samal, Robert Jackson, Auburn University, Auburn, AL

Commercial finite element software using the plane strain and plane stress element settings are used to make predictions of the contact behavior of elastic cylindrical contact. In a recent work the predicted contact area, deflection and force of a three-dimensional finite element model were significantly different than those of the Hertz equations. This suggested that the assumptions of plane strain and plane stress, used to derive the Hertz equations, are not always applicable to real 3-D cylindrical contact. However, this work seeks to confirm that the Hertz solutions agreed with the finite element predictions using these assumptions directly. This confirms the effectiveness of the Hertz cylindrical contact equations themselves within the constraints of the plane stress and strain assumptions. In addition, the influence of friction on the contact behavior is also explored.

9:30 - 10 am
3668826: Contacting Asperity of a Surface
Shuangbiao Liu, Nicole Dorcy, Q Jane Wang, Yip-wah Chung, Northwestern University, Peachtree City, GA; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

A thorough understanding of the mechanics of asperity contact is critical to developing theories and models for analyzing rough-surface interactions. It is widely accepted that asperity contact is not a single-scale issue; however, the problem is how the scale issue should be properly handled? Since the asperity of a surface is a microscopic feature of the macroscopic body, and therefore, both should be modeled

together in mechanics. The current work considers a microscopic asperity on a half-space to obtain the combined responses of the asperity and the base in both elastic and plastic regimes. The contact behavior of this asperity is numerically simulated with the finite element method (FEM), and a rough-surface contact model based on the Boussinesq half-space solution. The results are compared and discrepancies are discussed. Three stages of asperity contact are revealed: the Hertzian, non-Hertzian, and deep-contact stage where the base body also takes a part in the contact.

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

10:30 - 11 am
3644301: Combined Numerical and Experimental Approach for Scuffing Prediction in Aeronautical Power Transmission
Nicolas Grenet -- de Bechillon, Fabrice Ville, Jérôme Cavoret, LaMCoS, Villeurbanne, France; Thomas Touret, Christophe Changenet, LabECAM, Lyon, France; Dhafer Ghribi, Safran Transmission Systems, Colombes, France

Environmental concerns are driving aircraft manufacturers to develop new engine architectures that lead to a reduction in the weight and size of power transmissions. The need to transmit more power in smaller volumes has raised concerns about scuffing risks in such mechanisms. In order to provide reliable criteria for scuffing detection in gear transmissions, a combined experimental and numerical study is proposed: Firstly, the work focuses on understanding the scuffing phenomenon on a simplified two-disk contact. Experiments are conducted on a twin disc machine to investigate scuffing failure with a new test procedure. Simultaneously a finite element model is developed to account for roughness interactions in the flash temperature estimation in mixed lubrication.
The newly developed criteria are then adapted to gear contact. Experiments on an FZG test rig are used to confirm the developed criteria.

11 - 11:30 am
3667928: Elevated Temperature Contact Creep and Friction of Nickel-Based Inconel 617 Superalloy: Indentation Experiments and Finite Element Analysis
Ali Beheshti, Sepehr Salari, Farnaz Behnia, George Mason University, Fairfax, VA; MdSaifur Rahman, ATSP Innovations, Houston, TX; Andreas Polycarpou, Texas A&M, College Station, TX

Surface friction, wear, and contact properties are highly influenced by the surface oxides especially at high temperatures which in turn impacts the durability and performance of the tribo-components. This study investigates the influence of high temperature and helium aging on the mechanical and contact properties of Inconel 617 using nanoindentation along with complementary finite element analysis. The mechanical properties of the oxide layer are obtained through high temperature nanoindentations and consequently are utilized to study temperature and dwell time effects on contact area and friction coefficient variation using a spherical asperity contact. Utilizing a machine learning approach, friction coefficient and contact area sensitivity on load, temperature, and holding time are measured and consequently a model at asperity level is obtained. The findings show high dependency of the oxide friction coefficient on creep of the material during dwell time especially at higher loads.

3L — Northern Hemisphere E3

Gears I

Session Chair: Jeffrey Ewin, Naval Air Warfare Center, Patuxent River, MD
Session Vice Chair: Pinzhi Liu, ExxonMobil Research and Engineering, Annandale, NJ

8 - 8:30 am
3637554: Effects on the Wear and Micro-Pitting Behavior of Nitrided External and Internal Gears

Michael Geitner, Bernd Zornek, Thomas Tobie, Karsten Stahl, Gear Research Center (FZG), Technical University of Munich, Garching bei München, Germany; Stefanie Hoja, Leibniz Institute for Materials Engineering (IWT), Bremen, Germany

Nitriding is a common surface heat treatment process, which can significantly increase the load carrying capacity of gears, compared to e.g. through hardened gears. In current research, the wear and micro-pitting behavior of gears is analyzed within theoretical and experimental investigations. Different material pairings and structures of the nitriding zone are considered. In this publication, an overview is given by a systematic comparison of different nitriding variants regarding the material pairing and structure of the nitrided layer with through and case hardened gears. Recommendations are developed to allow an optimization of the wear and micro-pitting behavior of nitrided external and internal gears. The results enable an implementation into the existing load capacity calculation methods and can build the base for standardized rating methods regarding wear and micro-pitting, e.g. within ISO 6336.

8:30 - 9 am
3642844: Dynamic Seals for Future Industrial Gear Products
Paul Norris, Andrew Gant, Afton Chemical, Bracknell, Berkshire, United Kingdom; Arturo Carranza, Grant Pollard, Joseph Remias, Afton Chemical Corporation, Richmond, VA

Elastomeric seals are a crucially important part of an Industrial gearbox but are often the weakest link in terms of field failure. Evolving OEM specifications have made testing required to gain fluid approvals far more challenging than previously. As a result, additive formulators have had to seek new approaches in order to keep pace with the changes. Work has been carried out to investigate and determine the main failure modes for both the FKM and NBR elastomers. Understanding of the failure modes enables strategies to overcome, or mitigate, these to be devised and tested. Using the insights gained from the technical development project, formulations have been developed that are capable in the key OEM dynamic seals tests. Details of selected testing, and insights gained, will be shared during the presentation.

9 - 10 am - **Invited Talk**

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

10:30 - 11 am
3644372: On the Transition Between Micropitting and Pitting Damage in Rolling-Sliding Rough Surface Contacts
Benjamin Wainwright, Amir Kadiric, Imperial College London, London, United Kingdom

A study into the influence of the maximum Hertzian contact pressure, the Λ ratio and surface roughness on the transition between micro and macro-pitting has been undertaken on a triple-disc fatigue rig. Circumferentially ground test specimens, manufactured from case-carburized 16MnCr5 steel, and a custom lubricant formulated from a PAO base oil were utilized. Experiments showed that increasing pressure generally led to the transition from micropitting to macropitting. Sectioning specimens showed that this was accompanied by surface cracks turning deeper into the sub-surface. However, the onset of macropitting could be shifted to higher pressures if conditions, such as the combination of low Λ and high roughness, also allowed for a sufficiently high rate of micropitting wear. Contact mechanics simulations aid in explaining this transition - damage maps which illustrate regions of micropitting and/or macropitting in relation to Λ, surface roughness and pressure are presented.

11 - 11:30 am
3651997: Effect of Lubricant Viscosity on Dynamics of High-Precision Gear Considering Lubricant-Induced Backlash Reduction Under Deterministic and Uncertain Conditions
Zhou Chen, Zhejiang University, Hangzhou, China

The effect of lubricant viscosity on dynamics of a high-precision spur gear pair with near-zero backlash is investigated under deterministic and uncertain conditions via a tribo-dynamic model. This model, for the

first time, considers the backlash reduction induced by the lubricant film between meshing teeth. In general, increasing viscosity can mitigate vibration in off-line-of-action (OLOA) direction and decrease dynamic transmission error (DTE) but can hardly mitigate vibration in line-of-action (LOA) direction. Moreover, increasing viscosity can suppress the uncertainty of OLOA vibration caused by the uncertain backlash, supporting stiffness and meshing stiffness but cannot suppress the uncertainty of DTE. Therefore, gear dynamic performance can be improved by increasing lubricant viscosity. However, to what extent the gear dynamic performance can be improved depends on the operating condition and surface roughness.

11:30 am - 12 pm - **Gears Business Meeting**

3M Northern Hemisphere E4

Rolling Element Bearings III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3649632: Grease Lubricated Steel Ball on Flat Fretting Test Results
Robert Erck, Nicholaos Demas, Scott Mueller, Argonne National Laboratory, Lemont, IL

A fretting test machine was built which is able to test the sliding properties of balls on flats at small stroke lengths. Results are reported for type 52100 steel balls sliding against steel flats using commercial greases. Flat and ball volume losses were measured using white-light interferometry. Stroke lengths were typically 150 micrometers, although 90 micrometers to 540 micrometer strokes were used. Tests were nominally performed at 52 N at a frequency of 150 Hz. Oxidation was observed in dry sliding conditions. For some samples, at small stroke lengths pitting occurred in the occluded area, absent for longer strokes.

8:30 - 9 am
3658289: Improving Wear and Fatigue Resistance of Large Size Rolling Bearings by Tailored Forming
Felix Saure, Timm Coors, Yusuf Faqiri, Florian Pape, Thomas Hassel, Gerhard Poll, Leibniz University Hannover, Garbsen, Lower Saxony, Germany

Large size bearings, used in offshore wind turbines, are exposed to high contamination of the lubricant by salt water, which leads to corrosion on the raceway. Pre-damage to the contact partners in the rolling bearing leads to early failure. The materials frequently used for slewing bearings are 1.0503 and 1.7225. An approach to manufacture multi-material bearings with higher alloyed materials is Tailored Forming. A higher alloyed and corrosion resistant material in the rolling contact and therefore in the highly stressed contact zone below the surface improves fatigue and wear behavior. To examine the special application in oscillating pitch bearings, wear tests were carried out on the above-mentioned bearing materials and a corrosion-resistant steel, among others, under different ambient conditions including submerged tests in saline media. It could be proven that the presented approach features high potential to manufacture corrosion resistant and high strength large size bearings.

9 - 9:30 am
3669297: The Effect of Transverse Vibrations on the Performance of Rolling-Sliding Lubricated Contacts
David Uribe, Amir Kadiric, Imperial College London, London, United Kingdom; Armando Felix-Quiñonez, SKF, Houten, Netherlands

The contacts between rolling elements and raceways in bearings are frequently subjected to vibrations arising from operating conditions and internal clearances. In particular, the vibratory motion transverse to the contact rolling direction has not been widely studied but may have detrimental effects on bearing performance in terms of oil film thickness, friction and surface damage. The present study employs a novel experimental setup which combines a triple-disc contact fatigue rig with an electrodynamic modal shaker able to impose vibrations over a wide range of strokes and frequencies that are representative of those in practical application. Additionally, the lubrication condition is monitored using an electrical capacitance method and frictional forces are measured in both the rolling and transverse directions. The results are presented to investigate the effect of transverse vibrations on friction, film thickness and contact damage under EHL and mixed lubrication conditions.

9:30 - 10 am
3647986: In-Situ Measurement of Bearing Load from a Field Wind Turbine Gearbox Bearing
Gary Nicholas, Ben Clarke, Tom Howard, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom; Jon Wheals, Ricardo Innovations, Leamington Spa, United Kingdom

Failures in wind turbine drivetrain components, particularly the gearbox often, incur the longest downtime and costliest repairs. A significant proportion of these are attributed to bearing failures from white etching crack. In-situ monitoring of bearing load could assist in better understanding of real operating conditions. In this study, a field wind turbine gearbox bearing was instrumented with ultrasonic sensors. Ultrasonic waves were transmitted through the raceway and reflections from the raceway-roller interface were captured and processed to deduce individual roller loads and subsequently bearing load. Variation in roller load incurred by each rollers across a full complement was found to be more prominent compared to that incurred by the same roller across multiple revolutions. Comparison between measured load with modelled values were found to agree well. However, high and low load outliers exist which were attributed to transient events not simulated by the model.

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

10:30 - 11 am
3662731: Experimental and Simulative Investigations Into the Fatigue Life of Cylindrical Roller Bearings Under Mixed Lubrication with Differently Finished Inner Rings
Lukas Rüth, Flavien Foko, Bernd Sauer, Pascal Ostermayer, Bastian Blinn, Tilmann Beck, TU Kaiserslautern, Kaiserslautern, Germany

Although roller bearings exist in a wide variety of drive systems, existing design guidelines do not allow direct evaluation of the influence of surface morphology on the achievable fatigue life under mixed lubrication conditions. In this work, the influence of different surface finishing processes, that is, fine grinding, rough grinding, and hard turning, on the fatigue life of inner rings of radial cylindrical roller bearings, was analyzed. This was carried out by means of experimental investigations on four-bearing test rigs, metallographic investigations including topography and boundary layer, as well as theoretical methods. By using instrumented cyclic indentation tests the local mechanical properties were determined, while X-Ray diffraction was used to analyze the residual stresses. The simulative part of the work was focused on wear calculations using a co-simulation, which is composed of a multibody simulation and a half-space contact model.

11 - 11:30 am
3668715: Investigation of Asperity Conformation Between Varied Slip Conditions During Running-In of Rolling-Sliding Contacts Under Mixed Lubrication Regime
Maruti Sai Dhiraj Sakhamuri, Terry Harvey, Robert Wood, University of Southampton, Southampton, United Kingdom; Bernd Vierneusel, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

To predict wear in rolling bearings, it must be differentiated from normal running-in. Since this is only possible if normal running-in is fully understood, the conditions leading to it and the processes in the early operating phase are investigated in detail. For this purpose, the focus is on the role of slip in surface topography changes, which is assessed by replicating the rolling-sliding contact of a bearing in a

tribometer. AISI 52100 bearing steel samples are tested in three slip conditions under mixed lubrication regime with a PAO base oil. 3-D surface relocation is employed to measure the aerial roughness during set intervals to track the rate of change of roughness and asperity conformation. In addition to this, the surface and the sub-surface of the test samples are examined under a scanning electron microscope for signs of stress. Finally, conclusions on the effect of slip on surface modifications are drawn from a comparison between the running-in period of the three tests.

11:30 am - 12 pm
3647674: An Experimental and Analytical Investigation of Cage Pocket Lubrication
Thomas Russell, Farshid Sadeghi, Purdue University, West Lafayette, IN

This paper presents an experimental and analytical investigation into the lubrication state and frictional behavior of a deep groove ball bearing (DGBB) cage pocket. A custom acrylic replica of a cage segment was produced and installed on a cage friction test rig for the simultaneous measurement of frictional torque and visualization of oil flow inside of the cage pocket. Videos of oil flow were subsequently analyzed to calculate the ratio of oil and air inside the pocket. In addition, a numerical cage pocket lubrication model was developed that solves the Reynolds equation over a spherically defined cage pocket domain. Results from the experimental analysis of oil volume fraction were used to modify the fluid properties in the model. Predictions from the model agree well with experimental friction measurements. The presented results introduce a framework for the prediction of cage pocket friction based on a provided set of operating conditions.

3N — Asia 5

Metalworking Fluids II

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 9 am

9 - 9:30 am
3649866: Improve Metalworking Fluid Performance and Longevity with Sustainable Tank-Side Additives
Harish Potnis, Denis Buffiere, ANGUS Chemical Company, Mumbai, Maharashtra, India

Emerging Trends in the regional regulatory landscape, changes in process parameters, and a decreasing toolbox of globally acceptable chemistries are adding to the complexities facing today’s MWF's formulators and manufacturers. In addition, end-users continue to challenge MWF's formulators to develop cost-effective products that can improve fluid performance while reducing waste. Our most recent studies have been focused on using diverse combinations of approved biocides and specialty amines as tank-side additives to enhance the fluid longevity and performance of water-miscible MWF's. The data provided in this presentation provide formulators with a framework for analyzing and selecting a decisive path in developing robust tank-side additives with exceptional microbial control and enhanced fluid longevity while satisfying end-user demands like operational efficiency, global regulatory compliance, and minimizing waste to reduce the environmental impact.

9:30 - 10 am
3667456: Do Biofilms in Metalworking Fluid Systems Matter?
Frederick Passman, Biodeterioration Control Associates, Inc., Princeton, NJ

Historically, condition monitoring for microbial contamination has focused on measuring bioburdens in bulk fluid samples. However, biofilm communities create several significant metalworking fluid (MWF)

management challenges. First, they are non-uniform. Samples must be collected from diagnostic, rather than representative locations. Second, biofilms are resistant to microbicide treatments. Third, biofilms readily reinfect recirculating MWF once the microbicide concentration has decreased to less than its critical concentration. Although the use of bioresistant MWF has decreased the need for microbicide tankside additions to control planktonic populations, it has not necessarily reduced the risk of bioaerosol generation. This paper will address the importance of biofilm bioburden monitoring and control, and the implications of effective control on bioaerosol exposures.

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

10:30 - 11 am
3645159: Study and Development Of Free-Biocides Metalworking Fluids
Marco Bellini, Simone Pota, Bellini SpA, Zanica, Italy

Biocides contained in MWFs can cause skin irritations. Bellini SpA developed a new MWFs series called TORMA FB, where FB means 'Free of Biocides'. This project is based on the idea that pH hinder bacterial growth and that bio-stability can be achieved just by controlling pH. According to literature, over a certain pH value the time needed to bacteria for replication is longer than bacteria expected lifetime: bacterial growth will tend to decrease by itself if pH remains above this value. Correlation between chemical parameters and bacterial growth in working emulsions is analysed using chemometrics. After that, a new technology has been developed in order to keep pH of working emulsions in a safe zone. New products have a technology called dynamic buffering package, which maintain pH over a constant value by releasing an alkaline component on-demand. Bio-stability, MIC and other studies has been performed in order to compare TORMA FB products to 'standard' MWFs references.

11 - 11:30 am
3668798: Investigation of Tribological Properties of Water Based Metal Removal Fluids and Lubricity Additives on Titanium Machining
Yixing Philip Zhao, Quaker Houghton Company, Conshohocken, PA

Titanium alloys are used in aircraft components due to light weight, high strength, fracture resistance, corrosion resistance. Titanium has low machinability, high reactivity and low thermal conductivity. Metal removal fluids for titanium machining need to provide both high lubrication and good cooling. In the presentation we report the tribology investigation results of water metal removal fluids and lubricity additives for titanium cutting. Ball-on-plate tests were used to get COF at different loads on titanium. 3D profilometer was utilized to measure surface roughness of test scars. It was found the levels of oil, water and lubricity additives in MRF formulas contribute to both lubrication and cooling. The contributions from phosphate esters, synthetic esters and polymeric esters to lubrication and surface roughness are very differently. These results will help us to develop green and sustainable MRF to increase productivity for our aerospace customers.

11:30 am - 12 pm
3667018: A Novel Approach to Understanding Metalworking Fluid Distribution on Machined Surfaces
Michael Jones, Eleanor Riches, Gordon Jones, Caitlyn Da Costa, Jeff Goshawk, Waters Corporation, Wilmslow, United Kingdom

In this work, we show how the novel technique of Desorption ElectroSpray Ionization – Mass Spectrometry (DESI-MS) can be used to investigate the distribution of metalworking fluid (MWF) on machined surfaces. DESI-MS is an analytical approach that deploys a fine, focused solvent spray onto a sample to lift molecules from the surface and ionize those molecules; the ions formed are subsequently analysed by high-resolution mass spectrometry. The spray is moved across the surface in a pre-programed pattern, which enables the spatial imaging of molecules deposited across the surface. This can help to understand how the MWF coats the surface. We show comparisons between uncoated and coated surfaces, and the distribution of MWF components on different surfaces. We also demonstrate how DESI-MS can be utilized to monitor the efficacy of industrial cleaning processes intended to remove

MWF from finished parts.

4A Southern Hemisphere I

Electric Vehicles IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3667787: Improvement of Performances of Transaxle Fluids for Electric Vehicles
Hiroyuki Tatsumi, Kazushige Matsubara, Daisuke Takekawa, Keiichi Narita, Idemitsu Kosan Co., Ltd., Ichihara-shi, Chiba, Japan

In recent years, with the tightening of environmental regulations, reducing energy loss are required in many fields of industry. Transaxle for electric vehicles (E AXLE) which consists of motor, inverter and reduction gear can contribute to improving the efficiency because of its simple design. Cooling performance and protection for mechanical components are required for lubricants used in E AXLE. In this study, we investigated the influences of base oils and lubricant additives on these performances. As a result, the kinematic viscosity and the heat conductivity of base oils gave a large impact on their cooling performance. In addition, Quantitative Structure-Property Relationship (QSPR) revealed that the heat conductivity changes depending on the length of main chain and the number of branches. In particular, phosphorus-based extreme-pressure additives were effective of improving the durability of gear and bearings.

2:30 - 3 pm
3663017: Multi-Physics and Multi-Scale Prediction of Tribological Behaviour of Electric Powertrain
Mahdi Mohammadpour, Loughborough University, Loughborough, United Kingdom

The tribology of automotive powertrains is facing significant changes in the range of working conditions including speeds and loads and consequently the applicable failure modes and lubrication regimes. This is due to rapid electrification , introducing novel landscape . To facilitate objective design decisions at this demanding transitional stage, accurate methodologies are required. This may lead to ambitions vision of zero-prototype development.
Accurate modelling necessitates multi-physics method involving tribology, dynamics and electromagnetics. The method should embed a multi-scale approach to consider detailed physics-based phenomena at surface level which is the origin of tribological behaviour. In this paper, a multi-physics and multi-scale method is proposed for realistic predictions of modern electrified powertrains. Bearing and gear tribology of a case study is presented to demonstrate the concept in a realistic context.

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

4 - 4:30 pm - **TBD - Late Submission**

4:30 - 5 pm
3665967: Electric Vehicle Transmission Efficiency Prediction Using a Thermally Coupled Lubrication Model
Joseph Shore, Amir Kadiric, Imperial College London, London, United Kingdom

This work presents a new model for prediction of EV transmission efficiency. The model can differentiate between different lubricants in terms of their impact on transmission efficiency by use of measured rheological data at appropriate conditions to predict gear teeth losses along the path of contact. Gear loss predictions are combined with existing numerical models for bearing and gear churning losses so that

overall gearbox efficiency can be predicted. Temperature changes resulting from heat generation and gearbox cooling are accounted for by representing components as nodes within a thermal network. Temperature predictions show good agreement with measurements from road tests with a real EV. Further results are shown to assess transmission losses over a range of duty cycles including the standard WLTP cycle. The model provides a computationally efficient way to compare lubricant performance as well as aspects of the mechanical design of a transmission to improve energy efficiency.

5 - 5:30 pm
3669257: Thermal Management Aspects for Hybrid & Battery Electric Vehicles
Thomas Wellmann, Kiran Govindswamy, Dean Tomazic, FEV North America, Inc., Auburn Hills, MI

The presentation will showcase the use of a systematic process aimed at understanding the influence of operating temperatures of individual components on overall efficiencies. With an understanding of desired temperature ranges for subcomponents, a strategy for thermal management can be developed. Development goals include not only the cooling of components to stay below critical temperatures, but also quick warm up of the drivetrain components and battery during cold start or cold charging events. In addition, the integration of interior thermal comfort needs, in the context of overall vehicle thermal management for battery electric vehicles, will be discussed. Examples from testing and simulation of hybrid and battery electric vehicles will be utilized to describe the flow of energy in various portions of the drivetrain and battery, as well as full vehicle systems. The importance of lubrication and cooling fluids on overall thermal management and associated trends will be shared.

4B Southern Hemisphere II

Lubrication Fundamentals IV - Antiwear & Friction Control

Session Chair: Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria
Session Vice Chair: TBD

2 - 2:30 pm
3668999: Ashless Anti-Wear Synergies with ZDDP
Brendan Miller, Robinson Flaig, Ramoun Mourhatch, Chevron Oronite Company, Richmond, CA

There is a continual push for improved anti-wear performance while simultaneously pushing for lower ash content. Because Zinc Dialkyl Dithiophosphates (ZDDPs) are metal-containing anti-wear additives an ashless alternative to ZDDP could maintain wear performance while also lower ash levels. The authors show improved wear performance with ashless anti-wear additives compared to ZDDP plus synergistic performance when combining the two.

2:30 - 3 pm
3663146: Mechanism of Synergistic and Antagonistic Interaction between TiO_2 and ZDDP Under Boundary Lubrication
Pranesh Aswath, Vinay Sharma, UTA-Materials Science and Engineering, Arlington, TX; Richard Timmons, The University of Texas at Arlington, Arlington, TX; Ali Erdemir, Texas A&M University, College Station, TX

Interaction of ZDDP with TiO_2 and plasma functionalized TiO_2 nanoparticles was studied, under boundary lubrication using a pin on reciprocating flat configuration. Friction coefficients, wear loss and electrical contact resistance were measured. Tribofilms generated were subjected to extensive surface analysis using X-ray photoelectron spectroscopy (XPS) and X-ray absorption near edge structure spectroscopy (XANES) to determine tribochemistry. Results from tribological tests, coupled with chemical characterization of the tribofilms, suggest that both ZDDP and TiO_2 nanoparticles, by themselves, form effective protective films at the rubbing surfaces. However, when used as a mix in the oil, they surprisingly

behave antagonistically in terms of providing anti-wear films, resulting in severely increased wear. In order to better understand the mechanism sequential tests with different combination of additives were used to determine the impact of tribochemistry on friction and wear behavior.

3 - 4 pm - **Break**

4 - 4:30 pm
3645381: Formation Kinetics and Mechanical Properties of ZDDP Tribofilms
Victor Kontopanos, University of Virginia, Charlottesville, VA; William Anderson, Afton Chemical Corporation, Richmond, VA

Zinc diakyldithiophosphates (ZDDPs) are important lubricant antiwear additives. Their effectiveness as an antiwear in a particular application will depend on the type of ZDDP (primary or secondary) used as well as concentration. Often, secondary ZDDPs are used for early protection, and primary for longer-term protection. In this work we have investigated the kinetics of formation of tribofilms, and characterized the chemical, tribological and mechanical properties for common ZDDP types in simple systems in order to better understand the tribofilm formation. Results show significant differences in the tribofilm growth depending on the type and concentration of ZDDP.

4:30 - 5 pm
3669003: Improved Friction Performance in Fresh and Aged Conditions
Brendan Miller, Robinson Flaig, Ramoun Mourhatch, Chevron Oronite Company, Richmond, CA

Automotive fuel efficiency has been, and will continue to be, a key topic for OEMs and lubricant suppliers. As lubricant viscosities continue to drop for hydrodynamic gains in fuel economy, boundary friction reduction will play a larger role in fuel economy performance. It is well known that current organic and organometallic FMs can provide fuel economy performance in unaged conditions, but their performance fades as the oils age in the engine. The authors show improved fresh friction performance for new organic friction modifiers as well as persistent friction performance after aging.

5 - 5:30 pm
3647257: Pushing the Ultra-Low Viscosity Limit for Heavy Duty Diesel Engine Oil beyond 0W-20
Gwenaelle Philibert, Oluwaseyi Ogunsola, Jason Brown, Matthew Urbanak, Sarah Remmert, Shell Global Solutions US, Houston, TX

Lowering engine oil viscosity has proven to be an efficient way of reducing CO_2 emissions in the passenger car sector and has the potential to do the same in the heavy duty sector. In the US, an overwhelming majority of customers with heavy-duty diesel engines still use SAE 15W-40 engine oils, with a slow adoption of more fuel efficient viscosity grades like SAE 10W-30 or SAE 5W-30 oils. More benefit could be gained by going to even lower viscosities. To optimize engine protection with these lower viscosity levels, additive packages will require a significant redesign compared to those commercially available today. Shell Lubricants Technology is eager to help OEMs reach best fuel economy possible while still offering the same engine protection, especially against wear. In this work, we identified some bench tests that demonstrate the performance of SAE 0W-12 HDDEO oils and investigated the friction and wear protection characteristics of prototype low viscosity oils.

4C — Southern Hemisphere III

Commercial Marketing Forum IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm - The Lubrizol Corporation

2:30 - 3 pm - Clariant Corporation

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

4 - 4:30 pm - **Open Slot**

4:30 - 5 pm - **Open Slot**

4D Southern Hemisphere IV

Tribotesting IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3668929: Tribological Performance of Al_2O_3-B_2O_3 Composites: Role of CuO and CaO Constituents
Ashish Kasar, Brian D'Souza, Kevin Watson, Pradeep Menezes, University of Nevada, Reno, Reno, NV

Al_2O_3-B_2O_3 based composites for wear resistant applications (e.g., seal rings and bearings) were manufactured using powder metallurgy route. Four different compositions were considered to control amount of in situ phases. The composites were characterized using X-ray diffraction, micro-hardness and dry sliding tests against alumina ball at different humidity levels. The X-ray spectrum revealed that increase in B_2O_3 content in the composites increased the amount of aluminum borate phase that enhanced the micro-hardness. Aluminum borate enhanced the wear resistance of the composites, whereas the humidity-sensitive alumina phase reduced friction at higher humidity levels. The addition of CuO and CaO (2-5 wt%) resulted in increased density by 22-48 % that enhanced the hardness and wear resistance of the composites. However, the coefficient of friction was negatively affected. The friction and wear performance along with wear mechanism are discussed with respect to observed phases.

2:30 - 3 pm
3668952: Improvement in Tribological Performance of Plastic Oil by Incorporating Solid Lubricant Additives
Soumya Sikdar, Md Hafizur Rahman, Pradeep Menezes, University of Nevada Reno, Reno, NV

The inception of plastics has been a major development for the technological revolution. Its versatile nature has made it a popular material for various types of industrial and household applications. However, overwhelmed usage of plastics has generated millions of tons of non-biodegradable waste that have become a threat to the environment. One way to mitigate the pollution caused by waste plastics is to chemically convert them into pyrolyzed plastic oils (PO) for industrial applications. In this study, PO is considered as a potential lubricant, and pin-on-disk experiments were carried out by incorporating graphene (GNP) and hexagonal boron nitride (hBN) nanoparticles into the PO. Results showed that the coefficient of friction (COF) and wear volume significantly reduced compared to the base PO. The basic insights from this study can drive the research towards a more alternative forms of sustainable lubricants.

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

4 - 4:30 pm
3669397: Investigation of the Use of Demulsifier to Manage Gas-Phase-Synthesized Graphene Separation in Base Oils
Gordon Krauss, Albert Dato, Ethan Carroll, Max Castro, Harvey Mudd College, Claremont, CA; Matthew Siniawski, LMU, Los Angeles, CA

Gas-phase-synthesized graphene (GSG) has benefits over traditional graphene when used as a lubrication additive. Lubricated Pin-on-Disc tests of a 52100 steel ball sliding on a 52100 steel disc demonstrate reduced wear for minute amounts of GSG (≤ 0.1 wt%) added to canola oil, polyalphaolefin (PAO), fully formulated petroleum oil, and synthetic motor oil. GSG exhibits a crumpled morphology and has shown a high degree of persistent dispersion in multiple base oils as well as commercially available fully formulated motor oils for long periods. This morphology is believed to limit the opportunity for stacking of layers and thus surface energy reduction through agglomeration. However, suspension is not indefinite in base oils as it appears to be in fully formulated oil. In this study, we evaluate the addition of a demulsifier to a base oil to understand the degree to which it (and by extension, the presence of water) influences the separation of GSG when suspended in PAO.

4:30 - 5 pm
3668944: Tribological Properties of Porous Aluminum Borate Composite Infiltrated With Liquid Lubricants
Ashish Kasar, Brian D'Souza, Md Hafizur Rahman, Pradeep Menezes, University of Nevada, Reno, Reno, NV

Porous aluminum borate composite was fabricated as a novel self-lubricating material by reactive synthesis to store liquid lubricant and release it to the interface during sliding. In this study, room temperature ionic liquids (RTIL), namely $P_{6,6,6,14}$Salicylate, $P_{6,6,6,14}$Saccharinate and $P_{6,6,6,14}$Benzoate were infiltrated into the ceramic composite. The tribological properties were investigated using pin-on-disk setup against pure alumina ball at different sliding velocities and temperatures. In addition to the RTILs, canola oil and mineral oil were also infiltrated for comparison. Results showed that the RTILs outperformed the canola oil and mineral oil in terms of friction and wear, particularly at high temperatures. This work provides a strategy to design and fabricate porous ceramic material infiltrated with viscous ionic liquid for improved tribological properties that will be potential candidates for self-lubricating bearings and bushings.

5 - 5:30 pm
3669514: Assessment of Wear-Corrosion in a Controlled Testing Environment
Carlos Sanchez, Southwest Research Institute, San Antonio, TX; Jeremy Moloney, Alex Koerner, Champion X, Houston, TX

Standard oilfield production operations experience harsh environments that lead to high levels of wear, and corrosion of carbon steel assets. While it is common practice to use a corrosion inhibitor to mitigate corrosion, its effects on controlling metal loss are less understood. This study presents a new methodology for the evaluation of oilfield corrosion inhibitors on reducing wear and wear-corrosion. A Plint TE77 reciprocating tribometer was fitted with a sealed chamber, and a closed loop fluid and gas system to regulate the test environment. The temperature, operating pressure, and dissolved oxygen content of the test fluid were controlled. Tests were conducted to simulate a corrosive oilfield environment; with and without inhibitor. The corrosion inhibitor exhibited a pronounced effect on reducing metal loss from wear and wear-corrosion. The methodology herein demonstrates opportunities to prolong metal and asset life, reduce costs, and assist in more sustainable operations.

5:30 - 6 pm - **Tribotesting Business Meeting**

Nanotribology I

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3675453: Time Dependent Analysis of the Thermal Oscillations of AFM Cantilevers During Force Spectroscopy Measurements
Philip Egberts, Zahra Aboolizadeh, University of Calgary, Calgary, Alberta, Canada; Johanna Blass, Guenther Kraemer, Roland Bennewitz, INM-Leibniz Institute for New Materials, Saarbruecken, Saarland, Germany

Mechanical properties of surfaces can be measured with great precision and with nanoscale spatial resolution using atomic force microscopy (AFM). Two common modes, contact resonance and force modulation modes, require the excitation of the cantilever to track and control the amplitude and frequency of the cantilever oscillations. The driven cantilever oscillation can significantly disturb the sample in certain applications. In such cases, the oscillation of the cantilever can disturb the atomic arrangement of the atoms in the vicinity of the end of the AFM tip apex. In this study, we examine the cantilever deflection signal at high sampling rates over 1 MHz during force distance curves and use short term Fourier transforms to examine the evolution of the thermal resonances of the AFM cantilever during the experiment. A detailed analysis of the thermal resonances has been performed allowing for the extraction of time-varying contact stiffnesses during the experiment.

2:30 - 3 pm
3644465: In Situ Atomic Force Microscopy Evaluation of Pressure-Induced Changes in Structural Morphology of Phosphonium Phosphate Ionic Liquids
Filippo Mangolini, Zixuan Li, Oscar Morales-Collazo, Robert Chrostowski, Joan Brennecke, The University of Texas at Austin, Austin, TX

Phosphonium phosphate ionic liquids (PP-ILs) have attracted considerable attention in tribology owing to their high thermal stability, good miscibility in hydrocarbon fluids, and excellent lubrication performance. However, a fundamental understanding of their nanoscale lubrication mechanism is still lacking. Here, we use atomic force microscopy (AFM) to evaluate in situ the dependence of the structural morphology of confined PP-ILs on applied pressure. The results indicate a pressure-induced structural transition of PP-IL molecules upon sliding at a normal applied pressure up to 5.5±0.3 GPa, which leads to the generation of a lubricious, solid-like interfacial layer. The growth rate of this layer strongly increases with applied normal pressure and temperature. Based on molecular dynamics (MD) simulations of pressure-induced structural transitions in PP-ILs, a simple phenomenological model will be proposed to account for the observed morphological and nanotribological changes.

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

4 - 4:30 pm
3669446: Adhesion, Friction, and Wear Mechanisms in Si Tip and Si Substrate Indentation and Sliding
Judith Harrison, US Naval Academy, Annapolis, MD; Zachary Milne, Sandia National Laboratory, Albuquerque, NM; Robert Carpick, University of Pennsylvania, Philadelphia, PA; J. Schall, NC AT&T, Greensboro, NC

Adhesion between single crystal Si tips and Si(111) substrates was examined using molecular dynamics (MD) to model experiments of nanoscale silicon tip-tip contacts using nanoindentation coupled with TEM. Experimentally, adhesion was observed to increase by an average of nearly 20x when sliding occurred,

while low adhesion was recovered when contact was made without intentional sliding. MD simulations of contact with and without sliding were performed using Si tip-substrates couples that matched experimental conditions. Various H- and OH-terminations, tip-substrate alignments, and tip shapes/heights were examined via MD. Simulation results confirm the experimental hypothesis that repassivation of the surfaces reduces adhesion. Additionally, specific wear mechanisms were elucidated as a function of hydrogen termination, sliding direction, and tip specifications.

4:30 - 5 pm
3637797: Surface-Grafted Poly(ionic Liquid) that Lubricates in Both Polar and Non-Polar Solvents
David Burgess, Zhenyu Jason Zhang, Peter Fryer, University of Birmingham, Birmingham, United Kingdom; Ian McRobbie, Jacqueline Reid, Innospec, Ellesmere Port, United Kingdom

Surface-grafted polymers lubricate in solvents by taking up the solvent, swelling and extending out at the surface. This creates a lubricous layer that is fluid and resistant to penetration leading to excellent lubrication properties. Usually these polymers will swell and lubricate in one type of solvent but not another. Here we discuss a surface-grafted poly(ionic liquid) (PIL) exhibiting lubrication properties in both water and dodecane. Compared to a bare silicon wafer the polymer in water reduces the friction by up to 44% and in dodecane by up to 64%. Analysis using colloidal force spectroscopy showed that the PIL is reducing friction in both by changing the lubrication mechanism: in water the PIL is swelling and extending out at the surface reducing the interfacial friction, but in dodecane the PIL is not swelling but instead is creating densely packed layer on the surface that reduces interfacial adhesion and contact[1].
[1] - Burgess et al., ACS Macro Lett. 2021, 10, 7, 907–913

5 - 5:30 pm
3669366: Reviewing the Thermal Conductivity Benefits of Dispersed Nano Particles in Lubricants for EVs and Other Applications
Todd Cawley, LSI Chemical, Mount Gilead, OH

Nano particles have shown favorable results in friction applications, resulting in reduced operating temperatures, however with this technology being fairly novel, minimal research regarding thermal conductivity has been done. In preliminary third-party testing oriented toward EV drivetrain and refrigerant applications, Lubrication Specialties' results show that nano particles dispersed in multiple lubricants demonstrate various improvements in thermal conductivity. In our presentation, we will dive deeper and provide test results and important information regarding which types of lubricants benefit more from the addition of nano particles, as well as identifying other applications for which these discoveries may be most beneficial.

5:30 - 6 pm - **Nanotribology Business Meeting**

4H — Northern Hemisphere A3

Tribochemistry III

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3638908: Anomalous Friction and Wear Behavior of Hydrocarbon Oils on Precipitation-Hardened Steels
Andrew Clough, Peter Frantz, Edith Leung, Stephen Didziulis, The Aerospace Corporation, Culver City, CA

Commercially available multi-alkylated cyclopentane (MAC) oils are frequently chosen for spacecraft applications due to their favorable lubricant properties and low vapor pressures. Recently, we studied the behavior of MAC oils formulated with anti-wear additives on several precipitation-hardened (PH) steels and observed erratic friction coefficients and higher rates of wear than on other steel alloys. Notably, the wear rate appears to be impacted by the operating environment (dry N_2 versus ambient air), which suggests that the sub-surface chemistry of the PH steels plays a key role in the effectiveness of the oil. We also tested other hydrocarbon-based oils, and found high wear persists across multiple classes of oil. The results have implications for lubrication strategies when designing and building mechanisms for space applications.

2:30 - 3 pm
3668863: Tribocorrosion of Wrought and AM Stainless Steels: Understanding and Overcoming Wear-Enhanced Corrosion
Mary Parker, Christopher Chervin, Andrew Birnbaum, Anna Rawlings, John Steuben, Kathryn Wahl, Derek Horton, US Naval Research Laboratory, Alexandria, VA

We will present our work investigating the tribocorrosion behavior of wrought and additively manufactured (AM) 316L and exploring the impact of controlled alloying on wear-enhanced corrosion of stainless steels. Despite having superior corrosion resistance in the absence of wear, we show that AM 316L, made by selective laser melting (SLM), exhibits greater material loss during tribocorrosion testing compared to wrought 316L. Underlying reasons for this difference in susceptibility will be discussed. We also investigate the benefits of increased alloying with passivity promoting elements for AM 316L, using AM techniques to create specimens with a compositional gradient with increasing amounts of Cr, Mo, and Ni. We will present a spatially resolved current response across the compositionally varied sample, showing a transition in current response as a function of Cr, Mo, and N..

3 - 4 pm - **Break**

4 - 4:30 pm
3645982: On the Lubricity Mechanism of Carbon-Based Nanofluid Fuels
Frank Hong, Haoyi Wang, Nawaf Alghamdi, S. Mani Sarathy, KAUST, Thuwal, Mekkah, Saudi Arabia

Blending nanoparticles to fuels enhances lubricity. However, the underlying lubrication mechanisms remain unclear. In this study, we investigate fuel lubricity over low-sulfur diesel (D100), diesel fuel containing 10 wt% ethanol (DE10), and DE10 blended with 50 to 200 ppm surface-modified graphene oxide (mGO), i.e., G50, G100, and G200. The fuel lubricity experiment shows that as compared to D100, the DE10 fuel produced 50% larger wear volumes on rubbed balls, while lubrication with the G200 fuel reduced wear by 6%. The developed tribochemical reaction and kinetic model captures the lubrication mechanism of additive impacts and interactions. The tribofilm growth kinetics follows the autocatalysis process and controls surface material wear rates that govern lubrication performance. The blended mGO directly reduces metallic contacts, serves as tribo-active sources to initiate graphitic tribofilm growth, and replenishes damaged rubbing surfaces.

4:30 - 5 pm
3669252: Modelling the Mechanochemistry of Lubricant Additives: A ReaxFF Investigation of Phosphate Esters Confined Between Sliding Iron Surfaces
Carlos Ayestaran Latorre, Hugh Spikes, Daniele Dini, James Ewen, Imperial College, London, United Kingdom; Joseph Remias, Afton Chemical, Richmond, VA

Small changes to the molecular structure of lubricant additives affect their adsorption and dissociation behaviour at the nanoscale, as well as their friction and wear performance at the macroscale. Here, we show using reactive nonequilibrium MD simulations that secondary trialkylphosphates dissociate much faster than primary trialkylphosphates between sliding iron surfaces. For both molecules, dissociative chemisorption proceeds through cleavage of the carbon−oxygen bond. The rate increases exponentially with temperature and stress, which is indicative of a stress-augmented thermally activated process. When we fit the rate−temperature−stress data with the Bell model, both molecules have similar activation

volumes and energies. The difference in reactivities is mostly driven by a larger pre-exponential factor. These observations are consistent with recent macroscale tribometer experiments of the antiwear additive ZDDP.

5 - 5:30 pm
3647041: Interfacial Bonding Controls Friction in Diamond-Rock Contacts
Jagjeevan Bhamra, James Ewen, Daniele Dini, Imperial College London, London, United Kingdom; John Bomidi, Marc Bird, Baker Hughes, The Woodlands, TX

Using tribometer experiments with a diamond tip, we show that soft limestone rock (mostly calcite) gives much higher friction coefficients compared to hard granite (mostly quartz) in both humid air and aqueous environments. To uncover the physicochemical mechanisms that lead to higher kinetic friction at the diamond-calcite interface, we employ NEMD with newly developed ReaxFF parameters. The friction coefficients obtained from the nanoscale simulations and experiments are in good agreement for both the quartz- and calcite-containing rocks. The NEMD simulations show that the higher friction for calcite than for quartz is due to increased interfacial bonding. The rate of interfacial bond formation increases exponentially with pressure, which infers a stress-augmented thermally activated process. The agreement between the friction coefficients obtained from the NEMD simulations and experiment suggests that interfacial bonding could also control diamond-rock friction at the macroscale.

4I — Northern Hemisphere A4

Biotribology IV

Session Chair: TBD
Session Vice Chair: TBD

Presentations Pending

4J — Northern Hemisphere E1

Wear IV

Session Chair: Chinpei Wang, Cummins, Columbus, IN
Session Vice Chair: Arnab Bhattacharjee, University of Delaware, Newark, DE

2 - 2:30 pm
3668811: Multi-Scale Wear of Helical Gear Pairs
Jack Walker, Mahdi Mohammadpour, Stephanos Theodossiades, Loughborough University, Loughborough, United Kingdom; Stephen Bewsher, Guenter Offner, Hemant Bansal, Michael Leighton, Michael Braunstingl, Heinz-Georg Flesch, AVL List GmbH, Graz, Austria

Design of automotive transmissions must consider a multitude of performance criteria, including durability, noise vibration and harshness and efficiency. Often, modelling efforts of transmission constituent machine elements consider ideal contact geometries representing early life operation. Consideration of worn surfaces are required to achieve optimal designed components for their operational lifespan. Typically, ‘Archard’s Law of Adhesion’ has been used to model wear of sliding contacts exhibited in cylindrical gears, which inherently requires empirical data. However, a mechanistic understanding of adhesive wear has been made available by the ‘critical length scale’. This study applies a lubricated multi-asperity ‘critical length scale’ wear modelling approach to a helical gear pair. The presented methodology aims to alleviate reliance of adhesive wear modelling upon empirical wear coefficients. The impact of adhesive

wear on the gear pair performance metrics are also evaluated.

2:30 - 3 pm
3644953: Detection of Micropitting Initiation Using Acoustic Emission and Electrostatic Sensing Techniques
Zaihao Tian, Shuncai Wang, Robert Wood, University of Southampton, Southampton, Hampshire, United Kingdom; Daniel Merk, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

Rolling bearings perform under most operating conditions without any problems, but there are certain conditions, where micropitting appears. Considerable work has been conducted on investigating drivers of micropitting based on post-test inspections. However, due to its fast process, micropitting initiation has been poorly captured by online sensing and its mechanisms remain to be understood in detail. This work aims to achieve detection of micropitting initiation using acoustic emission (AE) and electrostatic (ES) sensing techniques and identify the wear patterns using physical inspections. A twin-disc tribometer was used to perform tests on discs with seeded defects. The results showed micropitting was produced and various wear patterns were identified. Sensor data analyses indicated the AE sensing was sensitive to asperity contact conditions and crack/pit propagation, and the ES sensing was capable of detecting the seeded defects and generated tribofilms, cracks, and pits.

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

4 - 4:30 pm
3641733: On the Mechanism of Abrasion
Kenneth Budinski, Bud Labs, Rochester, NY

The accepted definition of abrasion is progressive material removal from a surface produced by rubbing contact with hard sharp particles or protuberances. What is the source of abrasion in a metal-to metal tribosystem? What is the source of scratching abrasion on the metal member in a plastic-to-metal tribosystem? These questions are addressed in this study. Tests were conducted to determine the effect of prevailing surface texture and directionality on abrasion in metal–to-metal tribosystems. It was determined that the nature of the tribocouple (hard steel vs. hard steel, hard steel vs. soft steel, soft steel vs. soft steel etc.) as well as surface texture height, lay and surface generation process play a role in determining the abrasion that occurs in sliding systems that do not intentionally contain “outside” abrasives. It was concluded that adhesive interactions are a significant mechanism of material removal in polishing abrasion.

4:30 - 5 pm
3690593: Enhanced Wear Performance of Lubricants with a Balanced Holistic Approach
Hong Gao, Shell, Houston, TX

Wear performance is a complicated engineering subject under lubricated conditions in a rubbing system. The lubricant plays a critical role to enhance the wear performance to extend the service life of the moving components. The additive types and synergistic balance can affect and eventually determine the wear performance of the tribosystem. In this presentation, different additive ingredients were studied in a fully formulated lubricant environment under a mixed to boundary condition on wear performance. With the lower viscosity lubricants to improve the fuel economy and reduce CO2 emissions, the wear durability will become a basic requirement and enabler to make the system work.

5 - 5:30 pm - **TBA**

5:30 - 6 pm - **Wear Business Meeting**

4K — Northern Hemisphere E2

Contact Mechanics II

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3669314: Under the Surface: Observing Subsurface Response Using 2D DIC
Kyle Schulze, Auburn University, Auburn, AL; Alexander McGhee, University of Wisconsin, Madison, WI; Eric McGhee, University of Florida, Gainesville, FL

Mechanics below the surface at an interface have a profound affect on what we observe on the surface. Researchers such as, but not limited to, Sneddon, Timenshenko, Johnson, and Popov have developed models that estimate deformation, strain, and stress fields of the subsurface under contact exceptionally well. With any model there are assumptions: deformations are small, the material observed is isotropic and does not exhibit rate or time depend responses to load, etc. Here, we examine these relationships with materials that push up to the limit of these assumptions and beyond: soft and active matter. Using 2D digital image correlation we are able to observe in situ the subsurface response to contact and sliding of these soft materials and compare the subsurface fields to previously observed results.

2:30 - 3 pm
3668777: Controlling Dry Adhesion Through Multi-Scale Surface Texturing via Grayscale Lithography
Luke Thimons, Arushi Pradhan, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA; Nickolay Lavrik, Ivan Kravchenko, Oak Ridge National Laboratory, Oak Ridge, TN

While surface texturing to control adhesion is quite sophisticated, advancements in this area commonly proceed through empirical testing. Fundamental understanding, prediction, and optimization has been elusive, primarily because of the difficulty of measuring and controlling all size scales of surface topography. Here we impart rationally designed roughness onto silicon substrates using grayscale lithography, then perform macroscale adhesion tests against a polished silicon probe. Adhesion was reduced by more than an order of magnitude, with all length scales contributing significantly to the change in performance. The data was also analyzed numerically, using on a cohesive zone model, to characterize interfacial interactions. Overall, this investigation demonstrates the impossibility of linking adhesion to simple scalar parameters (such as RMS height or slope), and demonstrates the improved prediction that can be achieved through multi-scale topography characterization.

3 - 4 pm - **Break**

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

4L — Northern Hemisphere E3

Gears II

Session Chair: TBD
Session Vice Chair: TBD

Presentations Pending.

Rolling Element Bearings IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3644765: Formation Mechanisms of Dark Etching Region in Bearing Steels Due to Rolling Contact Fatigue
Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom; Alexander Schwedt, Joachim Mayer, RWTH Aachen University, Aachen, Germany; Bernd Vierneusel, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

RCF-induced microstructural transformations, such as dark etching region (DER) and white etching bands (WEB), in bearing steels play important role in bearing durability. However, the formation mechanisms of DER and the link between DER and WEB is not fully established. Through detailed micro-, nano-structural analysis of DER formed at different stages using optical microscopy, SEM, EBSD and nanoindentation techniques, it has been discovered that DER develops initially as dark patches when etched, consisting mainly of elongated grains at defined orientations and dispersed equiaxed grains with high misorientation indicating plastic deformation. The DER subsequently becomes brighter corresponding to grain refinement at later stages. The evolution has been confirmed by the increase in the micro-hardness leading to energy build-up and stress concentrations in the region where low angle bands initiate due to recrystallization.

2:30 - 3 pm
3663200: Formation of WEA/WEC: Mechanism and Driver of Premature Bearing Failure - Insight to the Damage Mechanism Within WEA/WEC Formation
Adrian Mikitisin, Central Facility for Electron Microscopy, Aachen, Germany; Florian Steinweg, Chair and Institute for Materials Applications in Mechanical Engineering, Aachen, North Rhine-Westphalia, Germany

Despite the research in the past years, premature bearing failures because of White Etching Cracks (WEC) are still challenging because the formation mechanism of White Etching Area (WEA) is not fully understood. This work aims to provide further insight into the damage mechanism within WEA formation. WEAs were generated on a three ring on roller test rig using rollers made of SAE 52100. Parameters such as electrical current density and slip were varied. Rollers were stopped manually to investigate the early stages of WEAs. Microstructural investigations were done utilizing SEM and TEM. We reveal and describe formations of early local defects during severe plastic deformation (SPD) followed by local recrystallization, then leading to a phase transformation of the martensite. Contrary aspects of plastic deformation near the surface and under the surface are shown. A correlation between the shaping of the defects with the stress state is made, and a formation scheme is introduced.

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

4 - 4:30 pm
3647440: Change in Metal Structure by Sliding and Debris Formation Process
Kenji Matsumoto, Honda R&D Co.,Ltd, Nerima-ku, Tokyo, Japan; Naoaki Yoshida, Kyushu University, Kasuga, Fukuoka, Japan; Akira Sasaki, Maintech, Yokohama, Kanagawa, Japan

We previously reported that debris generated by sliding in automotive mechanical parts (e.g., ball bearings and pulleys) were formed in a few micrometer thick zone just below the sliding surface. In this study, we observed in detail the metal structure just below the sliding surface damaged by sliding by using a transmission electron microscope (TEM), and investigated the relationship between the electron diffraction (ED) pattern and the size of the debris generated. When there was a face-centered cubic

lattice (FCC) metal structure just below the sliding surface, the debris released were large, and scale-like particles with an appearance of having been pressed repeatedly by sliding. In contrast, the debris released from a body-centered cubic lattice (BCC) metal structure were found to be small, and granular particles. This paper discusses the mechanism of change in metal structure in the process of sliding and debris formation.

4:30 - 5 pm
3659098: Analytical Investigations of the Tribological Layers in WEC Failed Specimens - Influence of the Oil Formulation
Florian Steinweg, Chair and Institute for Materials Applications in Mechanical Engineering, Aachen, North Rhine-Westphalia, Germany

Roller bearings can fail under specific operating conditions depending on the selected oil formulation due to White Etching Cracks (WEC). In this context, the focus is on specific additive packages and their influence on the formation of tribofilms. In this work, investigations on a three-ring-on-roller test rig with different fully formulated oil formulations were performed. EPMA was conducted to investigate possible differences in the additive-derived boundary lubricating layers. The microstructural composition of the tribomutation layers was studied using TEM. Finally, the sample's diffusible hydrogen concentrations were analysed. The results reveal that WEC formation can be promoted or suppressed under mixed lubrication conditions depending on the utilized oil formulation. In particular, a significant effect on the formation and composition of the tribofilms and the occurrence of WEC is shown.

5 - 5:30 pm
3696287: Atomistic Understanding of Grease Tribolayers on Bearings Surfaces
Vikram Bedekar, Kuldeep Mistry, Rohit Voothaluru, The Timken Company, N. Canton, OH; Jonathan Poplawsky, Oak Ridge National Laboratory, Oak Ridge, TN

Grease lubricated bearings are commonly utilized in multitude of industrial applications. Greases and thickener chemistries have a big impact on the bearing lubrication. This study investigates morphological and compositional characteristics of grease-generated tribolayers at an atomistic level. Tribolayers from lithium-based and polyurea based grease thickeners formed on 52100 bearing steel were investigated using atom probe tomography and transmission electron microscopy. The results reveal formation of multilayer chemistries resulting from tribochemical reactions between the steel interfaces, featuring evidence of oxygen diffusion, air pockets via mechanical deformation, and metallic clusters. The results indicate that the polyurea grease tribofilm's amorphous nature, size of the air pockets, and top FeS layer provided exceptional friction and wear properties compared with tribofilm generated using greases with lithium complex thickeners.

4N — Asia 5

Metalworking Fluids III

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3669258: Lubrication Behavior of Metalworking Fluids on Tribometer and in Cutting Process
Haichao Liu, Florian Pape, Lars Ellersick, Berend Denkena, Gerhard Poll, University of Hannover, Garbsen, Germany

For a better understanding of the lubrication action of metalworking fluids (MWFs) in cutting, the lubrication behavior of water-miscible MWFs has been tested on a model tribometer and in an orthogonal cutting. The lubricating film forming ability and the frictional property of MWFs have been tested with the

model ball-on-disc tribometer. The chip formation process and the cutting forces are compared under dry and wet cutting processes for different cutting speeds. The penetration ability of MWFs into the chip-tool contact zone and the lubrication effects of MWFs in cutting are discussed.

2:30 - 3 pm
3645789: Boundary Lubricant Additive Response Comparisons on Copper Alloys Using Twist Compression Tests (TCT)
Ted McClure, Sea-Land Chemical Co. / SLC Testing Services, Westlake, OH; Alexes Morgan, Sea-Land Chemical Co., Westlake, OH

The Twist Compression Test (TCT) is a bench test that creates lubricant starvation under high pressures and sliding contact. It is used to evaluate the boundary lubrication performance of lubricants and galling resistance of material couples. This presentation is an extension of work on other metals presented at earlier STLE conferences. Materials and manufacturing processes continue to evolve quickly in response to changing industry requirements, requiring rapid lubricant development, and testing. Electric vehicles (EV) require changes in the way vehicles are manufactured as well as the fluids used in operation. Electric current and heat management are important considerations, involving copper. In this work, TCT is used to compare boundary additive responses on copper alloys. Boundary lubricants evaluated include polymers, esters, phosphorus bearing, and combinations. The aim is to provide useful data for formulation of lubricants in applications involving copper triboelements.

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

4 - 4:30 pm
3669331: Optical Characterization of Metal Working Fluids (MWF) for Robust Formulations, Improved Batch Lifespan and MWF Recycling
Ravinder Elupula, Charles Nider, Formulaction, Piscataway, NJ

Metalworking fluids (MWF) play an important role in the high productivity, reliability of metal processing, and improved lifespan of machines used in the industry. Current technologies used for MWF analysis (visual observation, DLS…) do not provide direct aging information. Some of these current methods require the samples to be diluted and thus will not give an accurate determination of native MWFs. Obtaining reliable information on emulsion stability requires an analytical solution that offers a direct measure of occurring phenomena and does not rely on external stress or any sample modification. Herein, we show how Static Multiple Light Scattering (SMLS) and the Turbiscan® can be used to detect and efficiently quantify destabilization phenomena such as particle size growth and concentration changes up to 200 times faster than visual observation. We will also show how the Turbiscan helps formulators and scientists in decision taking all over the MWF life cycle.

4:30 - 5 pm
3663177: The Application of Electrochemical Analysis in Metalworking Fluids (MWFs) Evaluation
Tian Zhang, Feng Jiang, Huaqiao University, Xiamen, Fujian, China

Traditional evaluation method for MWFs consists of numerous repetitive mechanical testing and compositional analysis experiments. These experiments tend to be long and costly. In this work, two faster and cheaper electrochemical analysis methods were introduced to MWFs evaluation, called Tafel polarization and electrochemical impedance spectroscopy. Commercial cutting fluid E206, extreme pressure additive chlorinated paraffin (CP), and a kind of martensitic heat-resistant steel (MHRS) were selected as experiment material. The results showed that MHRS surface corrosion current density I_{corr} increased as E206 concentration increasing. After CP was added in cutting fluid, the I_{corr} decreased and the charge transfer resistance R_{ct} increased. It was indicated that MHRS is prone to corrosion in high concentration cutting fluid, and the corrosion process can be effectively alleviated by adding CP. The reliability and advantages of electrochemical analysis in MWFs evaluation were verified.

4 – 6 pm Northern Hemisphere C

Roundtable Discussions

A scientific brainstorming and networking event is organized on the basis of discussion round tables (DRT) by the rolling element bearing technical committee together with other technical committees. This event aims to encourage open discussions between experts of different disciplines on various topics of interest. The format of the DRTs is very fruitful to facilitate a creative atmosphere on complex topics character and to find technical impulses by brainstorming. The topics are proposed by the table hosts themselves and are based on current interests. A typical property of DRTs is the writable table cloth to inspire the discussion as well keep notes for subsequent discussions. The benefit of DRTs goes beyond the technical impulses. During the DRT the hosts will guide the discussion only and not give a lecture. Active participation, including experience sharing of each participant, is one of the main features of this event providing an unique opportunity to connect and learn.