**5A** Southern Hemisphere I

**Engine and Drive Train V**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3668676: The Effect of Lubricant Choice on Valvetrain Tappet Performance**
Rai Notay, William Barton, Lubrizol, Derby, United Kingdom

The mechanical contact between a camshaft lobe and a tappet in an engine valvetrain system is a complicated and dynamic tribological interaction consisting of both sliding and rolling friction. The geometry of the system is such that the tappet rotates when interacting with the lobe and in order to maintain component durability it is required to constantly rotate in service. The choice of lubricant can dictate the tractive effort of the tappet and it is often difficult to understand how well a tappet has performed in test from end of test visual inspections or analytical drain analysis of elemental wear. This presentation highlights the use of advanced metrology techniques to evaluate a tappets' rotational experience and how the choice of lubricant can impact its performance.

**8:30 - 9 am**
**3668832: Development of Turbocharger Bearing Systems Compatible with Low-HTHS Oils**
Zachary Ashton, Raj Chandramohanan, BorgWarner, Arden, NC

With Automotive Original Equipment Manufacturers (OEMs) pursuing efficiency gains across conventional, hybrid, and down-sized powertrains, adoption of lower viscosity High Temperature High Shear (HTHS) oils has become a regular means of increasing system performance. Significant development work has occurred at the OEMs to enable the application of lower viscosity oils. Notably, however, many of these high efficiency engine configurations are also equipped with turbochargers that rely on the same oil system as the engine and were developed in the decades preceding the prevalence of low HTHS oils. To meet these requirements, a turbocharger bearing system must be analytically and experimentally validated to meet the reduced viscosity targets. Prior investigations have focused on the application of low HTHS oils to existing bearing systems (1). The focus of this work will be on the development of a new bearing system with low HTHS oil requirements.

**9 - 9:30 am**
**3669348: Confirmation of Radioactive Tracer Testing (RATT®) Technique**
Peter Lee, Southwest Research Institute, San Antonio, TX

Radioactive tracer Testing (RATT®) is a method to measure real time wear of interacting metal components. The process involves surface activating and/or bulk activating components to produce unique isotopes. As these components wear and the wear material becomes free to move either in air or fluid, these isotopes emitted from the wear particles can be measured. This technique can be used for a number of different applications, engine component wear being one of the most common. Recently SwRI did some internal research to make this measurement technique more robust and this will be discussed during this presentation along with some example results.

**9:30 - 10 am**
**3641292: Failure Characteristics of Friction Clutches for Limited Slip Differential Application**
Thomas Schneider, Katharina Völkel, Hermann Pflaum, Karsten Stahl, Technische Universitat Munchen, Munchen, Bayern, Germany

In rear-axle locking differentials, the high locking effect is typically realized by using wet-running multi-plate clutches. In this study, the spontaneous damage behavior of the clutches is studied by experimental and simulative investigations. Three clutch variants with carbon friction linings are investigated and compared with regard to damaging modes. In the experiments, the damage patterns buckling of the steel plates and lining detachment were found. With the aid of temperature measurements, statistically validated temperature criteria can be developed. In addition to the experimental tests, validated thermomechanical simulations are carried out, which allow a large parameter study. Thus, the effects of steel plate thickness, E modulus, thermal conductivity and heat capacity of the lining on the thermal behavior of the clutch can be analyzed. The experimental and simulation results allow recommendations for the development of clutch systems with regard to prevent damage.

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

**10:30 - 11 am**
**3648091: Retention of Fuel Economy Performance of Engine Oils Formulated Using Comb Polymers**
JoRuetta Ellington, Peter Moore, Evonik Oil Additives USA, Inc., Horsham, PA; Thorsten Bartels, Selin Manukyan, Evonik Operations GmbH, Darmstadt, Germany; Alan Flamberg, Retired, Blue Bell, PA

The influence of two VII-technologies, Olefin Copolymer or Comb polymer, on fuel economy and fuel efficiency retention was investigated, with a focus on the impact of aging within the engine oil. The engine oils were aged for 20,000 km using Artemis Urban, Artemis Motorway, or Sierra Nevada driving cycles. Fuel consumption was measured on fresh and aged oils using NEDC and WLTC. The Comb formulations consistently showed reduce fuel consumption (higher fuel efficiency) throughout the testing, and this efficiency was retained after each of the three distinct engine driving cycles.

**11 - 11:30 am**
**3663259: Reducing GHG Through Innovative Engine Oil Development**
Jeremy Styer, Glenn Mazzamaro, Vanderbilt Chemicals, LLC, Norwalk, CT

While auto manufacturers progress electrification to reduce greenhouse gas (GHG) emissions, the vast majority of vehicles on the road will continue to rely on an internal combustion engine for primary or secondary power generation for at least another 20 to 25 years. With an estimated 1.2 billion vehicles on the road today, employing innovative engine oil formulation technology can provide GHG reductions in these vehicles in the near term, providing significant improvements in air quality throughout this transition period. The authors have used a low phosphorous, high molybdenum (LPHM) formulation approach to enable CO2 reductions through direct fuel economy improvement as well as by extending catalytic converter life, without any negative impacts on durability. Data from industry standard engine tests, vehicle chassis dynamometer tests and multiple field trials demonstrate no less than a 1.7% fuel economy improvement vs. conventional GF-5 oils of equal viscosity across all test types.

**11:30 am - 12 pm**
**3669382: Tribology-By-Design**
Vern Wedeven, William Black, Graham Wedeven, Robert Homan, Anita Patterson, Wedeven Associates, Inc., Edgmont, PA

Tribology-by-Design (T/D) is a culmination of actions to create a methodology to revolutionize the way tribology technology is created and applied. The purpose T/D is to reduced the time, cost, and risk of introducing urgently needed tribology materials and component designs into targeted applications. While developments for aerospace applications have been aided by the Technology Readiness Level (TRL) approach to reduced risk, it has proven to be slow and costly. T/D targets the application system and components at high level TRL using first principles for motion, stress and temperature (MST). The targeted MST, along with their tribology materials, mechanisms and manifestations ($T_m$) during operation are extracted and developed on a pseudo virtual basis at TRL 4 using specialized analysis and simulation testing tools. The T/D methodology uses surface analysis, gear/bearing codes, single contact simulation

testing and a single contact model (SCM) for rapid TRL success.

**5B** Southern Hemisphere II

**Lubrication Fundamentals V - New Chemistries**

**Session Chair:** Pranesh Aswath, UTA-Materials Science and Engineering, Arlington, TX
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3652639: Oil-miscible ZnS Nanoparticles as High-Performance Antiwear Additive**
Chanaka Kumara, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN; Inwoong Lyo, HongWook Lee, Hyundai Motor Corporation, Seoul, Republic of Korea

Oil-miscible and oil-transparent ZnS nanoparticles (NPs) with a nominal diameter of ~5 nm were synthesized using dodecanethiol as a ligand. The ZnS NPs form a stable suspension in both PAO4 base oil and commercial engine oils and maintained good transparency in oils for more than a year. Tribological bench tests were conducted at room temperature, 100 and 150 $^{o}$C under reciprocating sliding at 100 N load for 1000 m. The ZnS NPs performed very well when added into the PAO4 base oil to provide effective scuffing prevention, friction reduction, and wear protection. The ZnS NPs outperformed a secondary ZDDP by an additional 20% friction reduction and 60% wear reduction. The top and cross-sectional worn surface characterization revealed the formation of a Zn- and sulfur-rich polycrystalline 5-250 nm thick tribofilm protecting the surface. Preliminary screening with commercial engine oil suggested the necessity of dedicated formulation to optimize the antiwear performance of ZnS NPs.

**8:30 - 9 am**
**3647941: Mechanism of Low Friction of Multi-Layer Graphene in Ambient Air Condition**
Hitoshi Washizu, Ryo Matsuoka, Yoshiki Ishii, University of Hyogo, Kobe, Hyogo, Japan

The mechanism of low friction of graphite in ambient air, is difficult. Rational mechanism base on the concept of thermal escape motion is found to understand this phenomena using coarse-grained simulation [Washizu et al., Faraday Disc. 2012]. In this theory, the transfer layer finds a plain potential way on the surface using thermal fluctuation. The motion is confirmed by all-atom molecular dynamics (MD), but this mechanism only occur in very low temperature [Maeda, Washizu, Microsyst Technol. 2018]. In this presentation, low friction mechanism of layered graphene is analyzed by molecular dynamics simulations with surrounding waters using reactive force field. At the hydrogen termination case and in vacuum and in 50 K, the thermal escape motion is reproduced. This is also reproduced with a population of water molecules in room temperature. Thus, it is found that the low friction of graphite is greatly affected by the surrounding water molecules due to hydrophobic interaction.

**9 - 9:30 am**
**3648899: Improving Weld Load of Lubricating oil Using Magnetic Nanoparticles and Performance Enhancing Additive**
Kinjal Trivedi, P D Patel Institute of Applied Sciences, Anand, India

In the present study magnetic nanoparticles (MNP) having an average particle diameter of 11.7 nm were synthesized and dispersed in synthetic lubricating oil. The solid weight fraction of MNP in the lubricating oil is 4 wt %. The tribological properties were studied using a four-ball tester. Results demonstrate that with the addition of MNP weld load enhance by 20 % (200 Kg) compared to a base oil (160 Kg). This increment is similar to the mixture of lubricating oil and performance enhancing additive (PEA). But, industrial applications such as industrial gearbox and windmills require a higher value of weld load (> 250 kg). Hence, a study was conducted to increase the weld load by adding MNP and PEA in lubricating oil simultaneously. The weld load improves by 400 % which is explained based on the synergetic effect of MNP and PEA. The positive response of MNP in lubricating oil shows the potential replacement of

conventional lubricating oil.

**9:30 - 10 am**
**3669325: Microencapsulation of Lubricant Additives**
Stephen Hsu, GWU, Germantown, MD

Lubrication of engines is undergoing rapid changes, from internal combustion engines to electric motors, from petroleum fuels to biofuels, e-fuels, and others. Many formulations will need to be modified or reformulated to meet increasingly different demands. Compatibility of new additives with existing additives will become an issue. Microencapsulation of some additives will avoid conflict and expand to provide new functions. At the same time, the incorporation of microcapsules into lubricant will encounter many barriers. This paper will discuss these barriers and how they can be avoided. Successful incorporation of microcapsules into lubricants will afford many advantages such as time-release, targeted applications, and mini-formulations, and introduction of nanoparticles as lubricating agents without interference from dispersants and detergents.

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

**10:30 - 11 am**
**3669464: On the Requirements for Tribofilms From Green Lubricants**
Nicole Doerr, Serhiy Budnyk, Marcella Frauscher, AC2T research GmbH, Wiener Neustadt, Austria

A major challenge in tribology is the formulation of lubricants from environmentally harmless components with comparable or even better performance than conventional lubricant chemistries. With regard to the tribofilm, these are wear protection additives, especially ZDDP, and friction modifiers, especially molybdenum dithiocarbamate, for which environmentally friendly alternatives are being explored. For this purpose, the properties of tribofilms made from conventional additives that are beyond the chemical composition, such as mechanical properties, were elaborated and defined as benchmarks for alternative chemistries. Results on friction and wear from triboexperiments of oils with conventional additives and alternative chemistries are compared.

**11 - 11:30 am**
**3669342: Synthetic Lubricants Derived from Plastic Waste and their Tribological Performance**
Istiaque Alam, Seungjoo Lee, Ali Erdemir, Texas A&M University, College Station, TX; Ryan Hackler, Massimiliano Delferro, Argonne National Lab, Lemont, IL; Wang Yi-Yu, Ranjan Behera, Wenyu Huang, Aaron Sadow, Iowa State University, Ames, IA

Roughly 75% of the plastics manufactured are discarded as waste materials due to inefficient post-consumer plastic processing. In this work, we present the tribological performance of high-quality liquid (HQL) lubricants derived from single-use pre and post-consumer plastic wastes. Sliding tests showed that some of these lubricants reduce wear by as much as 44% compared to the conventional mineral oils (Group III) while having comparable friction and wear performance to those of the synthetic PAO10 base oil. Additionally, a synergistic reduction in friction and wear was observed when HQLs derived from high-density polyethylene (HDPE) and bubble wrap plastic wastes were combined with base oils. Surface analysis revealed the chemical nature of the tribofilms responsible for such favorable tribological performance. Out of this study, we hope to create a blueprint for the design of next-generation eco-friendly lubricants for various industrial applications including electric vehicles.

**11:30 am - 12 pm**
**3640719: Selecting Suppliers for Your Lubricants**
Michael Holloway, 5th Order Industry, Highland Village, TX

The proper selection of oils and grease can become very cumbersome and complicated. This session looks to establish the framework and foundation for the minimum requirements necessary. This session helps navigate through the maze of quality, performance, supply considerations, as well as safety and storage. In this session, the attendee will learn how to establish a performance profile for quoted

products. Attendees will understand the structure and how to properly utilize a Safety Data Sheet for products quoted and purchased. In this session, the attendees will be able to understand and request the various package and storage options as well as how to navigate geographic and shipping concerns. This session also explores how the procurement process should select products according to performance.

## 5C Southern Hemisphere III

**Commercial Marketing Forum V**

**Session Chair:** TBD
**Session Vice Chair:** TBD

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

**8:30 - 9 am** - **Open Slot**

**9 - 9:30 am**
**3648488: SEQENS: Introducing LOSMA® CARB M, A New Multifunctional Additive for Water-Based Metalworking Fluids**
Marie Legatte, SEQENS, Porcheville, France

The choice of multifunctional amines is a key factor as the metalworking industry is moving.
LOSMA® CARB M can help formulators in finding an answer to their need for longer lasting and higher performing metalworking fluids has grown, while stricter regulations and safety concerns have limited available additives. LOSMA® CARB M is a colorless, water soluble, low volatile liquid with a mild odor. It is an additive for water-based metalworking fluids formulations with alkaline buffering capacity.
LOSMA® CARB M is an alternative to primary amines that is used in water miscible systems to boost pH and improve additional buffer capacity. It also provides good protection for ferrous metals corrosion and have a safer labelling than conventional amines.
To support formulators, SEQENS has run performances tests of LOSMA® CARB M: alkaline reserve, pH stability, VOC content, foaming, metal compatibility and resistance to micro-organisms were evaluated compared to typical amines.

**9:30 - 10 am**
**Falex Corporation**

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

**10:30 - 11 am**
**The Lubrizol Corporation**

**11 - 11:30 am**
**BYK-Chemie GmbH**

**11:30 am - 12 pm** - **Open Slot**

## 5D Southern Hemisphere IV

**Condition Monitoring I**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3637642: The Assumptions of the Lubricant Supply Chain - Fact or Fiction**
Michael Roe, MJR Lubricant Distribution Consulting & Auditing, Cypress, TX

This presentation will review 10-15 common assumptions about how to maintain lubricant quality in the Lubricant Supply Chain, and what may or may not be true about them. Examples include: air blowing of lubricants during change of service is effective; products received from suppliers have already been sufficiently filtered for the application; Certificates of Analysis provide specific information about the product received. The assumption will be stated and then what is true or not true about it discussed.

**8:30 - 9 am**
**3640176: Adjusting Oil Analysis to Quad Z Thresholds**
Henry Neicamp, Polaris Laboratories, LLC, O'Fallon, IL

Quad Z has oil analysis requirements for compression-ignition (diesel) and spark-ignition (natural gas) engines. Both rules require an oil analysis to demonstrate a fluid's viscosity and water level, but the diesel engine test requires a base number while the natural gas engine test requires an acid number. The EPA's National Emissions Standards for Hazardous Air Pollutants (NESHAP) Subpart ZZZZ, known as Quad Z, was created to reduce hazardous emissions from stationary reciprocating internal combustion engines (RICE) by requiring operations to change engine oil after operating a specific number of hours. However, the drain can be delayed if oil analysis demonstrates certain parameters of the lubricant are within Quad Z limits. The consequences of disobeying Quad Z are high as the EPA can levy fines up to $25,000. If the lubricant does not meet the Quad Z standards for acid/base number, viscosity or water content, operators only have two days to perform a drain or shut down the engine.

**9 - 9:30 am**
**3640717: How to Improve Any Lubricant Analysis Program**
Michael Holloway, 5th Order Industry, Highland Village, TX

Many practitioners of lubricant analysis do not get all they can out of the practice. This session explains the utilization of the compilation of data from multiple tests and how to manage accordingly. Attendees will be provided with valuable content by which to establish or enhance their existing lubricant analysis program. In this session, attendees will also be introduced or refreshed on the proper sample methods as well as locations for sample pull. Attendees will also be introduced with how to establish cautionary and critical limits or targets for the test results. The session will also cover the various tests that are most applicable for a given system.

**9:30 - 10 am**
**3644138: Electrical Impedance Spectroscopy Enabled In-Depth Lubrication Condition Monitoring**
Min Yu, Jie Zhang, Thomas Kirkby, Tom Reddyhoff, Imperial College London, London, United Kingdom; Arndt Joedicke, Shell Global Solutions (Deutschland) GmbH, Hamburg, Germany

Electrical contact resistance or capacitance as measured between two interfaces of a lubricated contact has been used in tribometers, partially reflecting the lubrication condition. In contrast, the electrical impedance spectroscopy (EIS) provides rich information of magnitude/phase spectrum, which is thoroughly investigated using a combination of electrical circuit models (equivalent to the lubricated contact) and in-situ measurements with a ball-on-disc contact. Results indicate a promising potential of EIS in lubrication condition monitoring, including the variation of lubricant film thickness as estimated using high-frequency magnitude response; the transition between full-film, mixed, and boundary lubrication regimes, as differentiated using extracted electrical resistance together with phase spectrum; the forming of anti-wear boundary film, where extra resistor/capacitor are added; and the degradation of lubricant, such as fuel dilution, oil oxidization, and water emulsifying.

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

**10:30 - 11 am**
**3646654: A Novel Method for Bearing Fault Diagnosis Based on High-Frequency Resonance Technique and Cepstrum Pre-Whitening**
Amirmasoud Kiakojouri, Ling Wang, Zudi Lu, Honor Powrie, University of Southampton, Southampton, United Kingdom; Patrick Mirring, Schaeffler Aerospace, Schweinfurt, Germany, Schweinfurt, Germany

A localized defect in a rolling element bearing (REB) typically results in periodic impulses in vibrational signals at bearing characteristic frequencies (BCFs). One of the most powerful methods for BCF detection is High-Frequency Resonance Technique (HFRT) based on the initial band filtration of the raw signal to highlight the BCFs in noisy signals. However, band-pass selection of this technique is a serious challenge in diagnostic procedures. Cepstrum Pre-Whitening (CPW) is a technique that can effectively eliminate discrete components while maintaining impulsive features in vibrational signals related to bearing defects. Nevertheless, this technique may attenuate the impulse responses induced by REBs incipient faults. In this study, an improved CPW combined with HFRT method for automated envelope analysis is developed to accurately identify BCFs. The results show this method is highly effective in detecting incipient as well as multiple faults in rolling element bearings.

**11 - 11:30 am**
**3648688: Advances in the Analysis of New and Used Lubricating Oils by High-Resolution ICP-OES**
Siqi Sun, Analytik Jena US LLC, Beverly, MA

Lubricating oils are the lifeblood of oil-wetted machinery. Elements such as barium, boron, calcium, copper, magnesium, molybdenum, phosphorus, sulfur, and zinc are used as additives in lubricating oils to improve their lubricating capability and properties. The quantity of those elements highly affects a lubricant's performance. Therefore, a rapid, sensitive, and precise measurement is crucial as part of its production.
In this paper, ASTM D4951 and D5185 methods are demonstrated with Analytik Jena's PlasmaQuant 9100 Elite, equipped with an organic sample introduction kit. Linear calibrations were obtained with correlation coefficients greater than 0.9997 for all elements in both methods. For most elements, the method detection limits (MDL) are below 5 µg/kg with the PlasmaQuant 9100 Elite in radial view. The QC samples, used and unused oil samples, and spiked samples were analyzed by D4951 and D5185 methods.

**11:30 am - 12 pm**
**3662738: Combining Tribological Properties With Analytical Sciences for Condition Monitoring**
Ameneh Schneider, Optimol Instruments, München, Germany; Mathias Woydt, Matrilub, Berlin, Germany; Franz Novotny-Farkas, Ingenieurbüro für Erdölwesen, Schwechat, Austria

Conditioning monitoring of lubricant in operation usually considers different physical and chemical quantities, but not functional properties. The identification of the induction time or off-set point ("cliff" or "jumping off point"), after which wear and friction will increase and thus improve the reliability of judgements and extend the service life on a knowledge-based decision. Tribological SRV quantitites are therefore combined with analytical sciences (Analysis, viscometrics, degradation, water&fuel dilution). This approach is not limited to condition monitoring, but can also be applied to oil development. This methodology supports as auxiliary method the interpretation of engine tests and enhances the values of expensive engine tests.

## Nanotribology II

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3637644: Nanotribology in Dynamic Crosslinked Polymers: Experiments and Simulations**
Zhijiang Ye, Nethmi De Alwis Watuthanthrige, Mehdi Zanjani, Dominik Konkolewicz, Miami University, Oxford, OH; Jian Wu, Harbin Institute of Technology, Weihai, China

Dynamically crosslinked polymers and their composites have tremendous potential in the development of the next round of advanced materials for aerospace, sensing and tribological applications. However, it is still lack of understanding how the configurational arrangement and the nano/microstructure affect the performance and the mechanical and tribological properties. Here, we report a combined computational and experimental study of the mechanical and tribological properties of self-healing polymer composites with different architecture: Interpenetrating and Single Networks and with/without carbon nanotube reinforcement. We further investigate the impact of mechanical forces on the self-healing of a model dynamic covalent crosslinked polymer system. We have also varied network type, chain length, dynamic bond composition, crosslink density and crosslink distribution within the system to explore the effect on the tribological and thermomechanical properties.

**8:30 - 9 am**
**3668235: Squeezing Behaviors of Octamethylcyclotetrasiloxane (OMCTS) Under Extreme Compression**
Gunan Zhang, Rong-Guang Xu, Yongsheng Leng, George Washington University, Washington, DC

Octamethylcyclotetrasiloxane (OMCTS) is a reference model lubricant in early SFA structural force measurements. However, there exist long-standing debates regarding its phase transition and shear properties under nanoconfinement, i.e., during the normal compression in boundary lubrication, what are the thermodynamic equilibrium or metastable states of molecular base fluids associated with the squeeze-out thinning or phase transition? And upon the start-up of shearing, how do nanoconfined fluids react to sliding friction and what are the effects of sliding velocity and loading conditions on the shear properties of the confined films. To resolve these issues, in this research we develop the realistic computational model for OMCTS using density functional theory (DFT), molecular dynamics (MD) and machine learning method. The performance of this model is also tested.

**9 - 9:30 am**
**3668526: Friction Simulation of a Polycrystalline Platinum Tip on a Gold(111) Surface**
Rong-Guang Xu, Gunan Zhang, Yuan Xiang, Yongsheng Leng, George Washington University, Washington, DC

Typically, the microstructure of the AFM tip made from the thermally evaporated metal coating on a silicon cantilever is polycrystalline. In this work, we perform MD simulations of a 10nm-polycrystalline Pt tip sliding on an Au(111) surface to investigate how an AFM metal tip with a polycrystalline structure can affect the frictional behavior of binary metal contact. It is found that the apex of the Pt tip with polycrystalline structure can induce severe plastic deformation of the gold substrate during sliding, resulting in irregular stick-slip friction. In order to achieve a clear atomic stick-slip friction signal in a single slip regime, the contacting apex of the Pt tip must adopt a single crystalline protrusion without any neighboring grains involved at the contact interface. We find that subsequent scanning of the AFM Pt tip on the Au(111) surface is very tolerant to the attached gold particles accumulated on the tip apex and can produce well-defined stick-slip friction signals.

**9:30 - 10 am**
**3669303: Understanding the Corrosion and Wear at Nanoscale Interface Using MachineL Learning Technique**
Saugat Tripathi, Ashutosh Pitkar, Ran Zhang, Miao Wang, Zhijiang Ye, Miami University, Oxford, OH

Tribological problems, such as wear and corrosion, is an age-old problem that still costs US an estimated $20.6 billion annually. However, it is still lack of understanding of nucleation process of corrosion and wear due to the complexity and heterogeneity of properties on material surface and interface. The recent proliferation of novel artificial intelligence and machine learning (ML) algorithms have provided a unique opportunity to address the issue. In this study, we investigate initiation of triboelectrochemical reactions (wear and corrosion) on metals using ML techniques. Both reactive molecular dynamics simulations and experiments (including conductive atomic force microscopy and scanning electrochemical cell microscopy) will be conducted to generate high-throughput synthetic data for machine learning training, validation, testing and prediction. Deep learning is exploited to understand the causality between the microstructural features and the multiscale properties.

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

**10:30 - 11:30 am**
**3678670: An Atomistic Perspective on the Nanoscale Behavior of Corrosion Inhibitors and Friction Modifiers**
Chiara Gattinoni, London South Bank University, London, United Kingdom

Modern lubricants include a zoo of additives whose effectiveness depends on their interaction with the base oil, the surface and with one another. Despite many decades of innovations in lubricant research, certain processes still lack an optimal additive. Insight in the behavior of additives can be obtained using quantum-mechanics-based "ab initio" computational methods. Here we show advances in the understanding of the behavior of corrosion inhibitors and friction modifiers. We show that the atomistic details of adsorption and of the onset of oxidation can inform the formulation of corrosion inhibitors . Moreover, we show that the atomistic details of adsorption of friction modifiers largely influence the macroscopic friction reduction behavior of these additives .

**11:30 am - 12 pm**
**3647953: Molecular Dynamics Simulation of Tribology – the Influence of Porous Surfaces on Wall Slip and Bulk Shear**
Seyedmajid Mehrnia, David Dexheimer, Peter Pelz, Technische Universität Darmstadt, Darmstadt, Germany

Molecular Dynamics simulation is a proven method to inspect behaviors of lubricant oils in nanochannels. However, most MD simulations on nanotribology have been performed with smooth walls to determine slip properties. This study will investigate the effect of porous walls, on wall slip of hydrocarbon oils confined between two metal walls in a Couette flow. Different pore geometries will be modeled to investigate the effect on wall slip.
In this MD tribology study, the PAO molecules are confined to a stationary and moving wall. A hybrid force field consist of different potential energy functions was employed in this simulation. The interactions among surface atoms were simulated with an Embedded Atom Method (EAM) potential function which can represent the characteristics of metallic arrangements very strongly. We implemented NERD forcefield for intramolecular potential energy function. Also, Lennard-Jones potential was employed for nonbonded intermolecular interaction.

## Wind Turbine Tribology I

**Session Chair:** TBD
**Session Vice Chair:** TBD

**Session Starts at 9 am**

**9 - 9:30 am**
**3648028: Investigation of Skidding in a Wind Turbine Double Row Spherical Roller Main-Bearing**
Elisha de Mello, Rob Dwyer-Joyce, University of Sheffield, Rugby, United Kingdom; Edward Hart, University of Strathclyde, Glasgow, United Kingdom

Wind turbine main-bearings (MBs) are failing sooner than expected, driving reduced reliability and increased costs. Recent work connects this to large repeating load structures acting at the MB. Such load fluctuations are expected to drive skid events which may lead to the premature failures seen in the field. Operating conditions inside a double row spherical roller MB in a 1.5 MW wind turbine are investigated through development and application of a dynamic bearing contact model. Realistic input loading is generated via aeroelastic simulation of the chosen turbine. The model resolves internal loading, speeds, patch dimensions and lubricant film thicknesses, from which frictional and inertial effects are accounted for when integrating the equations of motion in time. The severity of roller-raceway skidding will be reported over a range of turbine operating conditions, links between load patterns identified previously and potentially damaging skid events will be explored.

**9:30 - 10 am**
**3648275: Foaming in Wind Turbine Gearboxes: Causes, Impacts and Treatment**
Michael Blumenfeld, ExxonMobil Research and Engineering, Annandale, NJ; André Doucette, Majid Morshedisadeh, Marianne Rodgers, Peder Schlanbusch, Wind Energy Institute of Canada, Tignish, Prince Edward Island, Canada; Kurt Hartlen, Andrea Williamson, Imperial Oil, Sarnia, Ontario, Canada

Wind turbines are a demanding and cost-sensitive application where high availability and low maintenance costs are critical to industry success. One of the most frustrating issues that a wind turbine operator can experience is a foaming gearbox lubricant, which can trip oil-level sensors and cause unexpected downtimes. These foaming events may result in lost revenue, messy clean-ups and difficult troubleshooting. In this presentation, a case study documenting the impact of problematic gearbox foaming on the operation of a fleet of five 2MW turbines at the Wind Energy Institute of Canada will be shared. Steps taken to address the issues will be highlighted and potential root causes (contamination, over-filtration, mechanical issues, etc...) will be evaluated. Finally, a discussion on the chemical basis of foaming in lubricants will provide context for operators looking to evaluate their own practices and assist in solving and preventing future foam issues.

**10 - 10:30 am**
**3667455: Bio-Based Ionic Liquid Additives for Ester-Based Synthetic Oils for Wind Turbine Applications**
Md Hafizur Rahman, Soumya Sikdar, Pradeep Menezes, University of Nevada-Reno, Reno, NV; Ting Liu, Ashlie Martini, University of California, Merced, Merced, CA; Manish Patil, Nano Additive Technology Inc, Austin, TX; Ramesh Navaratnam, Patech Fine Chemical, Dublin, OH

Wind turbines are making a significant contribution in clean energy generation. Wind turbines are usually installed far from the ground and often offshore to utilize uninterrupted wind flow, which makes regular maintenance difficult. Therefore, minimizing tribological failure in wind turbine gearsets is critical. Ester-based synthetic oils have been widely used for wind turbine lubrication. Still, their performance can be further improved by incorporating additives. In this study, we synthesized bio-based ionic liquid and

evaluated their performance as additives for ester-based oils. For the steel-steel material pair, a significant reduction of friction and wear was observed. Then, the mechanisms behind the lower coefficient of friction and wear were studied and evaluated. This investigation will contribute to the expanded usability of bio-derived lubricants and improve the efficiency of wind turbine gearsets.

**10:30 - 11 am** - **Break**

**11 - 11:30 am**
**3669444: Efficiency and Lifetime Improvement for Wind Turbines by Using Silicon-Based Additive Technology**
Stefan Bill, Croda, Plainsboro, NJ

REWITEC® is a part of CRODA Int Plc and develops an innovative nano and micro silicon-based lubricant additive technology. The active silicon particles use lubricants as a carrier and build through their adsorption a protective and repairing silicon-based coating in combustion engines, gears and bearings. In this way it reduces friction, wear, surface roughness and temperature. This talk will look at several tribological tests, like MTM, 4-ball, false brinelling and 2-disc, which proves the significant effects of the coating technology. Generally, a 20 to 60% reduction in friction is achieved in these tests and at the same time the surface roughness is significantly reduced as well. Due to this tribo layer modification, the load distribution and so the surface stress is optimized and will lead to a longer lifetime and higher efficiency of tribological systems.

**11:30 am - 12 pm**
**3669399: Wear Process of the Gearbox Bearing Due to the Loos of the Yellow Metal Passivator**
Jorge Alarcon, Bureau Veritas, Stafford, TX

One of the most common problems in some wind turbine fleets is the accelerated wear of the gearbox bearings, which in many cases do not even reach 10% of the expected life. This phenomenon in many cases is irreversible and it was not until recently that the determination of the severity of the damage was possible with advanced oil analysis techniques. This talk covers a case with more than 10 machines with problems of this type and their follow-up over the last 10 years

## 5G — Northern Hemisphere A2

**Environmentally Friendly Fluids I**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3644013: Structure-Property Relationship of Phosphonium Ionic Liquids: A Molecular Dynamics Study**
Ting Liu, Pawan Panwar, Ashlie Martini, University of California Merced, Merced, CA; Md Hafizur Rahman, Pradeep Menezes, University of Nevada Reno, Reno, NV

The non-toxic and biodegradable phosphonium ionic liquids (ILs) are used in a wide range of applications, such as environmentally benign lubricants and lubricant additives in wind turbine and automotive. A deeper understanding of their structure-property relationship is desired to improve their performance and provide guideline for new fluids design. Classical molecular dynamics simulations are employed to study ILs with systematically varied cation sizes and anion chemistry. The simulations predict physico-chemical properties of neat phosphonium ionic liquids and their mixture with base oil, with comparisons to experimental measurements. Trends for each property are captured among the cation-anion pairs studied. The mechanism behind these trends is then analyzed using atomistic details

available in the simulations, including radial distribution functions. The structure-property relationship obtained from this study can ultimately be used to guide the design of new phosphonium ILs.

**8:30 - 9 am**
**3644791: Biomimetic Water-Based Lubricant Development: Nanoencapsulation with Liposomes**
Manoj Murali, Marc Masen, Philippa Cann, Imperial College London, London, United Kingdom

Replacement of oil-based lubricants with sustainable water-based lubricants is a long-standing unfulfilled ambition. The physical instabilities and poor wear performance associated with water-based lubricants has led to minimal adoption in mechanical systems. Our investigation focuses on the lubrication mechanism of liposomes with additive payloads in their core. Aqueous liposomal solutions (ALS) were separately encapsulated with mucins, sugars and wear additives. Tribology tests were carried out on a reciprocating device (HFRR) with ALS and hexadecane as a reference. Wear and friction were significantly reduced for the ALS compared to water alone. The test demonstrated that nanocapsules enter the contact and are ruptured by high shear stresses, allowing for the encapsulants to be released to lubricate the contact. The research forms a foundation to explore synthetic nanocapsules such as polymersomes which provide additional benefits in chemical stability, adaptability and longevity.

**9 - 9:30 am**
**3644879: How Low Can You Go? Esters for Arctic Applications**
Jared Nelson, Emery Oleochemicals, Cincinnati, OH

New applications in low-temperature regions of the world have necessitated the development of advanced lubricating oils which maintain their properties under increasingly demanding conditions. Lubricants and performance components with pour points below -40$^{o}$C are plentiful, but often are limited by other properties such as viscosity, cloud point, lubricity, etc. In this presentation, we will explore tribological performance in low-temperature settings, specifically with regard to sustainable feedstocks and related renewable products.

**9:30 - 10 am**
**3646093: On the Origins of Lubricity and Surface Cleanliness in Ethanol-Diesel Fuel Blends**
Frank Hong, Eshan Singh, S. Mani Sarathy, KAUST, Thuwal, Makkah, Saudi Arabia

Ethanol is the most used bio-derived fuel additive. However, adding ethanol in diesel fuel may negatively impact lubricity or surface cleanliness, which is critical for high-pressure fuel injection systems employed in compression ignition engines. This work investigates surfaces lubricated by ethanol-diesel blends. Adding 5 wt% ethanol in diesel showed negligible changes in fuel lubricity while blending 10, 20, and 40 wt% ethanol increased wear rates by 46, 81, and 239% respectively. These increases in wear rates (with increases in ethanol by wt%) correlate with the evolution of electrical contact resistance (ECR) values over time. As more ethanol was added, the ECR values signaled thinner fuel films, more metal-to-metal contacts, and delayed onset of frictional product growth. The absence of some frictional species in ethanol lubricated surfaces points to simultaneously improved surface cleanliness and reduced lubricity.

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

**10:30 - 11 am**
**3646350: Sustainable Metalworking Fluid Additives**
Jeffrey Mackey, Biosynthetic Technologies, Indianapolis, IN

The environmental and safety aspects of metalworking fluids are becoming increasingly more important. Forced by new regulations lubricants manufacturers worldwide are replacing the mineral base oils in metalworking fluids by natural sourced derivatives. As several additives have been eliminated from use in MWFs, including nitrites and short-chain chlorinated paraffins, there is a growing pressure to further eliminate additives that may be harmful to the worker or the environment. In this session, we will cover the new requirements for performance and reduced environmental and human exposure that lead to the development of bio-based metalworking fluids. In addition, this session will cover how government

regulation of MWFs (particularly their additives) is almost certain to tighten, creating a conundrum for formulators who need to produce fluids that perform well for extended periods and also protect the machinery, workpiece, environment and most of all the workers.

**11 - 11:30 am**
**3646474: The Importance of Sustainability and Carbon Negative Footprint in the Lubricants Industry**
Julie Austin, Biosynthetic Technologies, Indianapolis, IN

As many independent lubricant manufactures adopt strategies toward sustainable products and carbon negative footprint goals, the definitions become more important. In this session we will distinguish facts from fiction when it comes to sustainability and discuss the advantages and disadvantages of said strategies. In addition, we will cover the importance of a Life Cycle Assessment and all that assessment encompasses and how to effectively dissect the important elements of a Life Cycle Assessment.

**11:30 am - 12 pm**
**3646312: Tribological Testing of Possible Plant Oil-Based Lubricants With Environmentally Friendly Viscosity Improvers.**
Andrew Sakyi, University of Pretoria, Pretoria, Gauteng, South Africa

Plant oils have better lubricity and anti-wear characteristics than mineral or synthetic lubricant oils due to their amphiphilic properties resulting from their fatty acid content. Despite these benefits, plant oils have a narrow range of viscosities, which limits their usage as bio-lubricants in a variety of industrial applications. In this study 1 % (w/w) ethyl cellulose (EC) and 4 % (w/w) ethylene–vinyl acetate (EVA) copolymer were added as viscosity improvers to plant oil-based lubricants (i.e. castor, moringa and canola oils) to increase their viscosity range and enhance their thermal susceptibilities. Results obtained show that, ethylene–vinyl acetate copolymer has a minor effect on lubricant film-forming capabilities and hence aids in the reduction of friction and wear mostly in the mixed lubrication zone. Ethyl cellulose, on the other hand, was far more effective in improving both mixed and boundary lubrication, especially when combined with castor oil.

## 5H — Northern Hemisphere A3

**2D Materials + Superlubricity - Materials Tribology and Nanotribology III**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**Session Starts at 8:30 am**

**8:30 - 9 am**
**3647493: Tip-on-top Manipulations of Superlubric Gold Islands on Graphite: From Friction "Switches" to Contact Aging**
Wai Oo, Mehmet Baykara, University of California Merced, Merced, CA

The demonstration of structural superlubricity under ambient conditions [1] constituted the first step toward establishing intrinsic lubrication schemes for mechanical systems operating under ambient conditions. However, several important questions remain regarding the physical limits and robustness of this elusive, ultra-low friction state. In contrast to previous work where superlubric islands were laterally pushed from the side with an atomic force microscope tip [1], here we perform "tip-on-top" manipulations of gold islands on graphite that allow the collection of much more detailed data sets. Our results reveal previously undiscovered effects including spontaneous jumps between friction "branches" and prominent contact aging. Experiments conducted on a large number of gold islands with varying geometry under

different environmental conditions help elucidate the influence of contact size and contamination on these effects. [1] E. Cihan et al. Nature Communications 7, 12055 (2016)

**9 - 9:30 am**
**3648067: Tribological Behaviour of Graphene Quantum Dots as Novel Additives for Green Lubrication**
Mitjan Kalin, Irfan Nadeem, University of Ljubljana, Ljubljana, Slovenia

Reducing friction, wear and saving resources are crucial for sustainable engineering, where tribology and lubrication can make a difference. In particular, greener contacts with greener tribology are becoming a concern for new systems. One potential solution to the problem is nanotechnology with nanoparticles as additives to lubricants. In this work we studied the effect of graphene quantum dots (GQD) mixed in aqueous glycerol in self-mated steel/steel contacts. The results show that the aqueous glycerol with GQDs provide excellent dispersion stability and significantly reduce the friction and wear. Mechanisms leading to this behaviour are discussed in this work. We show that GQD-based green nano lubricants have a great potential in sustainable engineering and should be investigated further for better insight into their active lubrication mechanisms, which can lead to a relevant lubrication technology of the future.

**9:30 - 10 am**
**3669069: Nanoscale Tribology of 2D MXene Flakes**
Eui-Sung Yoon, Prashant Pendyala, Seon Joon Kim, Korea Institute of Science and Technology, Seoul, Seoungbuk-gu, Republic of Korea

2D materials are popular for nanoscale contact applications due to their dimensions, and compatibility with wafer-scale processing. A new class of 2D materials called ‘Transition Metal Carbides’ or ‘MXenes’ have emerged as a potentially versatile nanoscale tribological material due to their weakly-bounded multi-layered structures and a wide variety of nanoscale electrical and mechanical properties. We investigated friction and wear mechanisms of Ti3C2Tx form of MXene flakes by varying force for about two orders of magnitude. Mxene flakes exhibited significantly reduced friction and wear compared to the substrate. For up to a few layers in thickness, MXenes showed reduced friction with an increase in the number of layers. At large loads, MXene developed defects due to wear, which resulted in subdued frictional performance. Analysis showed that the fundamental mechanisms associated with friction are similar for MXenes and other 2D materials for up to a few layers in thickness.

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

## 5I Northern Hemisphere A4

**Biotribology at Nanoscale I**

**Session Chair:** Alison Dunn, University of Illinois, Urbana, IL
**Session Vice Chair:** Arzu Colak, Clarkson University, Potsdam, NY

**Session Starts at 8:30 am**

**8:30 - 9 am**
**3690904: Lubrication Mechanism of Poly(vinyl alcohol) Hydrogels probed by Infrared Nanospectroscopy**
Debashis Puhan, Alexander Fellows, Michael Casford, Paul Davies, University of Cambridge, Cambridge, N/A, United Kingdom

Polyvinyl alcohol (PVA) hydrogels have been in use in biomedical applications as artificial cartilage and tissues due to their excellent biocompatibility and tribological properties. The tribology and lubrication

mechanism of the hydrogels has remained a topic of extensive research and debate due to contradictory results surrounding biphasic lubrication and fluid load support mechanisms. Using Atomic force microscopy integrated with infrared microscopy, the lubrication film development of PVA hydrogels was studied at a nano-scale. Under static loading, the load is shared by both hydrogel and water. While when a gradually increasing lateral shear is applied, a transition from a boundary to a mixed lubrication regime occurs through a replenishing self-lubrication mechanism expending interstitial water from within the hydrogel network that supports the load under sliding conditions while maintaining lower friction.

**9 - 9:30 am**
**3641261: Interfacial Friction in Hair-Hair Contacts from a Molecular Perspective**
Erik Weiand, James Ewen, Stefano Angioletti-Uberti, Daniele Dini, Imperial College London, London, United Kingdom; Steven Page, Yuri Roiter, Peter König, The Procter and Gamble Company, Cincinnati, OH

Low friction between hair contacts is beneficial for maintaining a low degree of entanglement between hair fibers. A central characteristic of hair care formulations is to provide low friction at the hair interface. This is true in particular for mechanically or chemically damaged hair which is generally subject to higher coefficients of friction compared to their undamaged counterparts. In this work, we present insights on the lubrication behavior between hair fibers from a molecular perspective. Coarse-grained molecular models are used to mimic the outer lipid layers on the hair surface and solvent molecules at the interface. Dry and wet hair-hair contacts are investigated at different degrees of hair damage. A set of realistic sliding velocities and contact pressures is considered. Additionally, various solvent compositions are investigated to pave way for the design of novel care formulations with improved lubrication behavior.

**9:30 - 10 am**
**3663676: Gel Forming Mucin Improves Lubricity Across Model Gemini Epithelial Cell Interfaces**
W. Gregory Sawyer, Research Institute of Industrial Science and Technology, Gainesville, FL; Brent Sumerlin, University of Florida, Gainesville, FL

The glycocalyx is a glycosylated protein network gel that protects the underlying epithelial cells. Although the glycocalyx is thought to be lubricious, we found it have high friction ($\mu$ ~0.20). The model of the tear film is that of a delicate hierarchical multiscale assembly of mucins that form a network aqueous gel interface between the glycocalyces of the conjunctival and corneal epithelial layers to provide lubricity and gentle shearing. The integrity of this aqueous gel is maintained through mucin entanglement, and dynamic flickering bonds of disulfide bridges, $Ca^{2+}$-mediated links, and hydrogen bonding. We have demonstrated that the gel forming mucins are critical to lubricity. With the addition of the MUC2 (5 wt. %), friction reductions from $\mu$ ~0.20 to $\mu$ ~0.08 were observed. Micro-rheology experiments using magnetic tweezers showed a yield-stress for a MUC2 solution that is below the critical thresholds known to produce proinflammatory cytokines (<40 Pa) and apoptosis (<100 Pa).

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

**10:30 - 11 am**
**3666490: Molecular Control of Tactile Sensations for Haptics and Touch**
Charles Dhong, University of Delaware, Newark, DE

For the sense of sight, we can purchase HD screens to recreate nearly any image or movie. For touch, we are not yet able to recreate the variety of sensations from our everyday experiences. However, an accurate and rich recreation of tactile sensations could have broad implications in human machine interfaces, soft robotics, and disability rehabilitation. While most haptic devices rely on reconfigurable bumps or electrical stimulation, one possible avenue we explore for is creating tactile sensations through materials chemistry. By using silane-derived monolayers, we found that humans can perceive single atom substitutions within silane-coated silicon wafers, thus opening the possibility for molecular-scale control over touch. We will also discuss how simulations and mechanical characterization of stick-slip friction lead to predictions about human performance, rationalize the presence of human fingerprints, and help establish a materials screening library.

**11 - 11:30 am**
**3668979: Nanostructure and Frictional Response of Charged Copolymer Gels**
Rosa Espinosa-Marzal, Alexander Deptula, University of Illinois at Urbana-Champaign, Urbana, IL

Due to complications with in-situ probing of complex fluid materials from solvent phase interference and accurate tracking of particle motion, experimental support for proposed mechanisms for the microstructure in such hydrogels is largely lacking. Here, we investigate the surface structure and response of a poly(methacrylamide-co-methacrylic acid) gel, which exhibits a glassy colloidal structure, to various stimuli including pH, temperature, electrostatic potential, and salt concentration, using in situ Atomic Force Microscopy techniques complemented by ex-situ rheology, FTIR, and contact angle measurements. This system is particularly of interest due to the physical crosslinking of the system and delicate balance of inter and intramolecular forces during and post-synthesis leading to significant structural manipulation. Further, we demonstrate the applicability of this type of system as a semi-reversible responsive tribological interface.

**11:30 am - 12 pm**
**3650757: Visualization of Hydration Layer on the Surface of Contact Lens Before and After Friction by FM-AFM**
Ayaka Nakajima, Kaisei Sato, Graduate School of Tokyo University of Science, Tokyo, Japan; Seiya Watanabe, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

Contact Lens (CL) causes discomfort and eye damage by increasing friction with upper eyelids. To improve the safety and wearing comfort of CL, it is essential to understand the friction mechanism between a CL and an upper eyelid. In this study, we investigated the relationship between the frictional property and the hydration structure of CL surface in physiological saline using nanotribometer and frequency-modulation atomic force microscopy (FM-AFM) which enables to observe hydration structure at surface with high resolution. During friction test, friction coefficient gradually increased with increase in the number of sliding cycles. According to FM-AFM measurement, a hydration layer was observed on CL surface before the friction test, and its thickness decreased after the friction test. Moreover, the decreased hydration layer recovered by immersing in physiological saline, and the friction coefficient of the recovered hydration layer was identical to that before the friction test.

## 5J — Northern Hemisphere E1

**Materials Tribology I**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 9 am** - **Invited Speaker**

**9 - 9:30 am**
**A presentation by John Curry**

**9:30 - 10 am**
**3667647: Mitigation of Biomass Fouling by Non-Adhesion Coatings for High-Temperature Biomass Conversion**
Xin He, Jim Keiser, Jun Qu, Oak Ridge National Laboratory, Knoxville, TN; Rick Wang, Texas A&M University, College Station, TX; Jaya Shankar, Idaho National Laboratory, Idaho Falls, ID; Jens Darsell, Aashish Rohatgi, Daniel Howe, Pacific Northwest National Laboratory, Benton County, WA

Biomass can undergo thermochemical processing to convert into gaseous and liquid fuels. One challenge of the current feeder design is that thermal decomposition induced biomass deposit accumulation leads to

plugging of the feed line. This work focused on understanding the mechanism of biomass decomposition across the thermal gradient on the screw feeder and investigating the feasibilities of advanced materials or coatings as potential mitigation. We developed a thermomechanical simulation to study the temperature profiles of the screw feeder and the biomass feedstock traveling through. Characterizations were conducted on a used screw feeder to reveal the deposit morphology and composition. The correlative modeling-characterization study provided insights for optimizing the screw design, materials, and operating parameters. Tribological tests were carried out to validate the deposit formation process and evaluate the frictional and biomass fouling behavior of candidate coatings.

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

**10:30 - 11 am**
**3669321: Investigation of Tribological Behavior in Molten Salts for Power Plants**
Xin He, Chanaka Kumara, Kevin Robb, Dino Sulejmanovic, Nidia Gallego, Jim Keiser, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Being a thermal media, molten salts also function as the lubricants at contact interfaces in power plants. In this work, two power generation systems were investigated, concentrating solar power (CSP) plants and nuclear reactors. In CSP, a chloride salt mixture was proposed as the energy transfer media to increase operating temperature. The tribological performance of several ceramic-alloy contacts was evaluated in the molten salt. The top candidate pair was further studied for the influence of impurities. Characterization suggested the wear mechanism as a combination of adhesive wear, abrasive wear, and tribocorrosion. For the nuclear reactor application, friction and wear behavior of graphite sliding against stainless steel in a molten fluoride salt were investigated to gain an understanding of the mechanical and chemical interactions between graphite pebbles and the molten salt container wall. Results from the above studies provide insights into molten salt tribological properties.

**11 - 11:30 am**
**3647486: Linked Experimental Data in Tribology for Machine Learning Applications**
Nikolay Garabedian, Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Germany

Among the many reasons for implementing robust data management of scientific results, there are two that stand out: i) the increasing demand put forward by public funding agencies, and ii) the potential for accelerated scientific discovery by integrating machine learning into tribology research. Our group created a comprehensive showcase database of curated terms and descriptions, formalized within an ontology, that contains 4000 logical axioms. The resulting knowledgebase is integrated with an electronic lab notebook and supporting modules that annotate experimental data at source for a selected pin-on-disc experiment. The long-term vision of this project is to enable large datasets, collected by various different techniques, for the implementation of machine learning techniques. This vision will be illustrated with an example that combines data from a synchrotron XRD and tribometry of copper, and then analyzes it via neural-network and non-neural-network based techniques.

**11:30 am - 12 pm**
**3647295: Probing Process-Structure-Property Relationships of Ultralow Wear Plasma Enhanced Atomic Layer Deposited Nitrides**
Kylie Van Meter, David Ramos, Santiago Lazarte, Brandon Krick, Florida State University, Tallahassee, FL; Md. Chowdhury, Nicholas Strandwitz, Tomas Babuska, Tomas Grejtak, Lehigh University, Bethlehem, PA; Mark Sowa, Veeco, Waltham, MA; Alexander Kozen, University of Maryland, College Park, MD

Plasma enhanced atomic layer deposition (PEALD) techniques allow for the creation of thin films with atomic level thickness and compositional control at low deposition temperatures. Single atomic layers can be uniformly grown on non-planar and porous architectures, allowing for applications in silicon-based microelectronics and MEMS/NEMS. PEALD multi-metal nitrides have exhibited ultralow wear rates ($K < 10^{-7}$ $mm^3/Nm$) and low friction (<0.2). However, the dependence of the wear performance of the film on the growth parameters, and resulting film microstructure and properties, is relatively unknown. In this work, the effects of varying deposition parameters and its influence on film wear performance is

investigated. X-ray diffraction techniques are used to characterize the film properties and determine their relationship with tribological behavior.

**5M** Northern Hemisphere E4

**Rolling Element Bearings V**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**8 - 8:30 am**
**3647040: Comparison of Power Losses and Temperatures Between an All-Steel and a Hybrid Cylindrical Roller Bearing for Aero-Engine Applications**
Rami Kerrouche, Azzedine Dadouche, National Research Council Canada, Ottawa, Ontario, Canada; Salah Boukraa, University of Blida 1, Ottawa, Ontario, Canada

Modern aircraft engines have to meet rigorous requirements, such as, thrust to weight ratio, efficiency and environment protection. These requirements affect all engine modules and components, including rolling element bearings. The latter have to withstand very challenging operating conditions because of the high thermal impact due to elevated rotational speeds and loads. In this study, a series of experimental measurements were carried out under realistic conditions of load, speed, and oil supply temperature in a laboratory environment, to investigate and compare the heat generation and the temperature rise of two types of an 90 mm bore cylindrical roller bearings: a hybrid bearing with $Si_3N_4$ ceramic rollers, and an all-steel bearing (M50/M50-Nil).
Experimental measurements of bearing temperature and friction torque have been carried out using a high-speed rolling bearing test rig. The rig runs at speeds up to 30,000 rpm with the capability of applying radial loads up to 4,500 N.

**8:30 - 9 am**
**3650160: Influence of Different Manufacturing Processes on Ceramic Roller Surface Textures and Hybrid Bearing Life**
Nikhil Londhe, Carl Hager, The Timken Company, Canton, OH

Hybrid bearings consists of ceramic rollers and steel rings. These are commonly used to support high speed shafts in aerospace and machine tool applications. This study focuses on influence of different manufacturing process on ceramic roller surface textures and corresponding rolling contact fatigue (RCF) life of hybrid bearings. Ceramic rollers used in this investigation were ground, ground & tumbled, and honed. Metrology techniques were used to characterize surface textures of these rollers using four roughness parameters: 1) Arithmetic average (Ra) 2) RMS 3) Skewness 4) Kurtosis. Advanced stress based RCF life prediction model was used to analyze influence of these measured surface textures on hybrid tapered roller bearing life. Model predictions shows good agreement with experimental data and allows selection of appropriate manufacturing processes.

**9 - 9:30 am**
**3669402: Neural Networks Apply to Main and Blade Bearing Grease Ananlysis**
Jorge Alarcon, Bureau Veritas, Stafford, TX

The use of lubricating grease analysis in the wind power industry is well known. However, the efforts to improve the analysis of the data, considering that these give support to much more robust decision-making, is one of the frontiers that many operators have not yet been able to pass. Decision-making based on classic analyses has been left behind. This presentation combines a new approach based on the lab grease analysis of the bearings in the turbine (main or blade) by applying one of the tools of Artificial Intelligence, to improve decision making in the site.

**9:30 - 10 am**
**3669420: Lunar Dust Effects on Space Mechanisms Ball Bearings for Sustained Human Lunar Operations**
Samuel Howard, Christopher Dellacorte (Ret.), NASA, Cleveland, OH

NASA has plans to send humans back to the moon under the Artemis Mission. In 2024, the first humans will set foot on the lunar surface since Apollo 17 in 1972. Additionally, plans include a sustained human presence on the moon for long duration habitation. These lofty goals will require many different kinds of space mechanisms including: life support, mobility, excavation, etc. Many of these types of systems utilize rotating machinery which require rolling element bearings. As such, dust tolerance of bearings is a major concern for long life in these critical systems. A research activity has been undertaken to characterize and reduce the damage lunar soil dust causes to bearings. The present work details some preliminary results of ball bearings running with grease intentionally contaminated with known quantities and sizes of lunar simulant particles to assess damage. Various bearing material combinations were tested to determine how certain typical bearing materials respond.

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

**10:30 - 11 am**
**3668947: Influence of New Emerging E-Fluids Technologies on Rolling/Sliding Contacts**
Christine Matta, Aidan Kerrigan, Xiaobo Zhou, Robertina Filocomo, Roel Van der Zwaan, Muhammad Faizan Rabbani, SKF Research and Technology Development Center, Houten, Netherlands; Frank Berens, SKF Research Development Operations, Saint-Cyr-sur-Loire, France; Alberto Carlevaris, SKF Automotive Blue Lab, Airasca, Italy

The development of electric vehicles (EVs) is facing today different challenges mainly related to the extension of driving range, availability of charging point, increasing of charging time and effecting the overall vehicle and ownership cost. Reducing friction and securing cooling capacity is a key enabler to minimize energy loss and increase the performance of EVs. In order to meet the demands in terms of lubrication, lubricant manufacturers are exploring two mainly different e-fluids technologies: Low viscosity oils and Water based lubricant fluids. These technologies need new formulations with new additive packages, and, they are tailored mainly for sliding contacts. The influence of these new formulations on rolling/sliding contacts is not known and need to be explored. In this talk, we will present the cutting edge testing methodology used to explore the influence of these new technologies on rolling/sliding contacts.

**11 - 11:30 am**
**3644061: Parasitic currents in electric drive and their effect on rolling element bearings**
Azeez Abdul, SKF, Houten, Utrecht, Netherlands

Due to the trend to move towards Battery electric vehicles(BEVs), hybrid electric vehicles(HEVs) there is a renewed interest in electrical current discharge in the bearings due to the parasitic currents present in the electric drive units. To improve the power density, efficiency of electric drive units, EV makers are using fast switching IGBTs, MOSFETs and high voltage architectures combining with novel lubricants. These factors further increase the risk of electrical current discharge in the bearings leading to premature failure. This talk focuses mainly on the nature of parasitic currents in the electric drive, electrical behavior of the bearing, electrical current discharge damage prediction and mitigation solutions.

**11:30 am - 12 pm**
**3668719: Fatigue Life Investigations on Tailored Forming CRB‘s with AISI 52100 Cladding**
Timm Coors, Jonas Urban, Felix Saure, Florian Pape, Gerhard Poll, Leibniz University Hannover, Garbsen, Lower Saxony, Germany

Fatigue-critical stress levels in rolling bearings occur locally in a near surface area. A suitable approach is to clad only this area with a high-performance material, e.g. by means of tailored forming technology on a steel substrate. In this work, a shaft made of AISI 1022M is coated by plasma deposition welding of AISI 52100; followed by forming, heat treatment and finishing. In experimental life tests on a rolling bearing

test rig, the cladded shaft seat is radially loaded and operated to failure via an RNU204 CRB without an inner ring. Based on these tests, a fatigue life model for multi-material rolling bearing components is presented and validated. By reducing the material-specific fatigue stress limit in the model due to weld defects in the specimens, good agreement between the model and the experiments can be demonstrated. This generic approach can be transferred to other applications and is suitable for determining a necessary coating thickness.

## 6A Southern Hemisphere I

**Engine and Drive Train VI**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3646414: Seeded Fault Experiments to Determine Unique Acoustic Emission Signatures in Diesel Engine High Pressure Fuel Pumps**
Nikhil Murthy, Vincent Coburn, Jana Quan, Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

High pressure fuels pumps (HPFPs) are widely used in diesel engine fuel delivery systems. The HPFPs are susceptible to failure from excessive wear due to multiple fuel lubricated sliding interfaces. It can be difficult to determine where and when failure of the subcomponents occurs before reduction in pumping capacity. We created an experimental fuel pump stand to operate a HPFP under controlled conditions for speed, flow and pressure, while monitoring the condition of the HPFP with an array of sensors, such as acoustic emission sensors and rotary encoders. A series of experiments was conducted with a fault that was ‘seeded’ for each of the five most critical sliding interfaces. We determined how the various faults affected the operation of the HPFPs, as well how some faults contribute to propagation of damage within the HPFPs. In addition the acoustic emission data was analyzed using position correlation and frequency analysis to identify the unique signature for each of the faults.

**2 - 2:30 pm**
**3647231: Surface Texturing of a Fuel Pump Plunger for Enhanced Tribological Performance**
Henry Soewardiman, David Pickens, Blake Johnson, Yip-wah Chung, Q Jane Wang, Northwestern University, Evanston, IL; Nikhil Murthy, Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

The design of high pressure fuel pumps for modern diesel engine systems relies on the pump’s plunger-bore sliding interface, which has extremely small clearances of no more than a few microns. These small clearances coupled with misalignment of the plunger can lead to scuffing, especially as the system runs under marginal lubrication conditions. Placing proper textures at strategic surface locations of these components would allow for increased lubricant film thickness, lower friction, and reduced lubricant leakage. These textures therefore have the potential to increase the lifespan of the system. This presentation reports system models of the plunger-bore interface of a pump, which are used to design plunger surface textures and study the texture effects on the interface performance. Comparisons are made between the untextured plunger and various surface textured plungers to evaluate the designs. Results demonstrate that certain grooved surfaces can meet multiple performance metrics.

**2:30 - 3 pm**
**3668801: Analysis of In-Service Coolants With ICP-OES Technology Following ASTM D6130**
Anthony Palermo, PerkinElmer, Johns Creek, GA

Coolants are analyzed for different metals to monitor the additive levels (B, K, Mo, Na, P and Si), corrosion metals (Al, Cu, Fe, Pb, Sn and Zn), and contaminants (Ca and Mg). Monitoring these metals can determine if coolants have been mixed, if part of the cooling system needs replacing due to corrosion, or if the coolant has been diluted with tap water, which, in turn, could lead to engine corrosion. This work demonstrates the analysis of coolants with a fully simultaneous ICP-OES system following a common implementation of method D6130.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm** - **Engine and Drive Train Business Meeting**

## 6B Southern Hemisphere II

**Lubrication Fundamentals VI**

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

**Session Starts at 1:30 pm**

**2 - 2:30 pm**
**3669388: When Ionic Liquids Meet Polar Lubricants and Hard Coatings**
Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Ionic liquids (ILs), as lubricant additives, have repeatedly demonstrated effective friction-reducing and wear-protection functionalities. The consensus is that ILs have strong physical adsorption onto and chemical reactions with the metallic contact area. But what if they are used to lubricate a non-metallic surface? Does the oil's polarity or water content affect ILs' performance? Here we present some interesting observations when ILs were used in PAO, PAG, and water-glycol for steel sliding against various non-metallic coatings. Main conclusions are (i) Tribochemical reaction rate is critical: too low not providing adequate surface protection but too high causing wear acceleration; (ii) Using a reactive lubricant together with a self-lubricating coating could be antagonistic, (iii) ILs can tolerate some moisture in the lubricant but could lose its functionality or even become detrimental at water content above a threshold, e.g., >5%. Wear mechanisms are discussed for each scenario.

**2:30 - 3 pm**
**3643608: Shear-Driven Decomposition of Organosulfur Compounds on Ferrous Surfaces**
Karen Mohammadtabar, Ashlie Martini, University of California Merced - Merced, CA, Merced, CA; Stefan Eder, Nicole Doerr, AC2T research GmbH, Weiner Neustadt, Austria

Tribofilms protect the surface of mechanical components by reducing friction and wear, resulting in increased lifetime. The rate of the reactions that induce film formation is increased by shear, the mechanism of which is poorly understood. We used reactive molecular dynamics simulations to study the reactions between di-tert-butyl disulfide, an extreme pressure additive, and ferrous surfaces at different temperature and pressure conditions. We studied the reaction pathways for di-tert-butyl disulfide on crystalline iron and amorphous iron-oxide, with and without base oil. Simulations show that either shear stress and/or temperature can drive these reactions. Also, it was observed that the base oil does not directly participate in the reaction but slows the rate of reaction by limiting access for the additive to surface sites. Also, the study of the oxidized surface showed that the presence of oxygen introduces new reaction pathways that affect reaction yield under some conditions.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3647491: Tribology of Liquid Lubricants in Inert Atmospheres**
Hugh Spikes, Jie Zhang, Janet Wong, Imperial College, London, United Kingdom

The development of relatively low cost, lightweight air separation technologies makes it feasible to operate lubricated machine components in an inert nitrogen atmosphere. The consequent suppression of lubricant oxidative degradation may enable such components in mobile equipment to operate at higher temperatures than is currently possible. This presentation compares the tribological performance of model lubricants in nitrogen and air atmospheres. The aim is both to support to the design of lubricants and fuels for use in inert atmospheres and to explore the mechanisms of action of tribologically-active lubricants by identifying the role played by oxygen in their response.

**4 - 4:30 pm**
**3673176: Performance Review of Lubricants for Automotive Air Conditioning**
Bridgett Rakestraw, CPI Fluid Engineering, Swartz Creek, MI

Environmental regulation has shifted the refrigeration industry towards more reactive refrigerants such as hydrofluroolefins (HFO's) to reduce the emission of greenhouse gases and global warming potential (GWP). The primary modification in the automotive air conditioning industry is the incorporation of the HFO, R-1234yf, an unsaturated refrigerant, into these hermetically sealed systems. A comprehensive review of the chemical stability, miscibility and wear performance of R-1234yf in different lubricants will be reviewed here.

**4:30 - 5 pm**
**3671816: Thermodynamic Studies and the Effect of Base Oil Chemical Structure on Refrigerant Solubility in the Development of Refrigeration Lubricants.**
Ian Burton, Lubrizol, Midland, MI

Many refrigeration systems utilize lubricants to protect the bearings and moving parts of the compressor and to act as a seal between the high and low pressure sides of the compression cycle. Lubricant and refrigerant coexist in a hermetically sealed refrigeration loop and the lubricant must be optimized to provide balanced miscibility and solubility with the refrigerant. As the refrigeration industry transitions to new low global warming potential refrigerants, initial work has shown them to be highly soluble in traditional lubricants, with a concomitant reduction in operating viscosity and compressor failure. The effect of base oil chemical structure upon refrigerant solubility has been evaluated using thermodynamic and pressurized viscometric methods, both in the liquid and gaseous states. New base oil chemistries that reduce refrigerant solubility have been developed and good correlation with $k_{oc}$ coefficients and Hansen Solubility parameters as predictive tools have been observed.

**5 - 5:30 pm**
**3691258: Anomalous Engine Oil NItration in Stoichiometric Natural Gas Engines**
Fred Girshick, Infineum USA, L.P., Linden, NJ

In a field trial of three oils in both stoichiometric and lean-burn natural gas engines, targeting extremely long ODI's, a phenomenon was observed, previously unreported in the literature. Oil nitration in the stoichiometric engines decreased after 6000 hours until the end of trial at 11,000 oil hours.
Nitration in used oil analysis programmes is most commonly defined by infrared measurement of nitrate esters, compounds of the type $RONO_2$, where "R" is an arbitrary hydrocarbon. Therefore, the decrease in oil nitration really signifies a decrease in nitrate ester content, not a decrease of oil degradation. Most of the literature about nitrate esters focuses on atmospheric chemistry and its implications for smog and air pollution, which may not be relevant to the liquid state.
The current paper examines the causes for the decrease in nitrate ester signal – particularly air:fuel ratio and operating temperatures. and discusses the implications for future extreme-long-life engine oils.

**5:30 - 6 pm**
**3704952: Simplified Simulation Modeling of the Oil Pump System Applied to Reciprocating Compressors**
Mauricio Tada, Nidec GA, Joinville, Santa Catarina, Brazil

Variable speed compressors are more and more gaining space in the market due to the benefits they bring, which include lower energy consumption and noise levels. When a compressor works at different speeds all its components need to be designed to withstand the variation in the operating conditions. One of its components is the crank train, whose fundamental function is to ensure proper lubrication for the mechanical component. Through the use of commercial simulation software and physical experiments, this study aims to propose a simplified simulation model for the centrifugal oil pump system of reciprocating compressors. The input evaluated variables are: a) the crankshaft speeds; and b) the volume of oil in the sump. The main response variables are a) the volumetric oil flow rate; and b) the oil volume fractions. The numerical and experimental results have shown good agreement for the oil flow rates evaluated at different speeds and sump's oil volume.

**6 - 6:30 pm** – **Lubrication Fundamentals Business Meeting**

## 6C — Southern Hemisphere III

**Commercial Marketing Forum VI**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm** - **Open Slot**

**2 - 3 pm - Afton Chemical Key Driver Seminar**

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm** - **Open Slot**

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

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

## 6D — Southern Hemisphere IV

**Condition Monitoring II**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3640712: Predictive Maintenance vs. Corrective Maintenance: Choosing the Right Strategy**
Michael Holloway, 5th Order Industry, Highland Village, TX

Planned maintenance and maintenance work performed in response to a failure require very different procedures and protocols. By choosing the appropriate strategy, you can help increase equipment availability and optimize staff utilization. This session will outline the duties and tasks associated with

predictive maintenance versus corrective maintenance, as well as how to convey the differences to personnel. Attendees will learn how to set task intervals, develop clearly worded procedures, establish safe work practices and maximize reliability while satisfying operational requirements.

**2 - 2:30 pm**
**3666834: Development of Oil Monitoring System for Construction Machinery**
Hideki Akita, Akira Kurasako, Hitachi Construction Machinery Co., Ltd, Tsuchiura City, Ibaraki, Japan; Hisanori Kuwayama, Haruna Nagai, Mitsuhiko Honda, Hitachi Construction Machinery Co.,Ltd, Koutou Ku, Tokyo, Japan

Construction machinery industry has begun to provide machine operation information provision services that utilize ICT. Among them, there is a very strong demand for monitoring the condition of lubricating oil. Because lubricating oil is mainly sampled at 500 interval hours and oil analysis is performed, but it is difficult to capture sudden oil properties during the analysis interval. As a to this solution , constant monitoring of oil properties using sensors is required. In this presentation, various studies were conducted in the laboratory on oil sensors that could be used as online property monitoring sensors for construction machinery, and the results were obtained and actually mounted on a hydraulic excavator to determine the status of oil properties under actual operation. We report on verification of monitoring and data utilization methods using IoT. This technology won the 2019 Japanese Society of Tribologists Technology Award.

**2:30 - 3 pm**
**3647489: The Oil Chute: Development of a Novel Thermal Stress Test Rig**
Thomas Norrby, Nynas AB, Nynashamn, Sweden; Franz Novotny-Farkas, Lubex Consulting OG, Schwechat, Austria; Christoph Schneidhofer, Jasmin Pichler, AC2T, Wiener Neustadt, Austria

The properties of a range of novel Gas Engine Oils have been investigated utilizing a novel oil thermal ageing test rig which we call the Oil Chute. In the Oil Chute, oil flows under gravity down over an aluminium profile panel heated to 300°C, for a duration of 21 hours. This test procedure simulates transport over hot parts in a real stationary gas engine. A close comparison to thermo-oxidation stability of gas engine oils tested by the in-house method GEO-HTOST, a modified and adopted CEC-L-48-A-00 procedure, indicates that the novel test rig brings additional value to the investigation, as we could readily benchmark new formulations vs commercially available reference GEOs. This work was funded by the project COMET InTribology1, FFG-No. 872176 (project coordinator: AC2T research GmbH, Austria).

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3663833: Real-Time Multi-Parametric Oil Condition Monitoring Technology**
Leonardo Mattioli, Marco Cozzolino, Denise Pezzuoli, SanChip, Wantage, United Kingdom

SanChip helps machine owners implementing Industry 4.0 strategies by enabling real-time, remote monitoring of lubricant conditions. The value proposition is enabled by proprietary Lab-On-Chip (LOC) technology. This allows performing the analysis of all the lubricant parameters relevant for the specific application (Energy, Marine, Industrial, etc.) directly on the machine, enabling the implementation of predictive maintenance strategies.
The technology also allows autonomous measurements, performing deep learning and AI algorithms and communicating the analysis results remotely to a control station, allowing in turn to improve working conditions and safety, increase productivity and production quality of the plants, reduce maintenance and downtime costs while also reducing lubricant waste.

**4 - 4:30 pm**
**3647003: Prevention of Electrostatic Charge Generation in Filtration of Low Conductive Oils by Surface Modification of Modern Filter Media.**
John Duchowski, Johannes Staudt, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany; Stephan Leyer, University of Luxembourg, Luxembourg, Luxembourg

The electrostatic charging behavior (ESC) of filter elements in contact with functional fluids has been evaluated by examining the fundamental properties of the materials participating in the event. The previously proposed mechanism that focused on fluid and material conductivities. In contrast, new evidence strongly suggests that the relative placement of the materials in the triboelectric series must be taken into account to explain the observed donor/acceptor behavior when materials are brought to close proximity (≤ 10 nm). In addition, this outward manifestation must also consider fundamental properties such as the surface energies and even the associated electron work functions of the interacting materials. Herein we provide several examples of how this new model can be used to predict the ESC behavior in the course of filtration of hydraulic and lubricating fluids through modern filter elements constructed of synthetic glass fiber and polymer materials.

**4:30 - 5 pm**
**3667451: Combining the Characterization of Both Particles and Total Metal Content Into a Single Analysis of In-Service Lubricants**
Ryan Purcell-Joiner, Autumn Wassmuth, PerkinElmer, Shelton, CT

When particles are present in lubricants, they cause mechanical wear on surfaces, increasing the lubricant's particle concentration. Monitoring the particulate matter within an in-service lubricant gives information about the condition of the lubricated components. Single particle optical sizing (SPOS) is one technique used to count and measure the size of individual particles in a fluid. This is achieved by measuring the change in intensity of light transmitted and/or scattered across a flow channel when those particles pass through the beam. When particle data is added to the identification and concentration of wear metals in that same lubricant, an even clearer picture of component condition emerges. Placing an SPOS sensor into the flow path of an inductively coupled plasma optical emission spectrometer (ICP-OES) allows the user to use less than 1 mL of sample and a single run for the combined analysis. Data will be presented showing the efficacy of this hyphenated approach.

**5 - 5:30 pm**
**3645962: Oil Flushing: Case Studies with Challenges**
Anshuman Agrawal, Minimac Systems Pvt Ltd, Pune, Maharashtra, India

The most inevitable step for commissioning any plant or even equipment is oil flushing. Without its proper execution, the equipment should not be allowed to take into function. Nowadays oil flushing is not constrained to pre-commissioning but also in practices at the time of planned turn downs, oil replacement, annual shutdown and breakdown outages, etc. With the latest developments in predictive maintenance culture focusing on Lubrication Technologies for Rotary and Hydraulic Equipment, flushing has now become a mandatory activity for improving the efficiency & reliability of an asset. With this technical white paper, we attempted to offer a solution with decades of practical research, case studies, purely result-oriented execution, and continuously improved methodology. We are striving to create awareness about the importance of oil flushing for a plant.

**5:30 - 6 pm** - **Condition Monitoring Business Meeting**

## 6E Southern Hemisphere V

**Nanotribology III**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3644371: Atomic-Scale Insights Into the Friction of Hydrogenated and Fluorinated Carbon: The Role of Steric Effects**

Thomas Reichenbach, Leonhard Mayrhofer, Takuya Kuwahara, Michael Moseler, Gianpietro Moras, Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

Surface passivation underlies the outstanding friction properties of hard carbon coatings. To understand the structure-property relationship between surface chemical passivation and friction, we develop a quantum-mechanical-based force field for non-reactive interactions in dry hydrogenated and fluorinated diamond and diamond-like carbon [1]. Molecular dynamics simulations reveal a linear correlation between friction and the corrugation of the contact potential energy. At odds with what is often proposed in the literature, the latter is almost exclusively determined by the steric properties of the passivation species and not by their charge. These results are consistent with the rationalization of polar hydrophobicity in fluorocarbons [2] and we discuss their implications for solid lubrication of mechanical components by PTFE [3]. [1] Reichenbach et al., ACS AMI 12, 7, 8805 (2020), [2] Mayrhofer et al., JACS 138, 12, 4018, (2016), [3] von Goeldel et al., Tribo. Lett. 69, 136 (2021)

**2 - 2:30 pm**
**3644430: Triboepitaxy – Solid-Phase Silicon Homoepitaxy via Shear-Induced Amorphization and Recrystallization: Evidence From Atomistic Simulations**
Gianpietro Moras, Thomas Reichenbach, Michael Moseler, Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany; Lars Pastewka, University of Freiburg, Freiburg, Germany

We present the results of a reactive molecular dynamics study of mechanically induced phase transitions at tribological interfaces between silicon crystals [1, 2]. The simulations reveal that the interplay between shear-driven amorphization and recrystallization results in an amorphous shear interface with constant thickness. Different shear elastic responses of the two anisotropic crystals can lead to the migration of the amorphous interface normal to the sliding plane, causing the crystal with lowest elastic energy density to grow at the expense of the other one. This triboepitaxial growth can be achieved by crystal misorientation or exploiting elastic finite-size effects. We propose a model validation experiment that could enable the direct deposition of homoepitaxial silicon nanofilms via mechanical scanning-probe nanolithography with a silicon tip. [1] Moras et al., Phys. Rev. Mater. 2, 083601 (2018), [2] Reichenbach et al., Phys. Rev. Lett. 127, 126101 (2021)

**2:30 - 3 pm**
**3650706: Interfacial Adsorption of Additive Molecules and Reduction of Friction Coefficient in the Organic Friction Modifier-ZDDP Combination**
Weiqi Shen, Tomoko Hirayama, Masato Adachi, Kyoto University, Kyoto, Japan; Yamashita Naoki, Tokyo University of Science, Chiba, Japan; Tadashi Oshio, Hideo Tsuneoka, Kazuo Tagawa, Kazuhiro Yagishita, ENEOS Corporation, Yokohama, Japan; Norifumi Yamada, High Energy Accelerator Research Organization, Tsukuba, Japan

ZDDP is one of the essential additives in engine oil formulation to prevent direct contact of tribo-pairs which cause wear and seizure. Other additives such as organic friction modifiers (OFMs) which are effective in reduce friction in boundary lubrication regime are often used with ZDDP. The effect of ZDDP and OFMs have been studied separately, but the interaction between them is still unclear. This study used nanotribology techniques such as Atomic Force Microscope (AFM) and Neutron Reflectivity (NR) measurement to investigate the molecular adsorption, film formation and friction reduction properties of these additives and their mixtures. AFM measurement revealed that fatty acid-ZDDP combination resulted in synergistic effect on friction. NR measurement revealed that fatty acid-ZDDP combination promotes metallic soap formation. The results suggested that further friction reduction can be achieved by appropriate additive combinations.

**3 - 3:30 pm** - **Break**

**3:30 pm - 4:30 pm**
**3706706: Invited Talk: Towards Overcoming Fundamental Challenges to Achieve Superlubricity on Rough Steel Surfaces**
Anirudha Sumant, Argonne National Laboratory, Lemont, IL

In the last few years, the tribology community has witnessed significant progress on the topic of superlubricity, however, demonstrating superlubricity on rough, industrial grade stainless steel surfaces for extended periods at high contact pressures as well as at high temperatures remains a challenge and is the topic of great research interest due to its obvious implications in real-world applications. I'll present our recent work on achieving macroscale superlubricity on rough steel surfaces at high contact pressures as well as at high temperatures utilizing various combinations of nanomaterials. I'll discuss the role of nanomaterials to generate new lubricant through complex tribochemical reactions at the siding interface providing an impervious tribolayer during sliding. The combination of nanomaterials almost acts like a "crystalline oil" providing excellent wear protection and easy shearing, which is very distinct from the conventional wear mechanism of thin films coatings.

**6F** Northern Hemisphere A1

**AI and Machine Learning in Tribology I**

Session Chair: TBD
Session Vice Chair: TBD

The availability of large databases of observations, for example, of the behavior of individuals on the internet or available from continually monitoring sensors has enabled them to be analyzed to allow the correlations with various parameters (descriptors) to be obtained merely by using the large computer power currently available to test all available parameters. Testing these correlations uses conditional probabilities of a particular descriptor, or Bayesian probabilities, to assess the importance of each descriptor. As such, the computer "learns" which parameters can be used to predict future behavior and this ability of computers to seem to learn has also been dubbed "artificial intelligence, or AI or Machine Learning (MI).

It is clear that machine learning methodologies are developing quickly and economies and industries that do not take these developments seriously will run the risk of falling behind. It is evident that there should be a role for professional societies such as the STLE in the promotion and development of machine learning to the tribology community and for tribology-related industries. However, the data required to use Machine-Learning in tribology for the discovery of new tribological materials, tends to be sparse because the measurements of friction or wear, for example, are often difficult and are made under a wide range of conditions. They are often collected by industrial laboratories who may be reluctant to share their data. In addition, any data that are published in the open literature tend to be the 'best' results, while the ideal machine-learning database should include all data, irrespective of whether it is good or bad

The goal of this symposium is to discuss these issues and to introduce the concepts behind Machine Learning and its potential for rapidly designing new tribological materials. Machine Learning has already proven to be effect for establishing the key parameters for lubricious two-dimensional thin films and to design superior viscosity improvers. The symposium will have tutorial lectures on the capabilities of Machine Learning and how it could be used to design new materials related to tribology, followed by examples on the way that it has already been successfully used. This will be followed by a town-hall-style meeting to discuss how STLE can assist the tribology community to implement Machine Learning tools.

**1:30 - 2 pm**
**Krishna Rajan, SUNY University at Buffalo**

**2 - 2:30 pm**
**Subramanian Sankaranarayanan, Argonne National Laboratory**

**2:30 pm - 3 pm**
**3707750: Machine Learning in Tribology: Working with Spare Data**
Prathima Nalam, SUNY University at Buffalo, Buffalo, NY

Machine learning methods often use big data to observe correlations and conduct predictive analysis – for example – generating process-structure-property correlations to design a new material. While efforts in experimental and computational trials in tribology over the past several decades have accumulated enormous quantities of data with high dimensionality, however, this data is currently unorganized and sometimes not data-rich enough for a specific tribology-related process or application. Thus, employing data-sparse statistical methods backed with physics-based knowledge can be a useful approach to generate robust predictions for tribological processes. The scope of this approach will be presented with the help of a few case studies.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3706874: Polymer Genome: Accelerating Materials Discovery Via Data-driven Approaches**
Rishi Gurnani, Rampi Ramprasad, Georgia Institute of Technology, Atlanta, GA

The Materials Genome Initiative has heralded a sea change in the philosophy of materials and chemical formulations design. In an increasing number of applications, the successful deployment of novel materials and formulations has benefited from the use of informatics methodologies coupled with experiment. Here, I will use the polymer informatics ecosystem—pioneered in the Ramprasad group—as an example of how artificial intelligence (AI) and machine learning (ML) may be used to accelerate the development of new materials and formulations. I will describe the role played by computational and experimental data generation and capture, polymer fingerprinting, machine-learning based property prediction, algorithms for the inverse design of polymers meeting target property requirements, and finally, how prior physics knowledge can be woven into polymer informatics workflows. These efforts have culminated in the creation of an online informatics platform (https://www.polymergenome.org) to guide ongoing and future polymer discovery and design. Challenges that remain will be examined, and systematic steps that may be taken to extend the applicability of such informatics efforts to a wide range of technological domains will be discussed. These include strategies to deal with the data bottleneck, new methods to represent materials, chemistries and processing conditions, and the applicability of emerging AI algorithms for materials design.

**4 - 4:30 pm**
**Nikolay Garabedian, Karlsruhe Institute of Technology**

## 6G — Northern Hemisphere A2

**Environmentally Friendly Fluids II**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3646269: Lubricity Improvement of Diesel Fuel With Plant Oils.**
Andrew Sakyi, University of Pretoria, Pretoria, Gauteng, South Africa

Diesel is a complex mixture of hydrocarbons. To reduce pollution, some regulations have been framed to limit the amount of harmful components such as sulphur in diesel. Until the 1990s, sulphur was accepted up to a maximum value of 500ppm. However, in order to protect the environment, the regulations have been made more stringent and sulphur levels should no longer exceed 50ppm in most countries. So, it

must be removed through desulphurization. Unfortunately, many components that give diesel its natural lubricity are also removed, leading to loss of lubricity in the produced diesel. Most fuel manufacturers use various lubricity additives to increase fuel lubricity to acceptable levels after desulphurization, but those additives also present a possible problem of being environmentally unfriendly and expensive. Plant oils such as castor, moringa and canola oils are good replacements for these petroleum-based additives. They have good lubricity, are renewable and environmentally friendly

**2 - 2:30 pm**
**3646679: Impact of Ionic Liquid Additive and Inrganic Fullerene-Like Tngsten Disulfide on Steel Friction and Wear Under Aqueous and Abrasive Environments**
Ayesha Asif, Andreas Polycarpou, Ahmad Amiri, Texas A&M University, College Station, TX; Hyun Jo Jun, ExxonMobil, Annandale, NJ; Saifur Rehman, ATSP Innovations, Houston, TX; Yong Zheng, Applied Materials, Santa Clara, CA

Aqueous lubricants are environmentally friendly, tunable and thermally stable. The oil and gas industry can make use of such additives in water-based fluids for applications where low speeds and large lateral forces demand enhanced lubrication. Two such additives were studied: inorganic fullerene-like tungsten disulfide (IF-$WS_2$), and alkanolamine ionic liquid (AA-IL). These were tested in: deionized water (DIW), NaCl(aq), and $CaCl_2$(aq) which are commonly utilized in the field. The presence of IF-$WS_2$ into each fluid caused ≈30-60% decrease in the coefficient of friction (COF) due to exfoliated IF-$WS_2$ and a tribo-film of tungsten oxide confirmed through XPS analysis. The AA-IL formed a physically bonded film on the steel surface, reducing COF (40-50%). The DIW was additionally tested with abrasive sand particles. In DIW+IF-$WS_2$, the sand particles get coated with exfoliated IF-$WS_2$ layers, confirmed by EDS and optical microscopy, thus allow rolling of sand particles (three body sliding).

**2:30 - 3 pm**
**3646976: Sustainability in the Value Chain of Lubricants**
Inga Herrmann, VSI Verband Schmierstoff-Industrie e.V., Hamburg, Germany

Climate change and sustainability are key challenges for our future. What is this the right approach to a sustainable business –"Green processing" is the task "green washing" too often the reality! Sustainability means taking care of environmental impact, resource limitation and social aspects. Sustainable business is a key issue for the whole society and hits the lubricants industry at its core What changes can we expect in our upstream chain? What do our key customers expect and demand? How can a reliable and comparable carbon footprint be calculated in a competitive environment? Developing specific measures that are reliable, transparent and accepted is of great importance to lubricants manufacturers. The German Lubricant Manufacturers association is working in close collaboration with OEMs, institutions and others to establish a sustainability concept for calculate the carbon footprint of lubricants, evaluate the supply chain and develop business models for the circular economy.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3647583: Design of Environmental Acceptable Lubricants (EALs) for an Extended Life-Service**
Mar Combarros, Ariadna Emeric, Gerard Cañellas, Angel Navarro, Marc Alumà, Taro Ehara, IQL, Castellgalí, Barcelona, Spain

Nowadays EALs require high severe demands regarding temperature, speeds and loads while re-lubrication intervals are increasing. Aging affects the performance of lubricants, thus, there is the necessity of a methodology to predict the durability of the oils. In this study a new method was developed to assess the lubricating behavior when the oil is thermally aged in the presence of a catalyst and air. The aging is monitored by change on total acid number, viscosity, GPC and FT-IR. During thermal degradation, the oil experiments evaporation, an increase of viscosity due to polymerization and TAN increase. Furthermore, a study of the lubricity of the aged and fresh oil was performed using a MTM and SRV. One of the main advantages of using organic polymeric structures is that we can model and adapt to specific technical requirements. The methodology presented can be of great use to predict lubricating

life and will help us design new sustainable solutions for an extended life-service.

**4 - 4:30 pm**
**3653611: Sulfur Based Estolides for the Development of Anti-Wear Additives for Finished Lubricants**
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Historically sulfur when used in lubricating oil formulation chemistry, it has been used as an additive for an antioxidant, part of anti-wear (AW) compounding, extreme pressure (EP), and enhanced lubricity properties. The developmental approach of bio-based sulfur additives is limited and thus warrants the need to prepare and evaluate as a more sustainable choice for formulation and assessing high-performance finished lubricants. At Biosynthetic Technologies, the development of novel bio-based estolides with sulfur embedded has been successfully demonstrated, formulated into base oils, and anti-wear properties evaluated in comparison to other commercial based sulfur additives on the market. Results of sulfur based estolides do deliver competitive anti-wear properties compared to commercially petroleum-based sulfur additives and other bio-based sulfur additives.

**4:30 - 5 pm**
**3653834: Optimizing Pour Point and Oxidation Stability in Estolides**
Alex Kitchel, Biosynthetic Technologies, Indianapolis, IN

Some of the greatest innovations in the lubricants market have been in the development and utilization of high performance, environmentally acceptable lubricants (EALs), some of which are derived from estolide technology. However, sometimes the pour point for these base oils often do not meet the requirements set for the application. This presentation focuses on the development and creation of a low viscosity estolide and how to achieve low to extremely low pour points for demanding lubricant applications. Additionally, this presentation will cover the optimization of oxidative stability of a novel estolide technology.

**5 - 5:30 pm** - **EFF Business Meeting**

## 6I — Northern Hemisphere A4

**Fluid Film Bearings I**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3647913: Computational Fluid Dynamics Modeling of Direct Lubrication versus Conventional Tilting Pad Journal Bearings**
Cori Watson-Kassa, Minhui He, Roger Fittro, Houston Wood, University of Virginia, Earlysville, VA

Bearings with inlet groove supply are a popular option to mitigate high peak temperatures present in high speed turbomachinery. However, the mechanism by which these direct lubrication design exhibits lower temperature rise and lower peak temperature is not well understood. This study utilizes computational fluid dynamics (CFD) for a five pad load-on-pad journal bearing with full thermal, groove mixing, and turbulence effects for Leading Edge Groove (LEG) and conventional bearings tested in the literature. The CFD results match closely to the experimental values. The results also show that the mechanism of lower peak temperature in LEG bearing is that a groove pressure is converted to an additional film velocity. This additional velocity pushes more fluid through the thin film, leading to a higher pressure versus a conventional design when the same film shape is considered. This mechanism causes the LEG pad to operate with a greater film thickness, which reduces temperature rise.

**2 - 2:30 pm**
**3647131: Transitional Turbulence in Thrust Bearings**
Xin Deng, Cori Watson, Minhui He, Roger Fittro, Bob Rockwell, Houston Wood, University of Virginia, Charlottesville, VA

The working fluid in a thrust bearing goes through laminar, transitional, and fully turbulent flow regimes with increasing shaft speed. There are existing turbulence models that have been available for use in thrust bearing modeling, such as Shear Stress Transport (SST) and Eddy Viscosity Transport (EVT). However, SST tends to overpredict the film temperature while EVT underpredicts the film temperature. Because temperature is the most critical performance characteristic in a thrust bearing, these models lead to somewhat poor performance predictions. As a first step to improving bearing predictions, this study uses a new hybrid turbulence model over a range of operating speeds in a thrust bearing. Specifically, the relation between turbulence and the drop in temperature that is associated with turbulent transition is considered. One finding is that the turbulent variation in viscosity is a significant mechanism for this temperature drop.

**2:30 - 3 pm**
**3647907: Understanding the Mechanism of Load Capacity in Centrally Pivoted Thrust Bearings**
Cori Watson-Kassa, Minhui He, Roger Fittro, Houston Wood, University of Virginia, Earlysville, VA

Fluid film bearings are designed to support the load on the shaft. Central pivot bearing designs are necessary in machinery applications with reverse and forward rotation. It has long been believed that centrally pivoted thrust bearings are only able to produce load capacity due to deformation. That is, it is understood that a thrust bearing numerical model in the absence of deformation will be unable to find a nonzero loaded position. This study numerically models a central pivot thrust bearing and maps the moment on the pivot and load capacity as a function of tilting angles and runner height. It is when non-isoviscous, the variation of viscosity across the pad makes it possible to generate substantial load capacity even without deformation. This mechanism of load capacity for centrally pivoted thrust bearings could be described as a viscosity wedge effect. In real bearing applications, this study shows that 60-80% of load capacity comes from this viscosity wedge.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3669447: An Experimental Investigation of the Load Capacity of Thrust Wave Bearings**
Ahmed Paridie, Nicoleta Ene, Florin Dimofte, University of Toledo, Toledo, OH

A test rig was designed and built to evaluate the load capacity of thrust wave bearings. A thrust wave bearing consists of a rotating disk and a stationary disk with a wave profile on the surface that faces the rotating disk. The rotating disk is attached to the shaft of a ball bearing spindle that is driven by an air turbine. The stationary disk is attached to a stationary shaft supported by an air journal bearing guide. The clearance between the two disks is adjusted using a linear actuator. The load is measured with a load cell that is placed at the end of the air guide. The rig is also instrumented with thermocouples, accelerometers, speed sensor, and proximity probes. The load is measured for different speeds and clearances. The measurements are validated by comparing them with theoretical results obtained with numerical simulations.

**4 - 4:30 pm**
**3651697: Computational Fluid Dynamic Study of Fluid Film Tiling-Pad Journal Bearings: Influence of Supply Geometry on Groove Flow**
Zihao Huang, Cori Watson-Kassa, Minhui He, Chris Goyne, University of Virginia, Charlottesville, VA

Direct lubrication designs such as spray bars and inlet groove supplies are known to impose effects upon thermal distributions and peak temperatures of fluid film bearings. There have been multiple analyses on each of the designs, but few performed direct comparisons. This work adapts a computational fluid dynamics (CFD) model of a four pad, load-between-pad tilting pad journal bearing with conventional

supply geometry. The model is validated against experimental results from literature before varying to directed lubrication geometry designs. This work presents laminar results for all geometries. Streamlines and flow patterns of each of the designs are demonstrated. Compared to conventional lubrication, direct lubrication designs have more organized streamlines and flow patterns, which pose effects upon pressure and temperature distributions. The relationship between flow patterns in direct lubrication designs and their capabilities to block hot oil carry-over is discussed.

**4:30 - 5 pm**
**3669229: Influence of the Lubricant Rheology and Thermal Effects on the Design of Journal Bearings**
Diego Sacomori, Murillo Santana, Nidec Global Appliance, Joinville, Brazil

The design of journal bearings for high-performance applications usually requires in-depth knowledge about the lubricant, including its rheological behavior. The present paper explores the oil viscosity as a function of the pressure and temperature on the friction behavior of sliding bearings operating under hydrodynamic to mixed lubrication conditions. Numerical simulations are carried out for the big and small eyes of a typical connecting rod used in hermetic refrigeration compressors. The multi-body solver AVL Excite Power Unit is used for modelling the kinematics and extracting the bearings quantities of the elastohydrodynamic joints for a wide range of operating conditions. A comparative study is performed against the conventional numerical approach assuming constant viscosity. The results reveal how taking into account the rheological effects of the lubricant oil can help to optimize the bearings performance.

**5 - 5:30 pm** – **Fluid Film Bearings Business Meeting**

## 6J Northern Hemisphere E1

**Materials Tribology II**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3668172: Tribological Evaluation of Metal Particle Filled Fluropolymer Against Different Counter Surfaces**
Faysal Haque, Sifat Ullah, Mark Sidebottom, Robin Bridges, Miami University, Oxford, OH

Unfilled Polytetrafluoroethylene (PTFE) has a low friction coefficient, but also a high wear rate (K~$10^{-4}$ to $10^{-3}$ $mm^3$ /Nm). PTFE with alpha alumina filler particles is known to lower the wear rate of unfilled PTFE by ~ 10,000x ($mm^3$ /Nm). The wear performance of these composites is a function of tribochemistry, surface roughness, environment, tribofilm generation, etc. Recently, the focus has spread to study more filler materials which can achieve similar if not better performance than alpha alumina filler (for example $GeO_2$, BeO with K ~ 1-2 × $10^{-7}$ $mm^3$ /Nm). The identification of additional PTFE-metal-oxide composites with ultralow wear rates motivated the exploration of transition-metal filler particles in PTFE. Cr, Ti, Ni, and Ag particles were composited with PTFE and slid against different countersurface materials. The friction coefficient and wear of these materials will be presented and compared to previous studies on PTFE-metal oxide composites such as Al2O3 and GeO2 and BeO.

**2 - 2:30 pm**
**3668986: Effects of Metal-Oxide Fillers on Dry Sliding Wear of Novel PTFE Nanocomposites**
Quang (Mark) Pham, Brenden Miller, Harman Khare, Gonzaga University, Spokane, WA

The addition of nanoscale fillers is widely recognized as an effective means of reducing dry sliding wear of polytetrafluoroethylene (PTFE). Nanoscale alpha-phase alumina is considered the gold standard

metal-oxide filler, reducing wear of PTFE by nearly four orders of magnitude under dry sliding. Ultra-low wear of alumina-PTFE nanocomposites is enabled by the tribochemical generation of robust tribofilms, which develop due to applied tribological stresses and the availability of ambient humidity. In the current work, we report on the efficacy of novel metal-oxide chemistries in reducing PTFE nanocomposite wear. Reciprocating wear tests were performed to determine the effects of filler chemistry and concentration on the wear of PTFE nanocomposites. Tribological characterization, together with morphological and chemical analyses of worn interfaces is used to develop a fundamental understanding of the role mechanochemistry plays in driving wear behavior of these novel filler chemistries.

**2:30 - 3 pm**
**3669440: The Effects of Processing Conditions on the Wear of PTFE-PEEK Composites**
Kylie Van Meter, David Ramos, Brandon Krick, Florida State University, Tallahassee, FL; Christopher Junk, CJIdeas, LLC, Wilmington, DE; Tomas Babuska, Kasey Campbell, Lehigh University, Bethlehem, PA

Polytetrafluoroethylene (PTFE) is a desirable tribological material due to its low friction and low surface energy. However, it suffers from high wear rates (K~ $10^{-4}$ $mm^3$/Nm) when slid against stainless steel. In previous works, the addition of poly ether ether ketone (PEEK) as a filler material can reduce the wear rate of PTFE by over 4 orders of magnitude (K~ $10^{-8}$ $mm^3$/Nm). While PTFE-PEEK composites can achieve ultralow wear, they suffer from high degrees of variability in performance sample to sample. This variability could be attributed to variations in the processing conditions (composite mixing, molding, sintering, etc). In this study, processing parameters were varied during the fabrication of PTFE composites with 0-50 wt% PEEK. Friction and wear testing of the composites showed variations in sample performance based on changing processing parameters, and chemical spectroscopy (FTIR) was used to characterize the tribochemical behavior of the samples.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3666393: Investigation of Surface Finish and Applied Force on the Tribological Performance of Graphite-Filled Polyimides**
Sarah Herbruck, Faysal Haque, Sifat Ullah, Mark Sidebottom, Miami University, Oxford, OH; Edwin Goyzueta, Jennifer Vail, DuPont Company, Wilmington, DE

High-performance polymers are useful in aerospace applications (such as bushings within turbofan engines) when traditional lubricants may fail. These materials experience high mechanical and thermal loadings during flight. By evaluating such materials under simulated flight conditions, better material design choices may be made. Improved material design should allow for longer maintenance intervals, higher engine temperature (higher performance), and improve combustion output in turbofan engines. Graphite-filled polyimides are one type of polymer with enough mechanical strength and minimal frictional losses that allow for them to be used in turbofan engines. To investigate the efficiency of graphite-filled polyimide during use, the tribological performance is evaluated with a flat-on-flat tribometer. This material is tested against stainless steel with different surface finishes and at a varied range of applied forces (28N-280N) to gather comparative data on the material's behavior.

**4 - 4:30 pm**
**3667368: Tribological Study of Advanced ATSP- and PEEK-Based Polymer Coatings for Moon and Mars Applications**
Kian Bashandeh, Vasilis Tsigkis, Andreas Polycarpou, Texas A&M University, College Station, TX; Pixiang Lan, ATSP Innovations, Houston, TX

As NASA seeks to expand its exploration to Moon and Mars, novel materials with advanced tribological characteristics at extreme conditions have to be introduced to guarantee the functionality of the exploration systems such as rovers and robotic rotorcraft landers. This study reports on tribological solutions for extreme temperature ranging from -150 to 110 °C combined with abrasive sand/dusty environment, which simulates extreme operating conditions that bearing materials in Moon and Mars

environment. To this end, the tribological performance of PEEK-based and ATSP-based polymer coatings were evaluated at and it was demonstrated that ATSP-based coating vs ATSP-based coating and PEEK-based coating vs PEEK-based coating have excellent tribological performance, sustaining a low coefficient of friction (COF) and wear. Additionally, the micro and thermomechanical properties of the coatings were measured and correlations were made with tribological performance.

**4:30 - 5 pm**
**3648047: Hard Coatings in Elastohydrodynamically Lubricated Contacts with Engineering Plastics**
Stefan Reitschuster, Enzo Maier, Thomas Lohner, Karsten Stahl, Technicla University of Munich, Garching, Germany

Due to benefits like low density and cost-effective production, engineering plastics become increasingly important. The detailed comprehension of underlying tribosystems offers great potential to extend its application limits to highly stressed machine elements. Thereby, oil lubrication and recent surface coating technologies are promising.
This study investigates the potential of diamond-like carbon (DLC) coated engineering plastics in elastohydrodynamically lubricated (EHL) contacts. Thereby, tribosystems are investigated experimentally at a twin-disk tribometer and theoretically by numerical calculations. While interfacial contact friction is in the range of superlubricity, damping losses can lead to a significant bulk temperature increase. Hard DLC coatings show excellent wear protection for the soft plastic surface, particularly under severe lubrication. The results indicate a high potential of hard coatings on engineering plastics for tribological applications.

**5 - 5:30 pm** - **Materials Tribology Business Meeting**

## 6M — Northern Hemisphere E4

**Rolling Element Bearings VI**

**Session Chair:** TBD
**Session Vice Chair:** TBD

**1:30 - 2 pm**
**3648438: Condition Monitoring of Rolling Element Bearing Having Defect at Outer Trace Using Machine Learning**
Pallavi Khaire, Vikas Phalle, Veermata Jijabai Technological Institute, Mumbai, Maharashtra, India

The rotating machines typically comprise numerous components such as shaft and bearing. The health of these components contributes to overall machine performance. A methodology for ball bearing fault diagnosis using Decision Tree classifier is presented in this paper. The Finite Element analysis is carried out using ANSYS for a healthy bearing and a bearing having fault at outer race. The experimental vibration data for healthy and faulty is acquired using FFT analyzer for healthy and faulty bearing. Decision Tree Classifier is used for developing a machine learning model. The simulation data is used for training purpose whereas the experimental data is used for testing purpose. It is observed that Ball Pass Frequency at Outer Race is the indication of fault. The simulation and experimental results are in close agreement and the literature available. The proposed model of machine learning is able to identify rolling element bearing faults. The accuracy of DT classifier model is 89%.

**2 - 2:30 pm**
**3669182: Numerical Investigations Towards Friction-Optimized Design of Microdimple-Textured Surfaces for Tapered Roller Bearing Flange Surfaces**
Josephine Kelley, Norbert Bader, Florian Pape, Gerhard Poll, Leibniz University Hannover, Garbsen, Germany

Microtextured surfaces, though not commonly used in the context of Elastohydrodynamic Lubrication (EHL) problems, are known to reduce friction under certain conditions. Due to their widespread usage in the automobile industry, tapered roller bearings are of particular interest for studies in friction reduction. To investigate beneficial designs of microtextured flange surfaces, numerical investigations for bearings of type 31312-A are performed using the Reynolds equation. Geometric parameters that describe a microdimple texture such as the depth, size, and distribution of microdimples are varied in addition to the operating conditions. The computed film thickness and fluid shear stress are used to determine the effect of surface microtexturing on friction.

**2:30 - 3 pm**
**3650178: Tribological Prospects and Progress for NiTi Bearings for Aerospace Applications**
Christopher Dellacorte (Ret.), Samuel Howard, NASA, Cleveland, OH

Rolling element and sliding bearings made from dimensionally stable, nickel-rich NiTi alloys have been successfully manufactured, tested and applied in several different aerospace applications. In this presentation, the development history and material properties of NiTi alloys is reviewed and its behavior in sliding and rolling contacts is examined. Key material characteristics such as superelasticity and fracture toughness and their effects on bearing applications are considered. With proper application engineering, it is shown that NiTi bearings can resolve longstanding and persistent bearing problems related to heavy loads and operation in corrosive and debris contaminated environments.

**3 - 3:30 pm** - **Break**

**3:30 - 4 pm**
**3662736: The Use of Coatings to Improve Bearings Performance and Reliability**
Esteban Broitman, SKF B.V., Houten, Netherlands

During the last decades, the use of advanced coatings has enjoyed a growing interest in bearing applications because they can be engineered to provide properties like electrical insulation, low friction, and resistance to corrosion, rolling contact fatigue, abrasive wear, and plastic deformation. The main surface engineering processes include traditional technologies such as dipping and liquid spraying, chemical conversion, galvanizing and electroless processes, as well as sophisticated technologies such as thermal spray, PVD, diffusion, and ion implantation.
In this talk I will first introduce the main areas where coatings can contribute to improve the performance and reliability of rolling bearings made of standard AISI 52100 steel: lower friction, decreased wear, corrosion resistance, and electrical insulation. Examples of coatings for extending maintenance and life expectancy of specialized bearings will be described, including black oxide, aluminum oxide, and carbon-based coatings.

**4 - 4:30 pm**
**3669073: Feasibility Study of Dynamic and Electrical Performance as a Combined Generator Module Mounted on Ball Bearing**
Wonil Kwak, Yongbok Lee, Korea Institute of Science and Technology, Seoul, Republic of Korea

A rolling-element bearing integrated self-powered micro-electro-mechanical system is designed for a bearing health management system. The study aims to determine the correlation of the electrical damping effect, external force, and rotor-dynamics characteristics for the bearing combined with the generator system. The self-powered structure generated output voltage due to transfer residual vibration between flexible circular arc structures and each piezoelectric stack assembled the exterior of the bearing outer race, the piezoelectric stacks produce the electric signals. The goal of this work is to introduce a novel interaction system of the ball bearing structured integrated piezoelectric elements through the experimental results and provide the rotor dynamics analysis results for proving the combination dynamic model reliability of ball bearing integrated self-powered generator system.

**4:30 - 5 pm**
**3669395: Innovative Bearing Solutions for Electric Current Protection in E-mobility Applications**
Jitesh Modi, Schaeffler Group USA, Troy, MI

The electrified drivetrains for E-mobility applications pose a discrete challenge for bearings due to electric currents. The standard bearings can be damaged due to electric current passage, resulting in critical failures related to noise, pitting, white etching cracks (WEC) and fluting damages. To impart necessary protection against electric currents, innovative and engineered bearing solutions have been developed utilizing unique design approach, special materials and processes and value-added integration features. Innovative bearing solutions such as "Shunt Bearing, Hybrid Bearing and Overmolded Insulation Bearing" will be discussed. Based on the type of electric currents - Capacitive Discharge vs Circulating currents, the benefits and application of these bearing solutions will be described with supporting test results.

**5 - 5:30 pm** - **REB Business Meeting**