Preliminary Program

As of November 24, 2021

2022 STLE Annual Meeting Program-At-A-Glance

UPDATED - Preliminary as of 11-24-2021

Sunday, May 15, 2022

Registration
7 am – 6 pm – Convention Center Foyer

Education Course Speakers Breakfast
7 – 7:45 am – Northern Hemisphere C

Education Courses - 8 am - 5 pm
Advanced Lubrication 301 – Asia 1
Metalworking Fluids 115 – Asia 2
Basic Lubrication 101 – Oceanic 2
Synthetic Lubricants 203 – Asia 3
NLGI – Grease 101 – Oceanic 1
Electric Vehicles – Asia 4

Course F&B Breaks – Asia Foyer

Student Networking Reception - 6:30 – 8 pm – TBD

Monday, May 16, 2022

Registration
7 am – 6 pm –Convention Center Foyer

Monday Speakers Breakfast
7 – 8 am – Northern Hemisphere C

Technical Sessions - 8 am - 10 am
1A– Electric Vehicles I – Southern Hemisphere I
1B –Lubrication Fundamentals I – Contact Models I – Southern Hemisphere II
1C – Commercial Marketing Forum I – Southern Hemisphere III
1D – Tribotesting I – Southern Hemisphere IV
1E – Surface Engineering I – Southern Hemisphere V
1F – Seals I – Rotary Rod Seals – Northern Hemisphere A1
1G – Grease I – Northern Hemisphere A2
1I – Biotribology I – Northern Hemisphere A3
1J – Wear I – Northern Hemisphere A4
1K – 2D Materials + Superlubricity – Materials Tribology & Nanotribibology I – Northern Hemisphere E2
1L – Power Generation I – Northern Hemisphere E3
1M – Rolling Element Bearings I – Northern Hemisphere E4

10 – 10:30 am Beverage Break in Convention Center Foyer

Opening General Session - 10:30 am – 12 pm
Keynote Address TBD - Northern Hemisphere B-D

Lunch on your own - 12 pm – 1:30 pm

Commercial Exhibits and Student Posters
12 – 5 pm – Atlantic

Technical Sessions - 1:30 pm – 6 pm
2A – Electric Vehicles II – Southern Hemisphere I
2B – Lubrication Fundamentals II – Contact Models II – Southern Hemisphere II
2C – Commercial Marketing Forum II – Southern Hemisphere III
2D – Tribotesting I – Southern Hemisphere IV
2E – Surface Engineering II – Southern Hemisphere V
2F – Seals II - Mechanical and Elastomeric Seals – Northern Hemisphere A1
2G – Grease II – Northern Hemisphere A2
2H – Tribochemistry I – Northern Hemisphere A3
2I – Biotribology II- Northern Hemisphere A4
2J – Wear II – Northern Hemisphere E1
2K – 2D Materials + Superlubricity – Materials Tribology and Nanotribology II – Northern Hemisphere E2
2L – Power Generation II – Northern Hemisphere E3
2M – Rolling Element Bearings II – Northern Hemisphere E4

3:30 – 4 pm Beverage Break in Exhibit Hall – Atlantic

Networking Reception
6:30 – 8 pm – Northern Hemisphere C-D

Tuesday, May 17, 2022

Registration
7 am – 6 pm – Convention Center Foyer

Tuesday Speakers Breakfast
7 – 8 am – Northern Hemisphere C

Commercial Exhibits and Student Posters
9:30 am – 5:30 pm – Atlantic

Technical Sessions - 8 am – 12 pm
3A – Electric Vehicles III – Southern Hemisphere I
3B – Lubrication Fundamentals III - Stability– Southern Hemisphere II
3C – Commercial Marketing Forum III– Southern Hemisphere III
3D – Tribotesting III – Southern Hemisphere IV
3E – Surface Engineering III– Southern Hemisphere V
3F – Seals III -Hydraulic and Two-phase Seals – Northern Hemisphere A1
3G – Grease III – Northern Hemisphere A2
3H – Tribochemistry II – Northern Hemisphere A3
3I – Biotribology III- Northern Hemisphere A4
3J – Wear III – Northern Hemisphere E1
3K – Contact Mechanics I – Northern Hemisphere E2
3L – Gears I – Northern Hemisphere E3
3M – Rolling Element Bearings III – Northern Hemisphere E4

10 – 10:30 am Beverage Breaks in Exhibit Hall – Atlantic

President's Awards Luncheon/Business Meeting
12 - 2:00 pm – Northern Hemisphere B-D

Technical Sessions - 2 pm – 6 pm
4A – Electric Vehicles IV– Southern Hemisphere I
4B – Lubrication Fundamentals IV - Antiwear & Friction Control – Southern Hemisphere II
4C – Commercial Marketing Forum IV– Southern Hemisphere III
4D – Tribotesting III – Southern Hemisphere IV
4E – Nanotribology I – Southern Hemisphere V
4H – Tribochemistry III – Northern Hemisphere A3
4I – Biotribology IV – Northern Hemisphere A4
4J – Wear IV – Northern Hemisphere E1
4K – Contact Mechanics II – Northern Hemisphere E2
4L – Gears II – Northern Hemisphere E3
4M – Rolling Element Bearings IV – Northern Hemisphere E4

3 – 4 pm Beverage Break in Exhibit Hall – Atlantic

Roundtable Discussions
4 – 6 pm – Northern Hemisphere C

Wednesday, May 18, 2022

Registration
7 am – 6 pm – Convention Center Foyer

Wednesday Speakers Breakfast
7 – 8:00 am – Northern Hemisphere C

Commercial Exhibits & Student Posters
9:30 am – 12 Noon – Atlantic

Education Courses - 8 am - 5 pm
Automotive Lubrication 202: Gasoline – Asia 3
Basic Lubrication 102 – Asia 5
Metalworking Fluids 240 – TBD
Advanced Lubrication 302 – Asia 1
Hydraulics 101 – Asia 2
Synthetic Lubricants 204 – Asia 4

Technical Sessions - 8 am – 12 pm
5A – Engine and Drivetrain V – Southern Hemisphere I
5B – Lubrication Fundamentals V - New Chemistries – Southern Hemisphere II
5C – Commercial Marketing Forum V – Southern Hemisphere III
5D – Condition Monitoring I – Southerm Hemisphere IV
5E – Nanotribology II – Southern Hemisphere V
5F – Wind Turbine Tribology I – Northern Hemisphere AB
5G – Environmentally Friendly Fluids I– Northern Hemisphere A2
5H – 2D Materials + Superlubricity – Materials Tribology and Nanotribology III - Northern Hemisphere A3
5I – Biotribology at Nanoscale I– Northern Hemisphere A4
5J – Materials Tribology I– Northern Hemisphere E1
5K – Metalworking Fluids I – Northern Hemisphere E2
5M – Rolling Element Bearings V – Northern Hemisphere E4

Beverage Break - 10 - 10:30 am – Atlantic

12 pm to 1:30 pm - Lunch on Your Own

Technical Sessions - 1:30 pm - 6 pm
6A – Engine and Drivetrain VI – Southern Hemisphere I
6B – Lubrication Fundamentals VI– Southern Hemisphere II
6C – Commercial Marketing Forum VI – Southern Hemisphere III
6D – Condition Monitoring II – Southern Hemisphere IV
6E – Nanotribology III – Southern Hemisphere V
6F – AI and Machine Learning in Tribology I – Northern Hemisphere A1
6G – Environmentally Friendly Fluids II – Northern Hemisphere A2
6H – 2D Materials + Superlubricity – Materials Tribology and Nanotribology IV - Northern Hemisphere A3
6I – Fluid Film Bearings I – Northern Hemisphere A4
6J – Materials Tribology II – Northern Hemisphere E1
6K – Metalworking Fluids II – Northern Hemisphere E2
6M – Rolling Element Bearings VI – Northern Hemisphere E4

3 – 3:30 pm Beverage Break - Foyers

Thursday, May 19, 2022

Registration
7 am – 12 pm – Convention Center Foyer

Thursday Speakers Breakfast
7 – 8 am – Northern Hemisphere C

Certification Exams
8:30 am – 12:30 pm – Asia 4

Technical Sessions - 8 am – 12 pm
7A – Non-ferrous Metals I – Southern Hemisphere I
7B – Lubrication Fundamentals VII – Measurement – Southern Hemisphere II
7D – Condition Monitoring III – Southern Hemisphere IV
7E – Nanotribology V – Southern Hemisphere V
7G – Environmentally Friendly Fluids III– Northern Hemisphere A2
7H – Synthetics and Hydraulics I – Northern Hemisphere A3
7I – Fluid Film Bearings II – Northern Hemisphere A4
7J – Materials Tribology III – Northern Hemisphere E1
7K – Metalworking Fluids III – Northern Hemisphere E2
7L – Tribology of Biomaterials I – Northern Hemisphere E3
7M – Rolling Element Bearings VII – Northern Hemisphere E4

Beverage Break - 10 – 10:30 am – Foyers

12 noon to 1:30 pm – Lunch on Your Own

Technical Sessions - 1:30 pm - 6:00 pm
8A – Non-ferrous Metals II– Southern Hemisphere 1
8B – Lubrication Fundamentals VII - Rheology – Southern Hemisphere II
8E – Nanotribology V – Southern Hemisphere V
8G – Environmentally Friendly Fluids IV – Northern Hemisphere A2
8H – Synthetics and Hydraulics II – Northern Hemisphere A3
8I – Fluid Film Bearings III – Northern Hemisphere A4
8J – Materials Tribology III – Northern Hemisphere E1
8L – Tribology of Biomaterials II – Northern Hemisphere E3

Beverage Break - 3 – 3:30 pm - Foyers

Electric Vehicles I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3666962: Novel, Bio-Based Group V Basestocks for EV Applications: Customizable Performance with Reduced CO_2 Footprint
Ben Deweert, Oleon, Evergem, Belgium

Strengthening fuel economy, emission control regulations and consumer preferences are steering the automotive industry to switch to electric vehicles to reduce CO2 and other GHG emissions. OEMs are pushing the boundaries by continuously optimizing electric drivetrain design, performance, and efficiency. Performance characteristics of EV fluids can be enhanced by selecting the right basestock. Specific challenges will be reviewed like lowering fluid viscosity and decreasing the additives treat rate. The base oil must therefore largely carry the technical EV requirements by itself. Multi-purpose basestocks like Group V oils can address the industrial criteria. At the same time, the awareness for the carbon intensity of products and materials is also increasing. By designing new Group V base oils from renewable, sustainably sourced building blocks, these fluids can contribute to a further reduction of the total carbon intensity of electric vehicles, as confirmed by Life Cycle Assessments.

8:30 - 9 am
3659666: Advancing EV Fluid Development with Next-Gen Base Oil
Babak Lotfi, ExxonMobil, Baytown, TX

Over the last several years electric vehicle (EVs) design has rapidly evolved. The electric motor which is the key component in the EV drive-unit that differentiates EVs from conventional internal combustion engine-based vehicles, posed new fluid requirements e.g. thermal management in addition to conventional tribological properties.
This work demonstrate how next-gen PAO molecules can help to advance EV fluids formulation. The next-gen PAO bring a balance of low viscosity and low volatility (high flash point) that is first in class and not achievable by incumbent molecules like Gr III/+ and conventional PAO. The lower viscosity formulation is achieved by next-gen PAO. Testing results exhibit superior energy efficiency and cooling properties of next-gen PAO fluids, in a gear-box and an e-motor, which can result in extending driving range in electric vehicle.

9 - 9:30 am
3669418: Next Generation Basefluids for Electrical Vehicles - Optimizing the Performance Balance
David Gillespie, Croda, Inc., New Castle, DE

The requirements of next generation gear fluids for electric vehicles will require fluid optimization in both the additive package and basefluid technology. High efficiency of the electric motor means any efficiency losses in the gear system including the fluid are under scrutiny whilst thermal management of both the motor and battery pack continue to be essential along with safety aspects such as low electrical conductivity and high electrical breakdown voltage values. Here, next generation group V fluids are evaluated for their efficiency and cooling ability whilst also tested for other critical parameters such as oxidative stability, fluid and material compatibility and wear performance.

9:30 - 10 am
3664452: Do Esters Make Sense for Fluids in Electric Vehicles ?
Matthias Hof, Emery Oleochemiclas GmbH, Monheim, NRW, Germany

Driven by the intent to reduce emissions by limiting the use of fossil fuels alternatives to the internal combustion engine (ICE) are being developed. Electric mobility is evolving as the new dominating alternative drivetrain.
The change of the existing drivetrain technology to a full electric or hybrid drivetrain will require a new set of automotive fluids to be used. Currently most OEMs are using existing fluids with minor adaptations to meet new requirements related to the exposure to electric fields and temperature control. All major lubricant, additive and component companies are now engaged in the development of fluids specifically designed for the usage in the new vehicle generations in the future. This paper looks at the suitability of ester technology in future fluids for electric vehicles. Data will be presented how the chemical structure of ester shapes the physical and chemical properties and what impact the structure has on the dielectrical and thermal profile.

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

1B Southern Hemisphere II

Lubrication Fundamentals I - Contact Models I

Session Chair: Q Jane Wang, Northwestern University, Evanston, IL
Session Vice Chair: TBD

8 - 8:30 am
3640353: The Lubrication at the Piston-Ring and Liner Interface as a Subject of Trade-Off Between Competing Factors
Polychronis Dellis, ASPETE, Athens, Attiki, Greece

Lubricant flow in piston-rings and liner of ICEs has been challenging due to complexity contributing or obstructing effective, low emissions and efficient operation. Increasing efficiency and enhancing load capacity has led to extensive study that combine different conditions of speed, load, temperature, and geometrical aspects with varying lubricant properties. Example: experimental data showed that viscosity variation alters cavitation initiation and shapes that result to different shapes on the surface of the ring. Friction losses over a cycle is a factor that needs to be investigated constantly. More data showed that friction peaks at boundary regions show the effect of squeeze film and its dependence on HTHS, speed, load, temperature, and ring geometry. This study also showed that hydrodynamic losses-mainly due to viscous shear at the diverging wedge of the ring, when an effective trade-off is achieved, can be optimized towards recent lubricant trends and sophisticated additives.

8:30 - 9 am
3658966: Flow Around a Contacting Asperity Modeled in the Macro-, Micro- and Nanometer Scales
Shuangbiao Liu, Henry Soewardiman, Nicole Dorcy, Jannat Ahmed, Yip-wah Chung, Q Jane Wang, Northwestern University, Evanston, IL; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

Mixed lubrication problems involving asperity contacts have often been studied assuming a continuous medium, or continuum. However, the behavior of fluid flow around contacting asperities, where the gap between surfaces is extremely thin, requires investigation on the discrete molecular level. This work studies the three-dimensional flow at the corner of a fully flooded wedge, in which one surface moves at a constant velocity and the other remains stationary, with three computational methods involving three different scales: computational fluid dynamics, micro elastohydrodynamic lubrication modeling with the

Reynolds equation, and molecular dynamics. The flow fields are simulated; the flow statuses at the fluid-wall interface are examined; and the wall slip conditions are defined. From this work, the wall-slip behavior is quantified and the influence of the aforementioned scales on mixed lubrication is revealed.

9 - 9:30 am
3669142: Micro –Hydrodynamic Lubrication of Rough Thermoplasts in Parallel Sliding – The Role of Asperities, Cavitation, and Elasticity
Dilek Bulut, Norbert Bader, Gerhard Poll, Leibniz University of Hannover, Hannover, Germany

Traditionally, in order to include asperities or other deviations from perfectly flat surfaces when simulating hydrodynamic lubrication, the real roughness profiles have been transformed into abstracted parameters such as flow factors which then are used to modify the terms of Reynolds equation. These approaches obviously have their limitations. Therefore, it is reasonable to attempt to work with real 3-D scans of surface topography.
In a previous paper, the Reynolds-Solver of Elmer was fitted with a mass-conserving cavitation algorithm, and an iteration routine based on the force balance method was implemented. The validity of this approach was shown numerically and experimentally. In the current work, the numerical method is extended to include the micro surface features with elastic deformations. The simulations are compared with the optical experiments. The role of micro surface features, elastic deformations and cavitation is investigated via the simulations based on 3-D scans.

9:30 - 10 am
3668941: A Fully Conservative Thermo-Elastohydrodynamic Lubrication Model for Counterformal Contacts
Suhaib Ardah, Daniele Dini, Imperial College London, London, United Kingdom; Francisco Profito, Polytechnic School of the University of São Paulo, São Paulo, Brazil

The current contribution proposes an integrated and fully conservative finite volume framework to solve the coupled TEHL problem for counterformal contacts. The fluid flow behavior is predicted by solving the generalized Reynolds equation with the p-θ Elrod-Adams mass-conserving cavitation model and the energy equation for a viscous compressible fluid with proper boundary conditions for the fluid-solid interfaces. Advanced partitioned fluid-structure interaction (FSI) techniques are employed to handle strong nonlinearities exhibited by the coupled system of equations while simultaneously accelerating the solution convergence. The application of a body-fitted curvilinear coordinate system is explored to solve the energy equation from its strong conservation form. The performance of the model in terms of accuracy and computational effort will be evaluated against CFD-based TEHL models, while experimental validation will be assessed from infra-red thermal maps and other experimental data.

10 - 10:30 am – Break

1C Southern Hemisphere III

Commercial Marketing Forum I

Session Chair: TBD
Session Vice Chair: TBD

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

8:30 - 9 am
3668939: Oil Filtration Systems: Remote System Monitoring & Purification of Lubrication Oil Reservoirs
Tom Lisy, Ken Kaihlanen, Oil Filtration Systems, Boerne, TX

Hydraulic and lubrication oils become contaminated with solids and water through normal use. As part of their reliability program, plant personnel pull samples periodically and send them to a lab for analysis. Although the reports are usually accurate, it often takes several days to get them back, and this delay can slow down the response time to critical contamination levels and contribute to system degradation. Utilizing sensors and a PLC, the oil condition in critical hydraulic and lubrication oil systems can be continuously monitored in-situ, and when contamination levels above set parameters are detected, a filtration/dehydration system can come on automatically. When contamination levels are reduced to pre-set parameters (particulate and water), the system automatically shuts off. This technology is particularly useful in remote facilities where operators are not frequently available. Vacuum dehydration & barrier filters are used to purify oils and extend their useful life.

9 - 9:30 am
3647758: Biosynthetic Technologies: Estolides - High Performance Sustainable Base Oils for Lubricant and Metalworking Formulations
Matthew Kriech, Biosynthetic Technologies, Indianapolis, IN

Biosynthetic Technologies strives to deliver innovations for a sustainable future. As such, we offer products that are bio-based, biodegradable yet deliver superior performance characteristics. In this session we'll discuss our currently product line of sustainable base oils / estolides that are made from organic fatty acids found in various bio-derived oils. In this session, we provide in depth information on estolide hydrolytic stability, oxidative stability, seal compatibility and other performance characteristics. In addition, we share our knowledge on a modified hydrolytic stability test to monitor the extensive stability of estolides versus traditional lubricant esters over a long duration of time under real world applications. This 30 minute session will be a MUST for anybody looking to develop a high performance EAL product line!

9:30 - 10 am - **King Industries**

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

1D — Southern Hemisphere IV

Tribotesting I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3641067: Study of Friction and Lubrication in Wire-Drawing Process
Marie-Louise Schlichting, Marc Masen, Amir Kadiric, Imperial College London, London, United Kingdom; Stijn De Pauw, Hendrik Van Hoecke, Marc Derdeyn, NV Bekaert SA, Ingelmunster, Belgium

Steel wires are used in various engineering applications, from car tires, oil platform anchorage ropes to champagne corks. A commonly used process to produce steel wires is wire drawing where a wire is pulled through a series of conical dies to reduce its cross-sectional area. At the wire-die contact the wire is subjected to high frictional forces. The underlying friction and lubrication conditions have an impact on the wire quality as well as the total energy consumption in the drawing process. However, these tribological interactions at the wire-die contact are poorly understood due to complex process conditions

such as high pressures, high speeds, and the use of unconventional lubricants such as soaps. This work investigates friction and lubrication behaviour under conditions pertinent to wire-die contacts using lab tribometers and wire-drawing set-ups and typical soaps and wire steels. Presented results offer new insights into the tribological interactions at the wire-die interface.

8:30 - 9 am
3642543: The Assessment of Tribological Effects of Nanofluid Flow on Heat-Exchanger Materials
Gustavo Molina, Fnu Aktaruzzaman, Mosfequr Rahman, Valentin Soloiu, Georgia Southern U, Statesboro, GA

Nanofluids, the suspensions of nano-size powders in cooling or lubricant fluids, are an active field of tribology research. But while the tribology of nanofluid lubricant is being actively studied, there is little knowledge on the effects of nanofluid cooling mixtures, as nanopowders in water and ethylene glycol, on typical heat-exchanger material surfaces. The authors discuss their pioneer research work on the testing of such effects, and their development of tribology testing and wear-assessment methodologies. More relevant results of testing nano-alumina fluid tribological action on typical materials (aluminum, copper, and stainless steel) are presented and assessment methods (roughness changes, weight-removal, and microscopy) are discussed. New proposed assessment methodologies and their integration with other critical nanofluid tests (as the heat-transfer measurements) are discussed.

9 - 9:30 am
3642999: An in-situ study of lubricants and their thermal properties
Peter Renner, Yan Chen, Hong Liang, Texas A&M, College Station, TX

In electric-mechanical systems like electric vehicles, a lubricant's thermal performance is essential for efficiency. During operation, it is difficult to measure directly the dynamic thermal behaviors of the lubricant. As such, this research introduces an alternative approach to measure fluid film thickness experiencing shear at different temperatures using electrochemical impedance. Polyalphaolefin (PAO) and mineral oil were the lubricants used in this research. It was shown that the thermal properties of the lubricants are dependent on temperature. Additionally, the dynamic thermal conductivity of the PAO was lower than that of the mineral oil. This research showed a new method to measure the dynamic thermal properties of a lubricant.

9:30 - 10 am
3643909: Influence of Structural Depth of Laser-Patterned Steel Surfaces on the Solid Lubricity of Carbon Nanoparticle Coatings
Timothy MacLucas, Lukas Daut, Maria Agustina Guitar, Sebastian Suarez, Frank Mücklich, Saarland University, Saarbrücken, Germany; Philipp Grützmacher, Carsten Gachot, TU Wien, Vienna, Austria; Volker Presser, INM - Leibniz Institute for New Materials, Saarbrücken, Germany

The ability of carbon nanoparticle coatings to provide effective solid lubrication in ambient conditions has been demonstrated in numerous studies. When coated, the recesses of textured surfaces can serve as lubricant reservoirs, forming a solid lubrication system capable of maintaining lubricity over significant periods of time. To optimize the performance of such systems, we examine the influence of the structural depth of line-patterned steel surfaces coated with multi-walled carbon nanotubes (CNT) and carbon onions (CO) on their respective potential to reduce friction and wear. The results show that regardless of particle type, the shallower the coated structure, the lower its coefficient of friction. Furthermore, CNTs reach a minimum COF of just below 0.20 thus lubricate more effectively than COs. Additionally, CNTs show a strong tendency to remain in the contact and the immediate proximity during friction testing, whereas the majority of the CO coating is removed.

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

Surface Engineering I

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

8 - 8:30 am
3648360: Additively Manufactured Inconel 625 Subjected to Surface Strength Improvements-Part II: Elevated Temperature Fretting Wear Analysis
Manisha Tripathy, Ali Beheshti, George Mason University, Fairfax, VA; Lloyd Hackel, Curtiss- Wright Surface Technology, Livermore, CA; Keivan Davami, The University of Alabama, Tuscaloosa, AL

Inconel 625 is a nickel-based superalloy with excellent mechanical properties and corrosion resistance at high temperatures highly used in harsh environments as joints, seals, valves, etc; which are subjected to fretting loads. While fatigue and corrosion properties of additively manufactured (AM) Inconel 625 have been studied, knowledge on its wear, contact, and friction properties is limited. This part of the study evaluates the fretting wear properties of AM Inconel 625 with its wrought counterpart at high temperatures up to 700^{o}C. The samples were manufactured by metal powder bed fusion technology using different process parameters; whose surface properties are further strengthened using shot peening (SP), ultrasonic peening (UP), and laser peening (LP), respectively. SP and LSP showed significant changes in the surface roughness parameters compared to the as-built AM sample and wrought Inconel 625 sample with improvements in friction and wear properties at high temperatures.

8:30 - 9 am
3669511: Additively Manufactured Inconel 625 subjected to Surface Strength Improvements-Part I: Surface Integrity and Microstructural Characterization
Ali Beheshti, Manisha Tripathy, George Mason University, Fairfax, VA; Keivan Davami, University of Alabama, Tuscaloosa, AL; Lloyd Hackel, Curtiss Wright Surface Technology, Livermore, CA

Surface enhancement processes like laser peening (LP), shot peening (SP), and ultrasonic peeing (UP) are being extensively used in harsh environment applications for decades now to improve the mechanical and surface behavior of parts. With the rapid growth of the metal additive manufacturing industry, it becomes necessary to rigorously study the additively manufactured components trying to achieve comparable or even superior properties with reference to their conventional counterparts. The first part of this study showcases a detailed microstructural and surface property comparison between additively manufactured and traditionally manufactured Inconel 625 with LP, SP, and UP processes. Surface morphology and mechanical properties as well as advanced characterization techniques like XRD, EBSD, and TEM were employed to collate the changes due to the different types of peening processes

9 - 9:30 am
3646318: A Comprehensive Characterization of Laser Sintered Polyamide-12 Surfaces
Kieran Nar, University of Sheffield, Sheffield, United Kingdom

There are a number of factors which influence the resultant surface topography of polymer Laser Sintered (LS) components and consequently affect their functional performance, particularly when subject to dynamic contact. The scope of this research was to comprehensively characterize the surface topography of LS Polyamide-12 specimens and to specifically understand how resultant roughness is a function of applied energy density; XY location across the powder bed; part surface orientation; measurement technique and roughness descriptor. Results showed that the roughness profiles of top and bottom surfaces of cube-shaped LS PA12 samples were distinct in both size and shape. Moreover, micro-CT analysis provided insight into how the sub-surface microstructure was affected by part orientation and applied energy density. This work provides a benchmark for future Polymer Powder Bed Fusion (PBF) studies, specifically when characterizing the friction and wear properties of resultant samples.

9:30 - 10 am
3667955: Investigating the Tribomechanical Behavior of Hot Rolled and Additively Manufactured NiTi Alloy
Sougata Roy, Hyunsuk Choi, University of North Dakota, Grand Forks, ND

Nitinol is an alloy containing Ni and Ti can present two unique properties— shape memory effect and superelastic effect. For aerospace applications, superelastic effect of Nitinol alloy can be leveraged due to its ability to accommodate large elastic strain in load bearing applications. In this study, the tribo-mechanical behavior of superelastic 55NiTi alloy was investigated. Reciprocating friction and wear tests on 55NiTi alloy samples fabricated via conventional hot working and laser directed energy deposition (DED) based AM technique were conducted. Tribological tests were performed in unlubricated conditions against AISI 52100 balls at room temperature to 300C. Wear tracks were analyzed using a set of microscopy and white light interferometry techniques to understand the key wear mechanisms as a function of temperature and fabrication routes. The findings are expected to reveal the benefits and challenges of fabricating NiTi alloy using AM route from tribo-mechanical perspective.

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

1F Northern Hemisphere A1

Seals I: Rotary Rod Seals

Session Chair: Hongmei Zhao, Lubrizol, Wickliffe, OH
Session Vice Chair: Jing Yang, Texas A&M University, College Station, TX

8 - 8:30 am
3641477: Friction of Rod Seals at Pre-Defined Thin Lubricant Films analyzed with a New Measurement Procedure
Oliver Feuchtmüller, Lothar Hörl, Frank Bauer, University of Stuttgart, Stuttgart, Germany

The film thickness and lubrication conditions in the sealing gap of a reciprocating rod seal are of great interest due to their influence on friction, wear, and leakage. However, it is still a challenge to analyze the friction of rod seals in direct relation to the film thickness, shear rate, apparent viscosity and contact area. Thus, conclusions on the tribological mechanisms in the sealing gap are restricted. We developed a measurement procedure for analyzing friction at pre-defined shear rates. Therefore, thin lubrication films in the nanometer-range are produced and measured using ellipsometry. One unique feature is that practical-relevant sealing rings and various lubricants can be analyzed and compared. Results from a recent study including sealing rings with different geometry, surface topography and material are presented and discussed. The novel procedure and the empirical results can be used for optimizing modern sealing solutions.

8:30 - 9 am
3643939: Wear on Rotary Shaft Seals: Tribological Correlation Between Wear at Sealing Edge and Wear of Shaft
Lukas Merkle, Matthias Baumann, Frank Bauer, University of Stuttgart, Stuttgart, Germany

Elastomeric rotary shaft seals are a common seal type for automotive and industrial applications. The wear mechanism of these sealing systems is not fully understood and not predictable so far. If a lip seal fails, it causes high maintenance costs and environmental damage. In order to investigate the wear mechanism, an empirical test series is conducted with shaft seals on plunge ground shafts. Various tribological conditions are considered, including operating conditions relevant to practice. For a complete acquisition of the system condition, all shaft surfaces are measured 2- and 3-dimensional before and after the test runs. The wear of the sealing edges is evaluated with a recently developed laser line triangulation

method on the complete circumference of the sealing rings. Results show large amounts of wear, depending significantly on the operating conditions. We discuss the wear mechanisms and the correlations of wear effects in the tribo contact area of the sealing system.

9 - 9:30 am
3646391: Modeling of Mixed Friction on Rotary Shaft Seals under Consideration of Real Measured Surface Data
Jeremias Grün, Simon Feldmeth, Frank Bauer, University of Stuttgart, Stuttgart, Germany

Rotary shaft seals are machine components subject to high dynamic loads. They are used in complex applications where their lubrication conditions change rapidly. This study deals with numerical analysis of the lubrication condition of rotary shaft seals under different operating conditions. Measured surface data of rotary shaft seals serve as input for the numerical analysis. A mixed-EHL model involving a deterministic asperity contact model provides an investigation of the flow and solid contact. The approach presented aims at numerical determining different parameters for characterizing the sealing behavior of rotary shaft seals under different operating conditions. The dynamic lubrication gap height, hydrodynamic pressure, contact pressure, pumping rate and frictional torque quantify the lubrication condition. The results of the mixed-EHL model provide a realistic insight into the lubrication of rotary shaft seals in different operating conditions considering measured surface data.

9:30 - 10 am
3646402: Approach to the Description of Macro Lead Formation by Means of Kinematics Simulation
Georg Haffner, Matthias Baumann, Frank Bauer, University of Stuttgart, Stuttgart, Germany

Rotary shaft seals together with the shaft counterface form a tribological system. The interactions between these components determine the lifetime and the sealing function. In some cases, surface structures on the shaft counterface can create an unintended axial fluid flow through the sealing contact. This unbalances the sealing system and causes either dry run or leakage and therefore seal failure. These surface structures are called lead. Axially periodic and thread-like surface structures are called macro lead. The formation of macro lead is caused due to unfavorable grinding and dressing parameters in the manufacturing process. The functional interactions between manufacturing parameters and the formation of macro lead now has been investigated by means of a kinematic simulation tool. We present simulation results and give an overview about the functional relationship between manufacturing and resulting surface characteristics.

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

1G — Northern Hemisphere A2

Grease I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3647897: High Performance Greases Toolbox: Synthetic Basestock Effect
A Study of the Influence of Synthetic Base Fluids on High Performance Greases
Luca Salvi, ExxonMobil Chemical, Baytown, TX; Joe Kaperick, Afton Chemical Corporation, Richmond, VA

As demands on equipment productivity and reliability increases, it becomes more important to understand the impact of the base fluid in improving the performance of lubricating greases under more severe

conditions including higher loads and broader operating temperatures. This study was carried out to look at the performance of lithium complex greases produced with high vis metallocene PAO. Grease variations incorporated AN and EP polymer. A performance additive package was used in each of the base greases and were benchmarked against a mineral oil formulation. Performance of the base greases, as well as fully additized finished greases, were evaluated in a comprehensive study including a wide range of testing to evaluate high/low temperature performance, seal compatibility, and ability to protect against oxidation, wear, extreme pressure, and corrosion. Testing included evaluation against NLGI GC-LB and the new HPM specs. Impact of consistency is included comparing NLGI 1 and 2 greases

8:30 - 9 am
3648467: The Churning Mechanism in Grease Lubricated Rolling Bearings: Identification and Characterization
Sathwik Chatra K R, SKF, Houten, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Utrecht, Netherlands; Jude Osara, University of Twente, Enschede, Netherlands

The running process of a grease-lubricated bearing can be separated into two phases: the churning phase and the bleeding phase. The churning phase is characterized by a very transient high-temperature profile while the bleeding phase has a steady low-temperature profile. During the churning phase, the grease will experience high levels of shear resulting in degradation. Churning duration and intensity are grease-dependent. Here, we classify greases into “good/peak-type churning” greases and “poor/plateau-type churning” greases. The grease property responsible for this behavior is microstructural flexibility. Churning also consists of two phases: channeling and clearing. During the channeling phase of churning, a grease channel is created, and during the clearing phase, excess grease from the raceways is removed via side flow caused by over-rolling. The clearing phase is the longer of the two. Experimental results from lithium greases in 6204 DGBB bearings verified observed mechanisms.

9 - 9:30 am
3647990: A Model to Study Lubricating Grease Rheology: Exploring Molecular Dynamics Simulations
Femke Hogenberk, Sissi de Beer, Jude Osara, University of Twente, Enschede, Overijssel, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Utrecht, Netherlands

In the initial phase of bearing operation, the rollers in a bearing form a channel through the grease. For “good” channeling greases, this is formed easily. For “poor” channeling greases, it takes much longer, leading to increased degradation of the grease structure. Currently, it is unclear why a certain grease would be a good or poor channeling grease. This complex phenomenon is difficult to characterize due to experimental limitations. Here, we explore a potential solution via molecular dynamics modeling of grease. Simulations are performed to study the viscosity and the storage and loss moduli. The effects of fibre density, length, flexibility, and temperature are investigated. A Dissipative Particle Dynamics (DPD) thermostat represents the grease base oil in this study. Optimal fibre dimensions and equilibration time are obtained. This work provides the basis for future investigations into and experimental verification of the various effects of grease parameters on channeling.

9:30 - 10 am
3646574: Scale Up of a Preformed Polyurea Thickener for Grease.
Lauren Huffman, John Cuthbert, Kevin Capaldo, Bruce Hook, Dow Chemical, Midland, MI

Lithium based greases are the most common, but as electric vehicles become more popular, lithium availability is declining and prices are rising because of the demand of lithium for batteries. Other grease thickeners will need to fill in the gap left by lithium, and polyurea is a good candidate for many applications. However, polyurea based greases formed in-situ necessitate the handling of isocyanates which can be difficult and dangerous to work with and require special engineering controls to do safely. This presentation is on the scale up of a solid pre-formed polyurea based thickener for grease, which eliminates the need for a grease manufacturer to handle isocyanates. The efficiency and performance of the thickener will be covered.

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

1I Northern Hemisphere A4

Biotribology I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3668367: A Multiphysics Modeling Approach to Wear and Lifetime Prediction of Dual Mobility Hip Implants
Nia Christian, C. Fred Higgs III, Rice University, Houston, TX

Dual mobility hip implants are thought to offer an increase in patient flexibility and range of motion over single mobility hip implant designs, however there have been concerns about increased wear in dual mobility designs due to the increase in moving parts. Due to the use of polyethylene in the acetabular cup, accurate modeling of the wear process in dual mobility designs plays a crucial role in joint lifetime prediction. While many studies using mechanical hip simulators have been done to approximate wear in dual mobility hips, these studies use highly simplified input kinematics instead of real data from patients with artificial hip implants. In this work, a mixed lubrication modeling framework, able to scale to relevant timescales for physical activity for a hip implant, has been constructed using patient specific movement data in an effort to predict implant wear differences amongst patients with different gaits and physical activity levels.

8:30 - 9 am
3668774: Structural Insights Into the Interaction Between Hyaluronan and Phospholipids
Tooba Shoaib, Wei-Ren Chen, Changwoo Do, Oak Ridge National Lab, Knoxville, TN; Justin Silberman, UFL, Gainesville, FL; Rosa Espinosa-Marzal, University Of Illinois at Urbana-Champaign, Urbana, IL

Interactions between molecules in the synovial fluid and the cartilage surface play a vital role in the formation of adsorbed layers, which mediate low friction via boundary lubrication. Here, the association between phospholipids and hyaluronan has been of particular interest. Phospholipids are found both as vesicles in the synovial fluid, and in the form of lamellar structures on the cartilage's surface, while HA is found abundantly in the synovial fluid. Both phospholipids and the HA can influence the lubrication behavior of the articular surface synergistically, yet studies on their self-assembly and resulting structures are limited. We will study the interactions between HA and lipids by scrutinizing the structural arrangements of HA-lipid mixtures via SANS experiments. Preliminary data from DLS for a mixture of HA and DPPC in tris buffer showed the solution to be highly polydisperse. By combining USANS and EQ-SANS we will cover the length scales observed by DLS (up to ~300 nm).

9 - 9:30 am
3668230: The Dynamic Fluid Equilibrium of Articular Cartilage During Activity
Steven Voinier, David Burris, University of Delaware, Newark, DE

Articular cartilage longevity is directly related to its ability to continually withstand its mechanical environment. The biphasic material leverages fluid within the tissue to promote lubricity and support load. However, loading the porous tissue leads to fluid exudation, reducing preferential support. Recently, Moore et al. demonstrated that activity, via sliding cartilage tissue under load, promotes tissue rehydration to combat exudation. When the exudation and rehydration rate equate, the tissue sustains a dynamic fluid equilibrium at a sample-specific fluid strain. In this study, we demonstrate that the dynamic equilibrium is independent of the sliding speed at physiological conditions, indicating that the rehydration mechanism is hydrodynamic in origin, but is limited by fluid uptake through the interface. Additionally, the equilibrium

fluid strain increases linearly with load, resulting in a less favorable mechanical environment that could increase disk of tissue damage.

9:30 - 10 am
3645584: Exploring the Biotribological Characteristics of Surface Functionalised PEEK for Focal Cartilage Resurfacing
Robert Elkington, Andrew Beadling, Richard Hall, Michael Bryant, University of Leeds, Leeds, United Kingdom; Hemant Pandit, Chapel Allerton Hospital, University of Leeds, Leeds, United Kingdom

Current use of hard biomaterials such as CoCr or ceramic to articulate against the relatively soft, compliant cartilage surface increases contact pressure by up to 500% which promotes erosion of the mating cartilage leading to pain and loss of function. Biomimetic soft lubrication strategies have been developed by grafting hydrophilic polymers onto substrates to form a gel-type surface. Polymer brush graftings mimic the natural biphasic and hydration lubrication modes of friction dissipation in synovial joints, showing a promising potential for use in cartilage repair. PEEK surfaces functionalized with highly hydrophilic anionic SPMK were assessed for their wettability, nanomechanical properties and graft density. Cartilage pin-on-plate testing with gait-like dynamic loading cycles demonstrated that SPMK grafted surfaces reduce friction by an order of magnitude compared to untreated biomaterials and exhibit behavior auxiliary to rehydrating cartilage to preserve its natural function.

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

1J — Northern Hemisphere E1

Wear I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30am

8:30 - 9 am
3637599: Innovative Next-Generation Anti-Wear for New Industry Challenges
Christelle Chretien, Solvay, Bristol, PA

Growing demand for fuel economy, energy alternatives and durability, push the development of alternative solutions for components and additives for lubricants. In this context, Solvay has chosen new technology paths to develop sustainable anti-wears with enhanced performances and milder classification. The objective of this talk is to present an update on the development of next generation anti-wears especially based on a polymeric technology platform demonstrating performances of high potential.

9 - 9:30 am
3642599: Lubricity Improvements of N-Butanol Mixing in Ultra-Low-Sulfur Diesel: A Wear, Friction and Viscosity Study
Gustavo Molina, John Morrison, Valentin Soloiu, Cesar Carapia, Georgia Southern University, Statesboro, GA

Recent studies show that N-Butanol is a suitable alternative fuel for diesel engines. This study shows that N-Butanol in ULSD (ultra-low sulfur diesel) can also mitigate the wear effects of low-Sulphur-content in diesel fuels. Tribological studies of N-Butanol in ULSD mixtures by viscosity measurements, pin-on-disk tribometry and a crankcase lubricant interaction with oils are presented: Viscosity for the tested mixtures (of up to 35% of added N-Butanol) does not decrease below the recommended by standard ASTM D-975.

A unique wear minimum shows in tribometer testing for the 25% N-butanol in ULSD mixture, a wear reduction of 43% as compared to that of pure ULSD; the tribometer friction force evolution data supports that there would be a lubricity improvement around such dilution ratio. Finally, good compatibility of the NButanol/ULSD blend when mixed in engine oil is also successfully tested.

9:30 - 10 am
3642540: Wear Effects of Mineral Oil Dilution by Biodiesels: Is Viscosity Change or Methyl Ester Composition the Driving Factor?
Gustavo Molina, Emeka Onyejizu, Valentin Soloiu, Georgia Southern University, Statesboro, GA

The dilution of IC engine-oils by unburned biodiesels can substantially increase wear. Tribometer research shows varied levels of lubricity and viscosity degradations, which are very dependent on biodiesel feed-stock origin and composition, but it is not yet clear which one is the driving factor increasing the tribometer wear. Tribological studies are discussed of wear and lubricity testing by mixing individual methyl esters (as typical components of biodiesels) in SAE 15W40 mineral oil.

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

1K — Northern Hemisphere E2

2D Materials + Superlubricity - Materials Tribology and Nanotribology I

Session Chair: TBD
Session Vice Chair: TBD

8 - 9 am
3669344: Mechanism of Graphite Lubrication Under High Mechanical Load
Martin Dienwiebel, Carina Morstein, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Solid lubricants are used in applications where liquid lubricants reach their limits. One of the well-known solid lubricants is graphite, showing distinct lubrication properties in normal atmosphere but severe wear and friction in vacuum. The most common explanation for the good lubrication properties of graphite is the deck-of-cards-model or lattice shear model postulated by Bragg et al. [1]. Up to this day, this model is highly debated. Our research aims to shine light onto the mechanisms, properties, and limits of graphite lubrication underhigh mechanical load (> 1 GPa). Experiments were conducted in a microtribometer under reciprocating linear sliding. The sliding track and graphite layers were analyzed by confocal microscopy, SEM, FIB, and HR-TEM. Additionally, detailed MD simulations were performed under different amount of water. We show that the lattice shear model is not valid for highly loaded contacts. Instead, low friction is caused by a turbostratic microstructure.

9 - 9:30 am
3669354: Role of Environment on the Shear Driven Structural Evolution of MoS2 and Impact on Aging
Tomas Babuska, Tomas Grejtak, Lehigh University, Bethlehem, PA; John Curry, Michael Dugger, Sandia National Laboratories, Albuquerque, NM; Alexander Kozen, Sam Klueter, University of Maryland, College Park, MD; David Ramos, Florida A&M University, Tallahassee, FL; Kylie Van Meter, Brandon Krick, Florida State University, Tallahassee, FL

Due to prolonged storage in the presence of water and oxygen (aging) MoS_2 can degrade due to oxidation impacting the tribological properties such as initial friction and coating life. Practically, coatings are tested in lab air, resulting in different microstructures than inert environments due to interactions with H_2O and O_2. This work studies the effects sliding in lab air has on the evolution of the surface microstructure of MoS_2 coatings and the implications for aging resistance. TEM shows that sliding in air

and dry N_2 both result in a basally oriented surface. XPS taken on sheared and as-deposited regions show that sliding in lab air increases the amount of MoO_x at the surface. Interestingly, sliding in air allows for lower initial friction and shorter run-in to low friction before and after aging compared to an as-deposited surface. This work suggests that testing coatings in lab air before storage significantly improves the tribological properties after storage in H_2O and O_2.

9:30 - 10 am
3669363: Robust Vibration-Activated Lubricity
Arnab Bhattacharjee, David Burris, University of Delaware, Newark, DE; Nikolay Garabedian, Karlsruhe Institute of Technology, Karlsruhe, Germany; Brian Borovsky, St. Olaf College, Minnesota, MN

Friction can be reduced or eliminated when the contact interface is subjected to an external vibration; we refer to this phenomenon here as vibration-activated lubricity. According to prior literature, vibration-activated lubricity is limited to oscillation amplitudes and frequencies that depend strongly on case-specific experimental variables such as the instrument resonance frequency, sliding speed, and slip length of the tribo-pair. This study aims to overcome these limitations and clarify their origins. Specifically, we used a quartz crystal microbalance (QCM) to directly oscillate the sample at a fixed frequency and at oscillation speeds that exceeded the sliding speed by orders of magnitude. Under these direct oscillation conditions, vibration-activated lubricity persisted for alumina probes ranging from 50-1500 μm in diameter, loads from 20 μN - 5 mN, speeds from 5 μm/s - 1 mm/s, gold and MoS2 samples, and two instruments – a custom microtribometer and a commercial AFM.

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

1L — Northern Hemisphere E3

Power Generation I

Session Chair: TBD
Session Vice Chair: Salvatore Rea, Lanxess Corporation, Perkasie, PA

8 - 8:30 am
3644441: Demonstration of the Benefits of SAE 30 Monograde Stationary Gas Engine Oil
Zoe Fard, HollyFrontier Lubricants and Specialties, Mississauga, Ontario, Canada

Stationary gas engines are typically lubricated with SAE 40 monograde stationary gas engine oils (SGEOs). Despite the historic preference of gas engine OEMs for SAE 40 oils, several gas engine designs are capable to run safely on SAE 30 oils. This study evaluates the benefits of an SAE 30 monograde SGEO in comparison with SAE 40 monograde SGEOs with the focus on two main areas. First, to demonstrate and quantify the effect on the fuel consumption rate, and second to demonstrate the faster lubrication of hard to reach points (e.g. valve guide) in the engine during start up. The current industry recognized fuel efficiency test methods for passenger car and on-road diesel engine sectors are not suitable for evaluating the fuel efficiency performance of a gas engine oil because of the significant differences in fuel type, engine operating conditions, and oil formulations. This work, therefore, describes comparative studies of three different SGEOs in a fully instrumented MAN gas engine.

8:30 - 9 am
3647478: Gas Engine Oils with Enhanced Solvency Based on Novel Base Oil Blends
Thomas Norrby, Jinxia Li, Nynas AB, Nynashamn, Sweden; Franz Novotny-Farkas, Lubex Consulting OG, Schwechat, Austria; Christoph Schneidhofer, Jasmin Pichler, AC2T, Wiener Neustadt, Austria

Stationary gas engines are frequently employed to provide back-up electrical grid support, especially in combination with intermittent power generation from sources like wind and solar. The lubrication

requirements of the gas engine oil (GEO) are similar to other ICE engine oils but have additional challenges in matching fuel quality with GEO lubricity and thermal and oxidative stability. In this study, we investigate how the base oil selection with respect to solvency and thermal stability can be a design factor for novel GEO formulations with improved properties. Post-test run oil analyses were performed, and we show how blends of highly refined naphthenic base oils on combinations with paraffinic Group II and III base oils can provide improved cleanliness through better base oil solvency. This work was funded by the project COMET InTribology1, FFG-No. 872176 (project coordinator: AC2T research GmbH, Austria).

9 - 9:30 am
3668946: The Three Rs: A Sustainable Approach to Turbine Lubricant Maintenance
Matthew Hobbs, EPT, Calgary, Alberta, Canada

Sustainability and maintenance go hand-in-hand. By definition, something must be maintained for it to be sustained. To ensure sustainable power generation, turbine maintenance is, therefore, imperative. Despite its recognized importance, existing oil maintenance programs are often reactive instead of proactive in scope. Indeed, most programs target physical contamination without addressing the chemical causes of costly oil-related failures. This approach, inherently, treats turbine oils as consumables. For power generation to move towards true sustainability, however, oils must be regarded as assets to be proactively cared for rather than reactively replaced. Early sustainability programs highlighted the value of “The Three Rs” (Reduce, Reuse, Recycle). A different set of Rs are similarly effective with respect to making oil maintenance more sustainable: Rethink; Remove; Restore. By building on these pillars, turbine users can make meaningful contributions towards sustainability.

9:30 - 10 am
3646311: Power Plant Lubrication Reliability
Anshuman Agrawal, Minimac Systems Pvt Ltd, Pune, Maharashtra, India

An uninterrupted power supply is all that is needed to meet our lifestyle in the growing competitive world and the same is the goal of any power plant that is to maximize uptime by reducing the failure of the critical equipment involved in power generation like turbines, generators, boiler feed pumps, mills and many more. In a typical thermal power plant, the most challenging areas of lubrication maintenance are the Coal handling plant, Boiler, Turbine, and the Governing system where maintaining the cleanliness level of Lubricating fluid is of utmost priority. With this technical paper, we attempted to present the challenges associated with lubrication maintenance in a power plant and some important measures to achieve equipment Reliability. Our focus is to minimize downtime and maximize uninterrupted power generation.

10 - 10:30 am – **Break**

1M — Northern Hemisphere E4

Rolling Element Bearings I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3637818: In-Situ Measurement of the Oil Film Meniscus at the Entry and Exit of a Rolling Bearing Contact
William Gray, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

This work describes the use of ultrasonic sensors, instrumented to take measurements of the presence and thickness of the lubricant film at the contact entry and exit of a full-size wind turbine gearbox

cylindrical roller bearing. As ultrasonic waves can propagate through solid and liquid media, direct access to the lubricated surfaces is not required and measurements are truly in-situ, unlike more conventional methods. Results show that lubricant viscosity is the greatest determining factor for healthy lubrication, with less viscous oils being unable to develop a meniscus of adequate length. Bearing rotation rate was also crucial, with higher velocities being able to develop a more stable, repeatable meniscus at the contact inlet. Load was found to predominantly affect the outlet meniscus. This works shows the potential of ultrasound to be used as a lubricant monitoring tool in industrial bearings, helping to avoid premature failure due to inadequate lubricant supply.

8:30 - 9 am
3646294: In-Situ Measurement of Roller Skew and Lubricant Film Change Within a Rolling Element Bearing
William Gray, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

Rolling element skew, where a rolling element pivots about an axis normal to the roller-raceway contact, causes an increased frictional force between a roller end-face and flange and reduces bearing life. Ultrasonic reflections are very sensitive to bearing contact conditions, meaning they can be used to observe and time a contact passing over a sensor location. Additionally, the same reflections are sensitive to the lubricant thickness within the contact centre, with micron changes altering the reflection amplitude. In this work, ultrasonic sensors are instrumented across the axis of a cylindrical roller bearing test rig. The change in contact time across the axis is used to calculate roller skew, and results are presented with the corresponding change in film thickness. Results show that as a roller skews, the lubricant film thickens on one half of the roller and thins on the other. This occurs for all viscosity oils and greases tested.

9 - 9:30 am
3645188: Grease Performance in Ball and Roller Bearings for All-Steel and Hybrid Bearings
Piet Lugt, Marco Van Zoelen, Charlotte Vieillard, SKF Research and Technology Development, Houten, Netherlands; Frank Berens, SKF France, St-Cyr-sur-Loire, France; Robert Gruell, Paul Meaney, SKF Germany, Schweinfurt, Germany; Gerwin Preisinger, SKF Austria, Steyr, Austria

Grease life in hybrid bearings is longer than that in all-steel bearings. This will be shown in this paper by means of grease life tests with a large number of greases for both Deep Groove Ball Bearings (DGBB) and Cylindrical Roller bearings (CRB). The results show that grease life for hybrid bearings is always larger than that for equivalent all-steel bearings and that this varies between a factor 2 and 9 depending on the grease type that is used. For cylindrical roller bearings grease life does not increase with decreasing speed below a minimum value. However, also at these relatively low speeds, hybrid bearings give a longer grease life than all-steel bearings.

9:30 - 10 am
3645644: Analyzing Ball Bearing Capacitance Using Single Steel Ball Bearings
Steffen Puchtler, Julius van der Kuip, André Harder, Eckhard Kirchner, TU Darmstadt, Darmstadt, Germany

A precise modeling of the capacitance of rolling element bearings is of increasing significance over the last years, e.g. in the context of bearing damage estimation in electric drives. The complexity of a steel bearing as an electrical network makes reliable validation of calculation models under realistic operating conditions nearly impossible. A way to reduce complexity in yet realistic conditions is the use of hybrid bearings with a single steel rolling element. This helps to measure only one current path through the bearing at a time and thus, gives a much clearer picture of the contact capacitance of rolling elements in and out of the load zone. The usage of different materials comes with different thermal expansion coefficients and different elasticities, which cause a significant change in load distribution. For the first time, this work considers both of these effects in calculation and validates them with corresponding experiments using single steel ball bearings.

10 - 10:30 am – **Break**

2A Southern Hemisphere I

Electric Vehicles II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3669482: Additives for Improving Efficiency and Durability of Drivetrain Lubricants for Electric Vehicles.
Alexei Kurchan, Jacob Wegbreit, Croda Inc., Princeton, NJ

Future developments of electric vehicles will continue to focus on increasing single-charge range while controlling manufacturing and raw materials costs. Longer driving ranges can be achieved through progress in battery technology combined with improvement in the efficiency of the electric motor and drivetrain. Development of dedicated lubricants will provide for minimizing frictional and churning energy losses. Formulating drivetrain lubricants for electric vehicles present a unique challenge of minimizing energy losses, controlling corrosion of electrical components, coatings, and insulation compatibility, as well as maintaining excellent anti-wear, fatigue, and oxidation stability. These unique requirements drive development of new baseoils and additives. We will present our work on development of novel additives allowing formulation of lubricants with improved wear protection, friction, and traction characteristics in mixed and elastohydrodynamic lubrication regimes.

2 - 2:30 pm
3669347: Polymeric Additives as an Optimum Solution for Performance and Compatibility Challenges in E-drive Fluid Design
Peter Moore, Dmitriy Shakhvorostov, Stefan Wieber, Andreas Hees, Roland Wilkens, Evonik Oil Additives, Horsham, PA

An overview of the critical electric axle lubricant requirements and how tailor-made viscosity index improvers contribute to the full formulation performance in optimization of e-axle efficiency, electric conductivity, reduction of copper corrosion, thermo-oxidative stability, heat transfer, and low temperature performance. Tests used current industry standard ASTM and ISO methods, state-of-the-art methods for EV applications, and a modern E-drive gear box. Comb-like polymers in the fluids allowed use of a wider range of base stocks, which enabled the formulations to achieve significant reduction of gear box losses (>10%) as well as boosting heat transfer at relatively low temperatures. Targeted functionalization of polymers provided additional features, such as dispersancy and film-forming, with insignificant increases in electrical conductivity. Functionalization of polymers also helped withstand detrimental effects associated with the fluid aging (deposits and thickening).

2:30 - 3 pm
3648063: The Performance of Low Viscosity and Ex-High VI Engine Oils with MoDTC under Hybrid Electric Vehicles
Kenji Yamamoto, Shinji Iino, Yukiya Moriizumi, ADEKA Corporation, Arakawa, Tokyo, Japan

Electrified ICE equipped vehicles such as HEV and PHEV are considered to be important to reduce the CO2 emission for coming decade or using synthetic fuels made with renewable energy. Hybrid electric systems which operate its engine under low temperature more frequently, the effect of ultra-low viscosity engine oil for FEI would be significant. However, high temperature performance cannot be sacrificed because it is elevated as high as conventional ICE during long driving and high load operation. As it becomes more important to reduce engine friction under wide range of temperature, Ex-high VI engine

oils are being considered. In this study, the FEI performance is evaluated with the latest GF-6 and Ex-High VI formulation, under several types of engines with different displacements, including those for HEVs. MoDTC formulated Ex-high VI engine oil demonstrated significantly improved fuel economy performance than the latest GF-6 formulations under both conventional ICE and HEV systems.

3 - 4 pm - Break

4 - 4:30 pm
3669304: A Study of the Effects of Foam and Defoamer Performance in Electric Vehicle Fluids
Safia Peerzada, Stefanie Velez, Munzing Chemie GmbH, Bloomfield, NJ

Green, eco-friendly, and sustainable technology has become the future of the automotive industry causing a significant increase in the effort to develop Electric Vehicle Fluids. These lubricants exhibit different foaming tendency compared to traditional automotive fluids due to the difference in system chemistry, which requires different defoamer chemistry and test methods to simulate real world application. During use of the fluid, the defoamer functions to minimize foam buildup, which is undesirable for reasons such as reduction of lubrication and heat removal. A study of foam tendency in Electric Vehicle fluids using new lab foam test methods will be reviewed. Furthermore, the performance of various defoamer chemistries will be studied to understand the most optimal defoamer type for Electric Vehicle fluids.

4:30 - 5 pm
3663659: Impact of High Speed Operation on Lubricant Aeration in an Electric Drive Unit
Cole Frazier, Marshall Hudson, Caroline Mueller, Southwest Research Institute, San Antonio, TX

Compared to internal combustion engines, drive motors used in electric vehicles typically spin at much higher speeds. Current vehicles contain motors running up to 20,000 RPM, with trends moving towards faster speeds. Electric drive lubricants must perform in these high-speed environments – protecting gear interfaces and cooling components. The degree to which air is entrained in the lubricant as it makes contact with rotating components at 15,000+ RPM is currently not well quantified. Air entrainment in the lubricant can cause poor heat transfer and reduce wear protection. In the experiment described herein, the phenomenon of air entrainment was investigated. An electric drive unit was run in a laboratory setting with high speed data acquisition. Air entrainment was then measured across various operating conditions. Results showed an increase in air entrainment with both increasing speed and temperature, along with differentiation between fluids of varying aeration performance.

5 - 5:30 pm
3647009: How New E-Fluid Formulation Enable Efficiency and Better Performance Under High Speed Conditions
Torsten Murr, Shell Global Solutions Germany, Hamburg, Hamburg, Germany

For a number of years fluids for BEV s are available in the market. This first generation of fluids was able to satisfy the basic requirements on gear/ bearing protection, material compatibilities and fulfilling electrical requirements.
An obvious next generation of BEV Fluids in looking for further efficiency gains which reads direct into a more extended driving range. Based on this the presentation discusses the following topics: * Reflecting trends on adaption of ultra low viscosity fluids for BEV, * Efficiency Driveline testing with low and ultra low viscosity fluids
* Formulating high performing fluids for electric racing, * Safety risks and characteristics of ultra low vis formulation in realistic operating conditions

5:30 - 6 pm
3669345: Enabling Next Generation E-Fluids for Mobility, Electronics and Energy
Kai Wirz, Evonik Corp., Richmond, VA

Evonik provides innovative solutions for rising technologies in mobility, electronics, and energy. Applications including power electronics, e-drives, and battery thermal management benefit from a strong history in lubricants and metalworking fluid additives. Evonik Interface and Performance is one of the leading partners in specialty additives for critical performance enhancing effects, such as corrosion inhibitors, defoamers, friction modifiers, wetting agents, and lubricity enhancers. E-Mobility is changing the landscape of fluids and the related additives in order to meet demanding performance requirements. E-fluids for electric motors and batteries require additives that provide efficiency enhancing effects that that serve the special requirements, for example in thermal management and lubrification. Evonik Interface and Performance offers a broad range of solutions for these applications, strong customer focused development and service for these demanding applications.

2B Southern Hemisphere II

Lubrication Fundamentals II – Contact Models II

Session Chair: Gerhard Poll, Leibniz University Hannover, Hanover, Germany
Session Vice Chair: TBD

1:30 - 2 pm
3646378: Numerical Study of the Validity of the Reynolds Equation in the Nanoscale
Andrea Codrignani, Kerstin Falk, Michael Moseler, Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

In this work we aim to extend the validity of the traditional Reynolds equation in order to include typical aspects of nanoscale lubricant flows such as shear thinning, near wall effects and the partial slip of the first layer of lubricant at the liquid/solid interface. To achieve a proper description of these phenomena, we analyzed the flow of a mineral oil base (hexadecane C16H34) in a representative geometry of a lubricated contact (i.e. both parallel and converging-diverging channels) and we carried out a comprehensive parametric molecular dynamics study in order to analyze the influence of mild to severe operating conditions. As results we proposed a model to describe the occurring of slip at the nanoscale which is based on the local and the operating conditions of the system. The implementation of this model into the Reynolds equation results in an extension of the applicability of the latter and hence in a more computationally efficient way to describe lubricated nanosystems.

2 - 2:30 pm
3648103: Numerical Simulation of Contacts Working Under Mixed Lubricating Conditions
Ruchita Patel, Zulfiqar Khan, Adil Saeed, Bournemouth University, Bournemouth, Dorset, United Kingdom; Vasilios Bakolas, Schaeffler Technologies AG & Co. KG (Schaeffler Group), Herzogenaurach, Germany

Mixed lubrication offers significant asperity contact in severe loading conditions, which can initiate surface pitting and scuffing failure. Over the years there has been an increased interest in modelling and analysis of mixed lubrication regions, to avoid severe damage on the surface. However, a few researchers have addressed the problem by using Reynold’s equation, which assumes that a minimum thickness of lubricant film always exists between the contacts. Therefore it's uncertain that Mixed Lubrication (ML) can be modelled with the Reynolds equation. The current research presents a theoretical and mathematical background of asperity contact in mixed lubrication including CFD results which are compared with numerical simulation results with multilevel methods in lubrication. This paper discusses scientifically proven Mixed Lubrication theory based on numerical simulation of EHL models (Reynolds' equation) and is unique in addressing the roughness interaction within the Mixed region.

2:30 - 3 pm
3664184: Lubrication-Contact Interface Conditions and Novel Mixed/Boundary Lubrication Modeling Methodology
Shuangbiao Liu, Q Jane Wang, Yip-wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

Under severe conditions, solid contacts take place even when parts are lubricated. Precise mathematical conditions are needed to describe the interior interface between fluid lubrication and solid contact zones. In order to distinguish the conditions for this interface from conventional lubrication boundary conditions, they are named lubrication-contact interface conditions (LCICs). In this work, mathematical LCICs are derived with local flow continuity from the continuum mechanics point of view and pressure inequality across the interface. Numerical implementations are developed and tested with problems having simple geometries and configurations, and they are integrated into a new mixed/boundary elastohydrodynamic lubrication (EHL) solver that uses a new method to determine solid-contact pressures. This solver is capable of capturing film-thickness and pressure behaviors involving solid contacts.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3664197: Analyzing Transient Mixed Elastohydrodynamic Lubrication Considering Lubrication-Contact Interface Conditions
Shuangbiao Liu, Nicole Dorcy, Q Jane Wang, Yip-wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

In order to design tribological interfaces to meet required fatigue/wear lives and avoid scuffing, pressure and film thickness distributions are needed among other performance characteristics. Transient mixed EHL analyses involving asperity contacts were conducted to obtain these distributions in circular contacts with various asperities under pure rolling, simple sliding, and rolling/sliding conditions. An axisymmetric finite element model was built to quantify the effect of an asperity in the microscale on surface vertical displacement. This model simultaneously solves the Reynolds equation for lubrication regions, the zero-gap equation for the other locations during numerical iteration, and the load balance equation, particularly with the enforcement of complete interface conditions between lubrication and solid contacts. Transient EHL under unidirectional and reciprocating motions are analyzed to support laboratory tests and to facilitate understanding of engineering problems.

4:30 - 5 pm
3669192: Thermal Investigations into EHL Contacts –Determination of Solid Body Temperature at Lubricant Interface
Norbert Bader, Haichao Liu, Dilek Bulut, Gerhard Poll, Leibniz University Hannover, Germany, Germany

Elastohydrodynamically lubricated (EHL) contacts are found in numerous machine elements. To increase efficiency and reduce energy consumption better understanding of friction generation is necessary. It is dominated by lubricant rheology. As temperature is drastically changing lubricant behaviour the knowledge of local temperatures is important. In this work we present results from experiments with a twin-disc experiment where the local contact temperature was measured via infrared camera. Using a numerical method, the radiation components of the elements of the lubricating gap (film, surfaces) could be determined independently. Combined with simulation results the influence of each element’s temperature and the individual heating behaviour could be shown. Furthermore, in the simulations it could be investigated how physically sound rheological models can yield good agreement with experiment. This work contributes to better understanding and improved prediction of friction generation.

5 - 5:30 pm
3640731: Tribology for the Soul – How the Science of Tribology Can Help Companies (and People) Succeed
Michael Holloway, 5th Order Industry, Highland Village, TX

Friction, wear, and lubrication is typically considered the stuff of machines. Drawing a comparison between a bearing or gear set to the human condition is ripe for consideration. Humans require analogies, comparisons, similes, and poetic content to make sense of their world. While a world built on logic seems utopian it is not realistic, maybe never; we still use comparisons to understand and communicate. When examining a machine, the dynamics of a department, the working of a company or even a relationship, they all experience failure as well as a means to succeed. This presentation draws comparisons between the world of tribology and leadership as well as human interaction with the objective to learn how to utilize tribology to make your company and life run smoother.

2C Southern Hemisphere III

Commercial Marketing Forum II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm - **Clariant Corporation**

2 - 2:30 pm - **Kao Corporation USA**

2:30 - 3 pm - **The Lubrizol Corporation**

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

4 - 4:30 pm - **ANGUS Chemical Company**

2D Southern Hemisphere IV

Tribotesting II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3650703: Prediction of Retention of Fuel economy Capability in Aged Fully Formulated Fuel Economy Engine Oils containing Soluble Molybdenum Friction Modifiers using Laboratory Scale Bench Tests and Correlation with the Field Performance
Sanjay Kumar, Y Rao, David Hall, Chidambaram C T, Jencen Arivannoor, Vinod D, Vinith Kumar, Gulf Oil International, Chennai, Tamil Nadu, India

Molybdenum containing fuel economy engine oils lose their friction reduction capabilities over usage. In Sequence VI engine tests, an aging stage is included in which oil is aged within the engine before evaluation of fuel economy. The efficacy of friction modifier containing oils is currently estimated in a laboratory on a Linear Reciprocating Friction Tester. This study deals with a laboratory study to predict the effect of aging on the long-term fuel economy of friction modifier containing engine oils based on retention of its coefficient of friction values. The Aging of the oil sample in the laboratory was achieved through an oxidation test. Aging in the field was carried in a field trial. The aged samples were evaluated

on the Friction Tester to determine the coefficient of friction. Six friction modifier containing oils were evaluated. The study shows that aging effect can be predicted in laboratory scale bench tests and that the results correlate well with field performance.

2 - 2:30 pm
3644378: Electrical Impedance Spectroscopy to Study Sooty Engine Oils
Thomas Kirkby, Tom Reddyhoff, Imperial College London, London, United Kingdom; Mark Fowell, Volvo Group Trucks Technology, Göteburg, Sweden; Joshua Smith, Jacqueline Berryman, Infineum UK Ltd, Abingdon, United Kingdom

Electrical impedance spectroscopy (EIS) is a powerful tool used to determine electrochemical properties; however, it is underutilized in the field of lubricant monitoring. Soot is a problem in engines and can influence additives, leading to wear. Hence, a novel EIS probe was designed to monitor bulk properties of engine oils. Engine oils with specific additives removed were studied to identify the additive influence on resistance and capacitance. Results were compared with used sooty engine oils obtained from real-world field testing from heavy-duty diesel engines. This revealed that a higher soot content exhibited a lower resistance and higher capacitance than clean engine oils. High frequency reciprocating rig (HFRR) tests were also used to correlate bulk lubricant properties with friction and wear data, enhancing the understanding of the interactions between soot and different additives. This paves the way for EIS to be applied in both lab-based and online testing of engine oils.

2:30 - 3 pm
3645314: Adhesive Wear Performance of Specialty Bearing Steels
Daulton Isaac, Mathew Kirsch, Alexander Fletcher, AFRL Turbine Engine Division, Wright Patterson Air Force Base, OH; Hitesh Trivedi, UES Inc., Dayton, OH

In an effort to understand the parameters influencing a particular steel's tendency to scuff, a campaign has been undertaken in recent years to investigate this phenomenon in a wide array of steels. This most recent batch of bearing steels evaluated for their adhesive wear performance includes two high nitrogen stainless steels (HNS): CRONIDUR 30 and XD15VDW, powder metallurgy (PM) steels: T15 and CPM-REX76, and a carburizing stainless steel CX13VDW. HNS have excellent corrosion resistance but poor adhesive wear or scuffing resistance. PM steels are known for having favorable hot hardness. High chromium cobalt free CX13VDW is tested for comparison with Pyrowear675 (P675). Based on current and previous adhesive wear testing results, suggestions will be made as to the possible features of a steel that promote favorable scuffing resistance.

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

4 - 4:30 pm
3645609: Novel Compatibility Test of Seal Materials and Lubricants Under a Dynamic Stress Collective
Ameneh Schneider, Optimol Instruments, München, Germany

The ISO 1817 standard ("Rubber, vulcanized or thermo¬plastic - Determination of the effect of liquids") is a method by which the resistance of vulcanized or thermo¬¬plastic elastomers to liquids is tested. Sealing's damages caused by tribological-dynamic issues can often be observed in machineries. These damages result among others also from the counter surface, the lubrication and type of lubricant, the sliding speed as well as the temperature. Braun described the challenges of static test very well. This work represents added value to static compatibility test with conditions near to applications.

4:30 - 5 pm
3677562: Novel Method for Evaluating Lubricants in HD Bearing Interfaces
Michael Moneer, Peter Lee, Carlos Sanchez, Southwest Research Institute, San Antonio, TX

A methodology for evaluating friction and wear performance of lubricants against main bearings was developed. Modeled after a block-on-ring test configuration, this bench top test undergoes dynamic

speeds and loads under fully lubricated conditions in an effort to simulate the real system. Main bearings from heavy duty diesel engines were machined to fit the test geometry which presents an opportunity to evaluate new bearing materials and coatings in addition to lubricant formulations. Test results have shown to be effective in ranking the performance of material pairs and lubricants. This new method presents the opportunity for screener testing when developing new oil formulations as well as bearing materials and coatings.

5 - 5:30 pm
3647051: How Can We Evaluate the Frictional and Wear Performance of Shock Absorbers on the Lab-Scale: A New Tribological Approach
Emmanuel Georgiou, Dirk Drees, Lais Lopes, Michel De Bilde, Falex Tribology, Rotselaar, Belgium

Component testing is typically costly and time-consuming, and thus inappropriate for R&D activities. Researchers are inevitably forced to perform tribological analysis in simplified test rigs that do not always simulate the actual contact. For example, pin-on-disk tests under dry conditions are sometimes used to characterize shock absorbers. However, in the actual application the contact pressure is much lower (area contact), and the contact always operates under a thin layer of lubrication. It is essential to develop tribological methods that generate the same wear mechanisms as in the components. These methods should also provide additional information (e.g. friction evolution) that can assist in the further development and optimization. Having the above in mind a new test method was developed to directly test shock absorber components and to provide a meaningful relative ranking of both the wear resistance and frictional performance.

5:30 - 6 pm
3664941: Evaluation of cryogenic Pin-on-Disk Test to Improve Sliding Friction Interaction of Cryogenic Solid-Lubrication
Wonil Kwak, Yongbok LEE, Korea Institute of Science and Technology, Seoul, Republic of Korea

In the interaction of solid lubrication, the friction mechanism can determine the effect on the bearing performance of cryogenic fluids (liquid nitrogen) through tribometer experiments. In this study, friction mechanism analysis was performed considering the coupling of bearing friction characteristics and fluid dynamics by the dynamic interactions between the bearing components. In addition, in order to improve friction performance in a cryogenic environment, a pin-on-disk test was conducted according to various composite materials. The purpose of this study is to understand the correlation between parameters affecting the improvement of solid lubrication performance in cryogenic fluid environments and diagnostic parameters for predicting the lifetime. In particular, this paper proposes a dimensionless friction coefficient classification factor that can satisfy an appropriate wear rate and predict its lifetime for the operating stability of ball bearings.

2E — Southern Hemisphere V

Surface Engineering II

Session Chair: Auezhan Amanov, Sun Moon University, Asan, Republic of Korea
Session Vice Chair: Suvrat Bhargava, TE Connectivity, Middletown, PA

1:30 - 2 pm
3677795: Effect of Ultrasonic Needle Peening on Subsurface of Bronze casting alloy Caused by Fretting Wear
Seunghyon Song, Auezhan Amanov, Sun Moon University, Asan, Republic of Korea; Insik cho, Mboria, Asan, ChungNam, Republic of Korea

Bronze casting alloy is widely used for manufacturing engine bushing and bearing owing to the high corrosion, cavitation, and wear resistances. In this study, the samples made of NAB was subjected to ultrasonic peening technology with the aim of improving the fretting wear by eliminating casting defects such as voids, pores, etc. from the microstructure. The fretting wear behavior of the unpeened and peened bronze casting alloy samples fretted against SAE 52100 steel ball was evaluated using a high-frequency fretting machine. Cross-sectional microstructural evolution of the underneath fretting-induced wear and subsurface layer of the unpeened and peened samples were comprehensively discussed.

2 - 2:30 pm
3663198: Post-Thermal Spray Coating Surface Modification for Sliding Wear and Adhesion Strength
Auezhan Amanov, Sun Moon University, Asan, Republic of Korea; Stephen Berkebile, US DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

In this study, the effect of ultrasonic nanocrystal surface modification (UNSM) on wear and adhesion strength of two different Cr_2O_3 and Cr_3C_2 coatings was investigated. The objective of this study is to find an optimum coating for the application of a high-pressure common rail injection system, which operates under fuel-lubricated sliding conditions. The effect of UNSM treatment on the coefficient of friction (COF) and specific wear rate (SWR) was more pronounced to the Cr_3C_2 coating than Cr_2O_3 one against SAE 52100 steel, Si_3N_4 and Al_2O_3 in F24, dodecane and ethanol. The improvement in COF and SWR of the coatings was attributed to the reduction in surface roughness and formation of nanostructured layer having lower shear strength with good lubricating properties. The scratch-induced adhesion strength of the UNSM-treated coatings was found to be higher in comparison with the as-sprayed coatings due to the changes in microstructure and hardness.

2:30 - 3 pm
3669371: Development of Self-Lubricating Metal Alloys Using Laser Metal Deposition
Manel Rodriguez Ripoll, Hector Torres, AC2T research GmbH, Wiener Neustadt, Austria

This work presents the development of self-lubricating metallic alloys for laser deposition processes, as they offer a great flexibility and efficiency compared to traditional subtractive manufacturing processes. However, the extreme thermal conditions during deposition and the rapid cooling times pose great challenges in the alloy design. These challenges are illustrated using self-lubricating iron and nickel-base alloys incorporating lubricious soft metals and metal sulfides. The self-lubricating laser deposited alloys can control friction from room temperature to 600 °C in ambient air. In vacuum conditions, they can effectively reduce friction down to 0.25 without the aid of an additional lubricant against martensitic stainless steel at 300 °C. This overall tribological performance makes the presented self-lubricating alloys potential candidates for high temperature forming and space applications.

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

4 - 4:30 pm
3669286: A Study on the Influence of Spray Parameters on Adhesion of Cr3C2-NiCr Plasma Coating on Steel Substrate
Cuong Pham, Hanoi University of Industry, Hanoi, Viet Nam

This paper investigates the effect of spraying parameters including plasma current, powder feed rate and stand-off distance on the adhesion strength of Cr3C2-NiCr coated on 16Mn steel substrates by plasma spraying technique. The experiments were carried out according to the central composite design (CCD) method. Adhesion strength was measured in two directions perpendicular and parallel to the sample surface using a tensile compression tester. Quadratic polynomial regression models were developed to predict the adhesion strength of the coating in both directions. Results showed that the sprayed parameters significantly affected adhesion of the coating in both directions, in which the plasma current was the most influential parameter, followed by the stand-off and powder feed rate, respectively. In addition, optimization were performed to find out the spray parameters at which the adhesion of Cr3C2-NiCr coating to 16Mn steel reached highest value.

4:30 - 5 pm
3668698: Enhancing the Tribology of TWAS-Coated Cylinder Bores by Using the Triboconditioning(R) Process
Boris Zhmud, David Chobany, Applied Nano Surfaces Sweden AB, Uppsala, Sweden; Eduardo Tomanik, USP, Sao Paulo, Brazil

Despite the proliferation of e-mobility applications, the internal combustion engine (ICE) is going to be with us for decades to come in hybrid electric vehicles run on hydrogen and e-fuels. Hence, the development of low friction powertrains remains an important task. Advanced surface finishing and coating methods, such as thermally sprayed coatings and mechanochemical surface finishing, help improve fuel economy and reduce emissions.
TWAS (twin wire arc spraying) thermal spray coating technology is used by a number of car manufacturers for aluminum engine blocks. However, conventional carbon-steel TWAS coatings tend to have poor corrosion resistance. The use of stainless steel may address that problem but undermines the tribological properties increasing the risk of scuffing. The present study shows how the Triboconditioning(R) process implemented as the finish honing operation can be used to enhance the tribological properties of TWAS-coated cylinder bores.

5 - 5:30 pm
3669312: Tribological Test of Tungsten Disulfide Solid Lubrication Exposed to Simulated Space Environment
Ayaka Takahashi, AIST, Tsukuba, Ibaraki, Japan

Solid tungsten disulfide film can be use as a longer endurance lubrication than proven space lubricant at high vacuum with elevated temperature. Other space environmental properties also need to be evaluated in order to make tungsten disulfide to be option for space use. High-level radiation applied irradiation to the surface of tungsten disulfide coated on a SUS316L stainless steel substrate. It was confirmed that the coefficient of friction was low even after high-level radiation irradiated.

2F — Northern Hemisphere A1

Seals II: Mechanical and Elastomeric Seals

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3669268: Machine Vibration and Noise Effects on the Dynamics of Mechanical Face Seal
Itzhak Green, Georgia Institute of Technology College of Engineering, Atlanta, GA

Mechanical face seals are ubiquitous in many applications, such as centrifugal, submersible pumps, drill-bits (for oil and water), and turbopumps. Often vibration and noise are inevitable because of a constant changing environment which can be persistent and forceful. In critical applications if a seal fails it may have significant or even catastrophic consequences. While the exact root-causes and sources of machinery vibration is very difficult to ascertain, the current analysis uses some general common causes of noisy seal operation, and provides markers to be observed for diagnosis. Results show that under some design parameter, the seal response exhibits a rich spectral content that stems from various transient phenomena that include half-frequency whirl, synchronous steady-state response, and a rich spectral content.

2 - 2:30 pm
3645972: Numerical Transient Study of Two-Phase Flow in Inward Pumping Grooved Mechanical Seal
Abdel Salem Medjahed, Antoinette Blouin, PPrime Institute, Chasseneuil-du-Poitou, France; Noel Brunetiere, CNRS, Chasseneuil du Poitou, France; Balint PAP, Safran Transmission System, Colombes, France

This work studies the behavior of a mechanical seal in a two-phase environment (atmosphere on low pressure side and sealed fluid on the other side) in transient regime. One face of the studied seals contains inward pumping spiral grooves used to pump the external low pressure fluid and prevent leakage. The location of the boundary interface between the inner and outer fluids is then studied through numerical analysis. To determine the location of the boundary interface between the two fluids at each time step, a transport equation coupled with the transient Reynolds equation is solved using the finite element method. The model is then used to study the impact of the operating conditions including seal misalignment on the boundary location. In addition, several grooves geometries are used in the computation to find the best seal design.

2:30 - 3 pm
3647075: Measurement of Oil Film Thickness in Reciprocating Rubber Seals Using the Ultrasound
Rob Dwyer-Joyce, Xiangwei Li, Scott Beamish, Juanjuan Zhu, University of Sheffield, Sheffield, United Kingdom

Elastomeric seals function by allowing a finite leakage to lubricate the interface; but not so much to cause economic or environmental hazard. In this study, reflected ultrasound has been used to study the film formed by a rubber O-ring in reciprocating sliding. Measurements are challenging because the materials of seal and counterface are acoustically dissimilar so the measurement range when an oil film is interposed is small. Oil films were measured under varying speeds (2, 4, 6 and 8 Hz) and loads (10, 15 and 20 N). Central film thickness measurements were found to be in the range of 1.8 – 7 μm, which were comparable with predictions from the iso-viscous EHL models of Hamrock and Dowson and Nijenbanning et al. Measured contact size and oil film profiles were comparable with Hertzian simulations. Finally, the oil film along the reciprocating path was measured using an array of ultrasound sensors; this mapped the oil film formation covering the length of a reciprocating stroke.

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

4 - 4:30 pm
3645600: 3D Printed Surface Textured Seals with Superior Friction Properties
Markus Brase, Matthias Wangenheim, Leibniz University Hannover, Garbsen, Germany

The friction behaviour is an important property of dynamic seals. Surface texturing is an effective method to control the friction level without the need to change materials or the lubricant. However, the conventional production of surface textured seals is complex and expensive, in particular in the prototyping phase, when a variation of surface textures needs to be evaluated. Therefore, this study introduces novel 3D printed seals with surface textures. The textured seals are manufactured by using a Stereolithography printer. The textures are applied to the seal surfaces in the form of deterministic dimples. The geometry of the round dimples is defined by the diameter, distance, and depth. Based on the 3D printed seals, friction tests are performed to validate the positive effect of the 3D printed textures on friction.

4:30 - 5 pm
3647448: Bio-inspired pneumatic sealing disc of fluid-driven pipeline robot
Chunmei Yue, China University of Petroleum, Beijing, China

Pipeline inspection gauge (PIG) is a kind of pipeline robot used for pigging and internal inspection in the underwater oil and gas pipeline. However, the PIG is often stuck in the aging pipelines owing to the stacked objects and the limitation of its passive control. In this study, as for the elastomer material of the

PIG's sealing disc, a new type of sealing disc was designed combining with bio-inspired and soft robot technology to achieve its active control. First, the designed sealing disc was fabricated using 3D printing technology and multi-step molding, and the active control of it was realized by inflating the air chamber joints. Then the structure factors and material factors were studied and optimized using numerical simulation method to get the best performance structure. This study proposes an actively controlled bio-inspired pneumatic sealing disc of the PIG, provides a new idea to solve its blocking problems.

5 - 5:30 pm
3648363: High Temperature Sealing Advancements Utilizing Non-Contacting Gas Seal Technology
Robert McManus, John Crane Inc, Portsmouth, RI

Developments in gas seal technology now provide new technologies to solve challenging sealing applications in rotating machinery. Integrating a corrosion resistant, thermally compliant and pressure stable seal face assembly technology together with a completely non elastomeric design, high temperature gas seals can now be reliably applied in the most challenging applications. Dual gas seals can reliably seal hot and cold hydrocarbon process fluids found in process industries. High temperature gas seals eliminate the complexities and cost of the support system needed to reliably operate traditional single or dual wet contacting seal designs. Dual gas seals supported with an API plan 74 support system operate with zero emissions to atmosphere of the pumped fluid, have lower operating costs and a lower carbon footprint for the seal and support system.

2G — Northern Hemisphere A2

Grease II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3647445: Measuring Flim Thickness in Starved Grease Lubricated Bearings: An Improved Capacitance Method
Pramod Shetty, Robert Meijer, Jude Osara, University of Twente, Enschede, Netherlands; Rihard Pasaribu, Shell, Rotterdam, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Utrecht, Netherlands

Film thickness is a vital parameter that determines grease and bearing life. Measuring the film thickness in a real grease lubricated bearing is done by using the electrical capacitance method. In this paper, a new calibration method will be presented that significantly increases the accuracy of film thickness measurements when bearings are running under starved lubrication conditions. This method is subsequently used to study grease film thickness during the bleed phase as a function of speed for various temperatures. It was found that film thickness increases with speed showing similar behavior to base oil film thickness up to a certain speed. At higher speeds, it becomes almost independent of speed.

2 - 2:30 pm
3647029: How Does Temperature Affect Grease Adhesion and Tackiness?
Emmanuel Georgiou, Lais Lopes, Michel De Bilde, Falex Tribology, Dirk Drees, Rotselaar, Belgium; Erik Willett, Functional Products, Macedonia, OH; Michael Anderson, Falex Corporation, Sugar Grove, IL

Greases are extensively used in diverse applications, from machinery lubrication to demanding field like EV’s or wind power. Their performance in the field is directly linked to their ability to adhere onto a surface (adhesion), and to form threads (tackiness) when pulled apart, so that the transfer between moving contacts can be controlled. However, adhesion and tackiness cannot be characterized by a single value as they depend on the contact conditions, surface topography, environment etc. During the last 8 years,

Falex developed a method to quantify adhesion and tackiness of greases, based on indentation/retractions. It also allows to adjust the temperature, retraction speed and applied load. In this work, we attempt to gain a better understanding of the effect and synergism between contact conditions and temperature on the adhesion and tackiness of industrial greases. A temperature range between -20 and 100 °C was investigated.

2:30 - 3 pm
3646282: Calcium Sulfonate Greases – Improving Biodegradable Solution Thanks to 1-Step Process
Guillaume Notheaux, SEQENS, Porcheville, France

In 2021, during 75th STLE meeting, the advantages of the “1-step process” for OverBased Calcium Sulfonate (OBCaS) greases have been unveiled, especially the possibility to choose 100% of the carrier of the final grease. As a result, the first biodegradable OBCaS grease has been launched. For this second lap, keeping in mind the objective of biodegradability, and the new HPM specifications, research has been carried out to improve: - the corrosion preventive properties under dynamic wet conditions, thanks to different co-acid and additives- the behavior under cold environment, thanks to new carriers, - the oxidation stability (RSSOT), thanks to a DoE (Design of Experiment), to select the right blend of AO, and especially a surprising effect, on consistency according to the time of introduction during the process. Since the targeted greases are based on ester for biodegradability, oxidation will be the main key topic.

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

4 - 4:30 pm
3649678: Grease Material Properties from First Principles Thermodynamics
Jude Osara, University of Twente, Enschede, Netherlands; Sathwik Chatra K R, SKF, Houten, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Utrecht, Netherlands

Thermodynamics has long been used to derive characteristic material properties. In this study, fundamental thermodynamics is applied to lubricant grease. First-principle formulations of existing and new material properties are derived and experimentally determined. Measurements of the derived properties are performed in accordance with theoretical formulations, with procedures detailed for grease analysts. The potential impact of these material properties on grease performance and degradation is discussed. Properties values for fresh and aged greases are shown to conform with anticipated, observed, and established grease behaviors. The proposed properties can be used in grease performance and degradation analyses, as well as grease selection for bearing and other lubrication applications.

4:30 - 5 pm
3651539: Polyglycols as High Performing Base Oil Components in Modern Greases
Cristina Schitco, Clariant Corporation, Frankfurt, Germany; Stephanie Cole, Clariant, Mount Holly, NC

The industry growth and rise in automation trigger the need for improved quality greases with tailored properties to enhance equipment performance. Simultaneously, there is a significant demand for environmentally friendly greases to meet the worldwide sustainability efforts. The base oils are a significant component in greases and influence several essential properties of the final product. This paper discusses the relevant properties of polyglycols and how these synthetic base oils can meet the requirements of the grease formulators focusing on the following properties: low and high-temperature behavior, material and chemical compatibility, lubrication properties, heat transfer properties, and electrical properties, sustainability aspects. Several grease formulations are shown, and some of the properties mentioned above of polyglycols translate to the final grease properties. This paper describes polyglycols offerings in grease application for both performance and sustainability.

5 - 5:30 pm
3663806: On the Flow Dynamics of Polymer Grease
Josep Farré-Lladós, Jasmina Casals-Terre, UPC - Technical University of Catalonia, Terrassa, Spain; Lars Westerberg, Luleå University of Technology, Luleå, Sweden

In this paper polymer- and lithium based lubricating greases - both having the same rheology - are investigated using micro Particle Image Velocimetry. The main objective is to determine the reason for the differences in anti-wear and antifriction properties during running conditions as reported in the literature. To this end, low and high driving pressures have been considered in order to generate different ranges of shear rates in the flow. It was found that the observed flow behavior matches well with observations in previous research results, linking the thickener type and deformation characteristics to the flow dynamics and how that in turn affect the grease running properties. For polymer grease it is apparent that the change in flow dynamics is most apparent in regions of high- and low shear rates, which in turn links to the oil bleeding properties of the polymer grease.

5:30 - 6 pm
3688156: Fictitious Grease Lubrication Performance in a Four-Ball Tester
Sravan Josyula, Debdutt Patro, Deepak Halenahally Veeregowda, Ducom Instruments, Groningen, Netherlands

The extreme pressure (EP) behavior of grease is related to additives that can prevent seizure. However, in this study the EP behavior of greases was modified without any changes to its additive package. A Four-Ball Tester with position encoders and variable frequency drive system was used to control the speed ramp-up time. A tenth of a second delay in speed ramp up time had showed an increase in the weld load. Further increase in the speed ramp up time showed that the greases passed the maximum load possible in the Four-Ball Tester without seizure. The mechanism can be related to the delay in rise of local temperature, theoretically attributed to an increase in heat loss. Furthermore, the speed ramp up time increased the corrected load for all greases, resulting in lower friction. This study suggests that speed ramp up time is a critical factor that should be further investigated by ASTM and grease manufacturers, to prevent the use of grease with fictitious EP behavior.

6 - 6:30 pm - **Grease Business Meeting**

2H — Northern Hemisphere A3

Tribochemistry I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3644606: Aging Mechanisms of Molybdenum Disulfide: a Fundamental Surface Spectroscopic Study
Filippo Mangolini, Robert Chrostowski, The University of Texas at Austin, Austin, TX; John Curry, Michael Dugger, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) has been used as solid lubricant in aerospace applications because of its low friction response in inert environments. However, exposure to atmospheric conditions and periods of inactivity can cause MoS_2 to “age” into a high friction state. This poses a significant challenge in the reliable use of MoS_2. Despite the volume of the published literature, our understanding of the surface phenomena taking place during aging of MoS_2 is still elusive. Here, we performed XPS and ToF-SIMS analyses to identify the surface chemical changes occurring in MoS_2 upon aging in variable environments. This work was funded by the Laboratory Directed Research and Development program at Sandia

National Lab., a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the US Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

2 - 2:30 pm
3644588: Tailoring the Surface Reactivity and Tribological Performance of Phosphonium-Based Ionic Liquids by Varying the Anion Chemistry
Filippo Mangolini, Zixuan Li, Hugo Celio, Andrei Dolocan, Nicolás Molina, Jude Kershaw, Oscar Morales-Collazo, Joan Brennecke, The University of Texas at Austin, Austin, TX

Phosphonium phosphate ionic liquids (PP-ILs) are attractive lubricant additives owing to their miscibility in hydrocarbon fluids and excellent tribological performance. Most published studies evaluating the lubricating properties of PP-ILs were performed with high-purity ILs, whose high cost mainly derives from the time-consuming purification required to remove contaminants (e.g., residual halides from the synthesis). Here, we evaluate the dependence of the lubricating behavior of phosphonium-based ILs when used in steel/steel contacts on the relative concentration of phosphate and halide (i.e., bromide) anions. The results of tribological tests and XPS/ToF-SIMS analyses demonstrate that the friction and wear properties of phosphonium-based IL can be tuned by varying the amount of bromide in the IL, while maintaining high corrosion resistance in the presence of phosphate ions. This finding opens the path towards the cost-effective implementation of PP-ILs in tribological applications.

2:30 - 3 pm
3645158: Principle Frictional Properties in Boundary Lubrication by Ideal Nanoscale Gap Using MEMS
Wataru Yagi, Tomoko Hirayama, Kyoto University, Kyoto, Japan

Organic friction modifiers (OFMs) are considered that they have an effect on friction reduction by adsorbing and preventing contact between surfaces. The effects are investigated by many friction tests and the physical property of adsorption layer has begun to be observed by SFA, AFM and NR. However, it has not understood which layers of slip causes the low friction. It is because boundary and fluid lubrication are mixed in real sliding surface on micro scale. The result obtained by macro tribotest means just summation of the friction force produced by these conditions. Their lubrications are required to be separated to measure the friction realized by adsorption layer of OFMs. The ideal friction test requires nanometer-order gap and flat surface. In this study, a film-like specimen (~5 μm) was made by MEMS technology. We have developed a "microscopic surface contact tribotester" that realizes parallel of two surfaces in nano-order by applying a load with electrostatic force.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3644334: Understanding the Boundary Lubrication Tribochemistry of Tetrahedral Amorphous Carbon Coatings by Quantum Molecular Dynamics
Michael Moseler, Takuya Kuwahara, Gianpietro Moras, Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

Tetrahedral amorphous carbon (ta-C) exhibits high wear resistance and superlubricity under boundary lubrication with organic friction modifiers. Thus, ta-C is increasingly applied as a protective coating in machinery lubricated with oils containing various additives e.g. zinc dialkyldithiophosphate (ZDDP). Unfortunately, the tribochemistry of ta-C coatings interacting with friction modifiers and anti-wear additives is still poorly understood. This contribution reports quantum chemistry calculations that provide a mechanistic understanding of ta-C boundary lubricated by organic friction modifiers [1] as well as by ZDDP [2]. [1] "Mechano-chemical decomposition of organic friction modifiers with multiple reactive centres induces superlubricity of ta-C", T. Kuwahara et al., Nat. Comm. 10, 151 (2019). [2] "Interplay of mechanics and chemistry governs wear of diamond-like carbon coatings interacting with ZDDP-additive lubricants." V.R. Salinas Ruiz et al., Nat. Comm. 12, 4550 (2021)

4:30 - 5 pm
3645199: In Situ Tribochemical Formation of Superlubricious Interfaces in Vacuum and Boundary Lubrication
Takuya Kuwahara, Michael Moseler, Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany; Gianpietro Moras, Fraunhofer IWM, Freiburg, Germany

Superlubricity is a state where the friction between two sliding bodies is almost vanishing (in general, the friction coefficient $\mu < 0.01$). Achieving the superlubricity in industrial applications is crucial since it would significantly contribute to saving of energy and materials resources. In dry and boundary lubrication, the friction is dominated by chemical interactions between two surfaces, and large mechanical energies can induce structural transformations of the surfaces resulting in a drastic decrease of the friction coefficient. Our recent experimental/computational studies revealed that aromatic graphenoid layers form in situ via tribochemical reactions at various sliding interfaces in various environments. Here, we show examples of in situ tribochemical synthesis of superlubricious interfaces, which include ultrahigh vacuum friction of hydrogenated amorphous carbon, water lubrication of diamond, and boundary lubrication of silicon nitride with glycerol.

5 - 5:30 pm
3647723: Dynamic Tribo-Pair of PS400 and DLC for Planet Venus Application
Vasilis Tsigkis, Andreas Polycarpou, Texas A&M University, College Station, TX; Pixiang Lan, ATSP Innovations, Houston, TX

Bearing materials in future missions to Venus will encounter high temperatures (~462 °C) and extremely dense CO2 atmosphere. Herein, we report on the tribological behavior of PS400 coating (NiMoAl-based alloy) vs. DLC coating at 25, 300, and 500 °C under CO2 and air environments. We found that at 25 °C DLC provides excellent lubrication and extreme wear resistance. At 300 °C in CO2, oxygen-containing terminating groups passivated the dangling bonds of the graphitized DLC, and low friction was maintained. However, under air the friction increased significantly. At 500 °C, DLC was worn out and PS400 transfer oxides alleviated the wear in both environments. The unworn and worn surfaces were analyzed using different analytical techniques.

2I — Northern Hemisphere A4

Biotribology II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3651966: Effects of Plant-Based and Dairy Proteins on Oral Lubrication and Mouthfeel
Sorin Vladescu, Connor Myant, Tom Reddyhoff, Imperial College London, London, United Kingdom; Maria Gonzalez Agurto, Guy Carpenter, King's College London, London, United Kingdom; Michael Boehm, Stefan Baier, Motif FoodWorks, Boston, MA; Gleb Yakubov, University of Nottingham, Nottingham, United Kingdom

Meat-based diets represent one of the leading global contributors to greenhouse gas emissions and therefore climate change. Plant-based alternatives to meat, are increasingly perceived as the more sustainable solution. However, to be widely consumed as meat replacements, they must be sufficiently palatable for the broad population. Understanding astringency – i.e. food's property of causing oral mucosa cells to contract following ingestion, often ascribed to a reduction in oral lubrication – is the most promising way of making plant-based food tastier. This presentation will demonstrate how a custom-built, Laser Fluorescence microscope mounted inside a tribometer, was employed to detect both salivary proteins, as well as dairy and plant proteins, and understand their lubrication behaviour and key

underlying mechanisms. This multi-faceted study aims to ‘connects the dots’ between tribological measurements, physical and chemical phenomena and mouthfeel perception across plant-based foods.

2 - 2:30 pm
3651983: Measurement of Foot Plantar Skin Strain Using Digital Image Correlation Methods for Diabetic Foot Assessment.
Sarah Crossland, Heidi Siddle, Claire Brockett, Peter Culmer, University of Leeds, Leeds, West Yorkshire, United Kingdom; Alexander Jones, David Russell, Leeds Teaching Hospitals NHS Trust, Leeds, United Kingdom

Assessment of diabetic foot ulcer risk is a vital but challenging procedure. Tools to measure plantar pressure exist but these data have limited clinical utility. Plantar shear has promise to better predict ulcer risk, but lacks measurement tools and an evidence base. Two methods using Digital Image Correlation (DIC) were developed to assess plantar foot strains during shod and unshod gait. The unshod method uses a speckle pattern applied to the plantar surface of the foot with transference stamping and imaged through a custom glass walkway.. For the shod method, a plastically deformable insole with speckle patterned upper surface was developed through laboratory studies prior to a pilot study with three participants. In both methods, plantar strains were derived using DIC and segmented into anatomical regions for analysis. A pilot study with six participants was conducted, results show peak strains aligned with areas of high pressure and ulceration particular to each participant.

2:30 - 3 pm
3645981: The Effect of Hyaluronic Acid Concentration in Lubricant and Counter Material, on Friction Behaviour of a Hydrogel Composite
Rahul Ribeiro, Alliance University, Bengaluru, Karnataka, India

A hydrogel composite of polyhydroxyethyl methacrylate (pHEMA) and nanoclay was developed as a potential cartilage replacement material. The percentage of cross-linker was 10% by molecule of monomer. Nanoclay concentration was 1:1 by weight relative to the monomer. For the tribological studies, a lubricant made of simulated body fluid and varying concentrations (in the range found for healthy synovial fluid) of Hyaluronic Acid, was synthesized. The tests were conducted in pin-on-disk configuration. The pHEMA composite with clay was incorporated as the disk. Counter materials were pHEMA without clay and stainless steel 316L. Normal loads of 5N and 10N were chosen. With the stainless steel pin, the coefficient of friction was found to be around 0.34 and when the hydrogel was the pin material, the coefficient of friction was lower at around 0.24. This indicates the possibility of elasto-hydrodynamic lubrication taking place. There was no significant effect of changing the normal load.

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

4 - 4:30 pm - **Biotribology Business Meeting**

2J — Northern Hemisphere E1

Wear II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3669390: Understanding and Mitigation of Knife Mill Wear in Biomass Preprocessing
Jun Qu, Jim Keiser, Oak Ridge National Laboratory, Oak Ridge, TN; Jeffrey Lacey, Vicki Thompson, Idaho National Laboratory, Idaho Falls, ID; George Fenske, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL; Ed Wolfrum, National Renewable Energy Laboratory, Golden, CO; Peter Blau, Blau Tribology

Consulting, Enka, NC

Relying on shearing between rotary and stationary sharp blades, knife mills can efficiently cut biomass to a desired particle size with fewer fines compared with the more commonly used hammer mills. However, knife blades are susceptible to rapid edge blunting and recession when processing dirty feedstocks. In this study, we first determined the wear modes of a knife mill to be a combination of abrasive and erosive wear, and then selected wear-resistant candidate coatings and surface treatments accordingly. Bench-scale abrasion and erosion tests were used to screen the candidate materials and identified diamond-like-carbon (DLC) coating and iron boriding for actual knife blades. Knife mill testing currently is being conducted using an accelerated wear testing protocol with feedstock containing controlled add-on minerals. The goal is to demonstrate extended tool life as well as enhanced milling performance, e.g., particle size distribution and throughput, for improved economics.

2 - 2:30 pm
3648427: Elevated Temperature Helium Tribology of Inconel 617 Subjected to Laser Shock Peening and Thermal Engineering.
Vasilis Tsigkis, Saifur Rehman, Andreas Polycarpou, Texas A&M University, College Station, TX; Lloyd Hackel, Curtiss Wright Surface Technology, Livermore, CA; Keivan Davami, The University of Alabama, Tuscaloosa, AL; Ali Beheshti, George Mason University, Sterling, VA

Inconel 617 is among the best candidates for utilization in high temperature gas cooled reactor tribo-components. However, the combined effects of sliding contact, and very high temperature material degradation, deteriorates the alloy tribological performance, especially under a helium atmosphere. Laser peening can enhance the properties at the surface and subsurface. We present the tribological behavior of regular laser peened as well as thermally-engineered laser peened Inconel 617 under helium and air atmospheres at 800°C. Regardless of the peening process and post-process treatment types, it is observed that laser peening improves the tribological characteristics of Inconel 617. Interestingly, laser peening followed by helium thermal aging shows highly enhanced tribological behavior. This is attributed to the strengthening effect of the laser peening on the surface oxides providing an excellent and lasting protective and lubricating film under helium exposure.

2:30 - 3 pm
3647034: An Investigation into the Tribological Performance of Wear Resistant PVD Coatings Atop Various Tool Steels Used in Injection Moulding Applications
Roshan Lal, Michael Adams, Zhenyu Jason Zhang, University of Birmingham, Wolverhampton, United Kingdom

Wear is a recurring issue in injection moulding applications where abrasive formulations, high temperature and high pressures are employed. Multiple wear mechanisms can damage a single tooling part during production, so protective coatings are often applied by Physical Vapor Deposition (PVD). Wear resistance is shown as a function of both the coating and substrate properties. Lab-scale testing of TiAlN, AlCrN, diamond-like carbon (DLC) and CrN coatings on various tool steels helped identify substrate-coating systems for optimal performance. Two- and three-body wear mechanisms have been emulated by unique modifications to test equipment (tribometers and force measurement systems) to include particle entrainment at high temperature. Substrate-coating properties have been quantified using nanoindentation and nanoscratch, with different stages of progressing wear characterized using surface replication (Microset 202) and optical techniques (white light interferometry and alicona).

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

4 - 4:30 pm
3669385: New Anti-Wear Additives
Nathan Eckert, Nickie Norton, The Shepherd Chemical Company, Norwood, OH

The Shepherd Chemical Company is a family-owned, metal-based, specialty chemical manufacturing company. We have been growing our lubricant additive business significantly over the past several years

(from nearly zero in 2010 to greater than 3MM pounds in 2021). Most of this business has been cultivated through our custom co-development program, where we work with a single customer to develop a proprietary solution for their needs. As the lubricant additive market changes with the increase in hybrid and all-electric vehicles, we feel that our custom co-development program can help usher in the next generation of innovative solutions. In this presentation, we will share a bit about The Shepherd Chemical Company, how we work collaboratively with our partners to develop and deliver custom solutions, and, finally, share some recent anti-wear data on a series of novel, metal-based additives that we hope to introduce to your formulations in the near future.

4:30 - 5 pm
3646934: Is the Miller ASTM G75 Abrasivity Test Obsolete?
Dirk Drees, Emmanuel Georgiou, Lais Lopes, Michel De Bilde, Falex Tribology, Rotselaar, Belgium; Michael Anderson, Falex Corporation, Sugar Grove, IL

Many standard tests are done with procedures and equipment from decades ago. However, equipment has evolved and so have our insights. Thus, we need to look at these 'older' methods and consider how to update/modify them to obtain relevant and repeatable information for today's applications. ASTM G-75 Miller tests are used to rank the abrasivity of slurries or resistance of materials to slurry abrasion for over 50 years. The standard focusses on aqueous based slurries and standardized samples. This in relation to the simplicity of the method leads people to believe that the method has only a limited use or is becoming obsolete. However, wear problems due to slurry abrasivity phenomena continue to exist in various fields such as food, construction, mining, chemical processing etc. In this work, we present some examples on how a modified ASTM G75 method can be successfully used to investigate modern wear problems in industry.

2K — Northern Hemisphere E2

2D Materials + Superlubricity - Materials Tribology and Nanotribology II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:30 pm
3642860: Energy Dissipation Studies on a Local Scale
Ernst Meyer, University of Basel, Basel, Switzerland

We study the mechanisms of energy dissipation on a local scale. The probing tip of the atomic force microscope is used for high resolution to observe the molecular structure on the surface. In a second step, the probing tip is used as an active tool to pull the polymer across the surface or to detach it from the surface. A similar experimental setup can be used to study the motion of graphene nanoribbons on metallic surfaces. We do observe ultralow friction, also called superlubricity, which corresponds to ultralow frictional forces due to the incommensurability of the contacting surfaces. S. Kawai, A. Benassi, E. Gnecco, H. Söde, R. Pawlak, X. Feng, K. Müllen, D. Passerone, C. A. Pignedoli, P. Ruffieux, R. Fasel, E. Meyer, Superlubricity of graphene nanoribbons on gold surfaces, Science, 2016, 351, (6276), 957.

2:30 - 3 pm
3669471: Spectral and Frictional Analysis of Alkane Mixtures on Graphitic Surfaces
Behnoosh Sattari Baboukani, Thomas Bui, Medini Rajapakse, Luis Velarde, University at Buffalo, Buffalo, NY; Prathima Nalam, SUNY University at Buffalo, Buffalo, NY

Lubrication significantly affects the service life of metallic components. Graphite, due to its low interlayer shear strength is used as an additive in oil-based lubricants to enhance the load-bearing capacity of the contact. In this study, we employ atomic force microscopy (AFM) to measure nanoscale friction behavior

of highly oriented pyrolytic graphite (HOPG) in a lubricating oil containing linear (n-hexadecane), cyclic (cyclohexane) and the mixtures of a linear and cyclic hydrocarbons. Solvation forces and stick-slip patterns are measured to resolve the structure of the solvation layers at the vicinity of HOPG interface. Further, Sum Frequency Generation (SFG) spectroscopy was employed to measure interfacial interactions and orientations of hydrocarbon molecules with HOPG in presence of solvent mixture. The adsorption enthalpies and structural commensurateness of molecules with the underlying HOPG are considered to understand the impact on the measured friction forces.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3669467: Molecular Dynamics Investigation of Adhesion Between MoS2 Coated Scanning Probes
J. Schall, Sathwik Toom, North Carolina A&T, Greensboro, NC; Takaaki Sato, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Yeau-Ren Jeng, National Chung Cheng University, Chiayi, Taiwan

VDW materials such as MoS_2 have been proposed as release layers in the transfer process in flexible electronics devices. Studies of the adhesion mechanics of these materials are needed as processing and function of such devices hinge on the adhesive and mechanical properties. A collaboration with the AFRL Materials and Manufacturing Directorate and U. Pennsylvania has recently succeeded in producing MoS2-coated scanning probes; allowing adhesion between MoS_2 layers to be probed experimentally in an in situ transmission electron microscope based atomic force microscope. We will present results from molecular dynamics simulations of adhesion between two MoS_2 coated Si probes. Simulations were designed to match the TEM-based AFM experiments in terms of size, number of MoS_2 layers, orientation, and grain size. Results show that there are significant differences in adhesion as a function of MoS_2 grain size. Adhesion and variability in adhesion increases as the grain size is reduced.

4:30 - 5 pm
3647885: MD Simulation on Enhanced Wear Resistance of Nature Rubber Composites by Applications of Carbon Nanotube
Fei Teng, Jian Wu, Benlong Su, Youshan Wang, Harbin Institute of Technology, Weihai, Shandong, China

The carbon nanotube(CNT)can significantly improve the tribological properties of nature rubber(NR). So, alternative CNT/NR composites with different CNT content have been studied by MD simulation at atomic scale for better wear resistance. Results indicate that CNT/NR composite with high CNT content shows high hardness and less deformation in friction process. The worn atomic mass of 15wt.% CNT/NR composite reduced by 51.3% and 53.7% compared to 0wt.% and 5wt.% CNT/NR. The strong binding interaction prevented composite from large deformation and ensured less time for reaching stable dynamic friction state. In the application of aircraft tire, higher COF and better wear resistance are both needed. Therefore, the appropriate blending process to avoid CNT agglomeration and measures to increase the COF of product are needed when the high CNT content is selected for prescription with high wear resistance.

2L — Northern Hemisphere E3

Power Generation II

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

1:30 - 2 pm
3669338: Case Study on Autodegradation of Turbine Oil and Varnish Removal
Jorge Alarcon, Bureau Veritas, Stafford, TX

Although the process of generating varnishes in turbine oils has been determined with great precision, there are some factors that still need to be understood and analyzed. among them is the self-degradation of the oil itself due to the generation of aggressive chemical compounds that turn the oil into its own enemy. Is it possible to determine the level of self-degradation? On the other hand, among the possible corrective actions to eliminate the varnishes are oils or fluids of altra polarity that eliminate or dissolve the varnishes, allowing the oil to return to a less aggressive state for it and for the operation. Many of these products have been presented in the market showing great results, however in very few occasions cases have been presented from the neutral point of view of a laboratory for the evaluation of these products. This real case study shows both points of view, the self-degradation process, and the analysis of these chemicals

2 - 2:30 pm
3646994: Determination of Relative Concentrations of Phosphate Ester Isomers in Turbine Control Systems by Matrix Assisted Laser Desorption Ionization - High Resolution Mass Spectrometry (MALDI-HRMS).
John Duchowski, Johannes Staudt, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany; Gerard Palmer, HYDAC Technology LTD, Witney, Oxfordshire, United Kingdom

One of the approaching regulations dictated by the Registration, Evaluation, Authorization and Restriction of Chemical Substances (REACH) implementation is to replace trixylyl phosphate (TXP; CAS Reg. No.: 25155-23-1) presently employed in many turbine electrohydraulic control (EHC) systems by other phosphate esters deemed of lesser concern to the environment. These other fluids may include triphenyl phosphate (TPP) and/or tri-tertbutyl phosphate (TBP) of various isomers. The REACH regulations dictates that by 2022 TXP be replaced by TPP/TBP such that no more than 0.3 wt% of the former remains in the affected systems. In order to ensure smooth fluid replacement and confirm that that REACH guidelines were met required an adaptation of an analytical procedure based on MALDI-HRMS was required as it was conclusively shown that other MS based methods, such as LC-MS or standard GC-MS would not provide results of sufficient accuracy for positive determination.

2:30 - 3 pm
3669543: Filter Debris Analysis (FDA) of Solid Particles Trapped in Pencil Filter of Servo Control Valve in Steam Turbine Power Plant in Thailand
Surapol Raadnui, KMUTNB, Bang Sue, Bangkok, Thailand

Given the fine filtration used in steam turbine oil today to produce longer life cycles of servo control valve and hence the turbines, over half of the solid particles, which could provide useful insight into turbine control system condition, is caught in the pencil filter, and never end up in a turbine oil control sample. It is generally discarded with the pencil filter. Increasingly, fine filtration is making conventional monitoring techniques less effective at providing reliable indication of solid particles and turbine oil control component wear inside the system and contamination particles from outside. FDA captures this lost information and identifies the specific components that are wearing or contamination related failures, providing improved diagnostic and prognostic information about impending or catastrophic failures.

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

4 - 4:30 pm - **Power Generation Business Meeting**

Rolling Element Bearings II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3641055: Towards a Grain-Scale Modeling of Crack Initiation in Rolling Contact Fatigue
Lucas Fourel, Fabrice Ville, Xavier Kleber, Philippe Sainsot, INSA Lyon, Villeurbanne, France; Jean-Philippe Noyel, Etienne Bossy, ECAM Lyon, Lyon, France

Rolling contact fatigue is one of the major failure problems in rolling bearings. It is characterized by microspalling or spalling which are induced by surface or subsurface crack initiation and propagation. Prediction of crack initiation is rather difficult because mechanical phenomena operate at different scales. The accumulation of cyclic plastic energy is considered as a main factor at the meso-scale. A numerical model based on stored energy at Persistent Slip Bands (PSBs) inspired by Tanaka and Mura's dislocation pile-up approach is developed. Voronoi polycrystals and cubic elasticity FEM are used to evaluate the shear stress during a moving contact pressure cycle for different surface conditions. Crack initiation is located at the intersection between PSBs and high misorientation grain boundaries. Crack initiation depth distributions appear consistent with literature.

2 - 2:30 pm
3642431: Prediction of Surface Crack Propagation under Rolling Contact
Bjoern Kunzelmann, Amir Kadiric, Imperial College London, London, United Kingdom; Guillermo Morales-Espejel, SKF, Houten, Netherlands

This study investigates the propagation of surface initiated rolling contact fatigue cracks in rolling-sliding contacts of hard steels. This work combines experimental measurements of crack propagation with numerical simulations of stress fields experienced by such cracks under different contact conditions. A 3D FE model with a specific mesh considers the actual crack morphology observed experimentally to predict the associated stress intensity factors and thus explain the observed crack growth rates. The specific mesh implementation enables the model to resolve the evolution of displacements and stresses near the crack tip during contact over-rolling. The model simulates a contact passing over a crack and includes the effects of surface tractions as well as frictional contact between the crack faces and the effect of lubricant pressurization within the crack. The influence of a range of factors, including contact size, surface topography and fluid entry into the crack are considered.

2:30 - 3 pm
3668690: Fatigue Life Calculation of a Cylindrical Roller Bearing with Surface Damage
Armand Tamouafo Fome, Jan Hendrick Kehl, Norbert Bader, Gerhard Poll, Leibniz University Hannover, Hanover, Germany

Rolling element bearings are widely used in industrial applications. Bearing failure can lead to machine failure or costly repairs. Thus, estimation of bearing life still is a topic of research. Improper handling, impact loads, solid contaminants, or static overload may cause plastic deformation of the raceway. A bearing life model, based on the Ioannides and Harris model using the modified Dang Van criterion, was developed for cylindrical roller bearings to understand such defects. In endurance experiments, a surface defect was generated by impacting a roller and surface of the inner ring. This indentation process was simulated using FEM to obtain the dent geometry and the residual stresses in the deformed area. The different rolling contacts of the bearing including over rolling of dent were then simulated. The stress states obtained from these simulations were used to compute the bearing life using the above life model. The results correlate well with the results of endurance tests.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3648478: An Investigation of the Effects of Grain Refinement on Rolling Contact Fatigue
Steven Lorenz, Farshid Sadeghi, Purdue University, West Lafayette, IN

In this investigation a grain size dependent, continuum damage mechanics (CDM) framework was conjoined with finite element model to study the effect of grain refinement on rolling contact fatigue (RCF) of non-conformal contacts. The grain size dependent CDM framework enabled the simulation of material degradation as a function of cycle. To establish the CDM critical parameters, torsion stress-life data from open literature of three different grain sizes for the same material was used. In order to assess the effect of grain refinement on RCF, a series of unique Voronoi microstructures were constructed at eight mean grain diameters. FE simulations were devised at three contact pressures per grain size, and results displayed an exponential increase in life as grain size is refined. A predictive fatigue life equation was constructed using this investigation's simulations to evaluate the stochastic RCF performance of non-conformal contacts, given grain diameter and contact pressure.

4:30 - 5 pm
3667586: Fluid Structure Interaction Modeling of Surface Cracks in Elastohydrodynamically Lubricated Line Contact
Kushagra Singh, Farshid Sadeghi, Purdue University, West Lafayette, IN

This paper presents a fluid-structure interaction (FSI) based approach to model surface-initiated cracks in rolling-sliding line contacts operating under elastohydrodynamic lubrication. The lubricant flow behavior is determined by Navier-Stokes equations using a computational fluid dynamics solver. The structural response of the solid is governed by the stress-strain equations solved using the finite element method. The FSI model overcomes the limitations of the classical Reynolds based approach in modeling surface inclined crack geometries and produces fluid solution which is free from Reynolds assumptions. The effect of crack geometry on fluid pressure and structural response is studied by varying the crack length, crack width, crack inclination and crack tip radius. The results of this investigation identify the crack geometries that affect fatigue life of rolling elements in EHL contact and presents novel insights on lubrication of tribocomponents such as rolling element bearings.

5 - 5:30 pm
3647699: Fluid-Solid Interaction Modeling of Point EHL Contacts
Wyatt Peterson, Farshid Sadeghi, Purdue University, Lafayette, IN

Elastohydrodynamically lubricated (EHL) point contacts were investigated using a coupled fluid-solid interaction (FSI) model. A finite element model was used to compute elastic deformation of the solid bodies, while computational fluid dynamics (CFD) was used to model the fluid domain with the Navier-Stokes equations. The current model is not limited by Reynolds equation assumptions, allowing for the investigation of pressure, viscosity and temperature variation across point-contact EHL film thickness. Various slide-to-roll ratios were investigated considering a non-Newtonian fluid with thermal effects to characterize lubricant properties across the EHL film. Cavitation was also considered and cavitation bubble lengths were found to agree with results found in literature. The FSI model developed in this investigation provides new insights on a classical lubrication problem.

Electric Vehicles III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

electrical bearing damage.

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

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

10 - 10:30 am - Break

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

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

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

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

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

Today, all moving components on an automobile are investigated for friction and energy losses. Passenger cars and light trucks are major grease users, and a typical light vehicle may use up to 50 different greases to lubricate components. However, only a handful of these impact energy efficiency. This projected uptake in EV's, and hence electric motors, will increase grease volumes in a vehicle. A modern, high-end vehicle, could employ upwards of 40. Combined grease volumes could equate to approximately two kilograms per vehicle, and Lubrizol estimates 5,000 tons of grease could be required simply to lubricate electric motors in new vehicles each year[1] This presentation will highlight the challenges on future grease formulations – where they will (and won't) be required for EV's and how the industry is currently going about testing and qualifying greases for EV applications. 1 F+L Magazine, October 9, 2018

3B Southern Hemisphere II

Lubrication Fundamentals III - Stability

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

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

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

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

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

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

There are thousands of professional certifications for seemingly all disciplines. In the world of maintenance and reliability there are at least ten (10) for lubrication alone. With such an offering, it can be

confusing (and argumentative) as to which certification is best suited for a position. The intent of this session is to provide a structure to the offerings and align with job functions.

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

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

10 - 10:30 am - Break

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

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

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

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

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

Preventing deposit formation is a critical performance property for engine oils. In this study, we investigated the complex mechanisms of deposit control by bringing experimental colloids science and multiscale molecular modeling to present a unified approach. We started from first principles quantum

chemistry calculations of exact electronic structures and interactions between base oil-dispersant-detergent and insoluble particles that cause deposit formation. After quantum chemistry calculations, we carried out molecular dynamics simulations where we modeled up to 5 nm scale to understand solvation and mixing mechanisms. Finally, coarse-grained simulations were performed to observe system behavior under 50 nm, to explain experimental observations, and elucidate deposit control mechanisms of detergent and dispersant additives on a larger scale. We will discuss molecular level, mesoscale, and microscale mechanisms of controlling the rate and extent of aggregation and deposit formation.

3C Southern Hemisphere III

Commercial Marketing Forum III

Session Chair: TBD
Session Vice Chair: TBD

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

8:30 - 9 am - **Lubrication Specialties, Inc.**

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

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

9:30 - 10 am - **Munzing**

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

10:30 - 11 am - **Colonial Chemical Company**

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

11:30 am - 12 pm - **BASF Corporation**

3D Southern Hemisphere IV

Tribotesting III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

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

ASTM B611 has been the gold standard for 3-body abrasion testing of cemented carbides for decades. However, this test does not apply to metals and ceramics because of adhesive interactions with the steel wheel used in the test to force loose abrasive against the test specimen. This paper describes a two-body abrasion test that can be used to rank cemented carbides with other material systems (metals, ceramics,

coatings etc.). It is a modification of the ASTM G174 abrasive loop test using a more aggressive alumina belt as the abradant. The loose abrasive particles and steel contacting wheel in the ASTM B611 test are replaced by line contact of a test specimen with a fixed abrasive belt over a drive spindle. The test details and its development are described.

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

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

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

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

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

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

Lubricants are used on the rail/wheel interface to control friction, reduce wear and fatigue along with reducing noise. As a train proceeds around a curve its wheels (which are fixed) travel different distances and thus some sliding between the wheel and the rail is inevitable. This sliding can cause an unpleasant high pitched noise. The noise is generated by an unsteady dynamic where the sliding wheel alternates rapidly between two sliding speeds. This unsteady dynamic can be suppressed by lubricants added directly to the rail or wheel. To reduce noise the friction between the wheel and rail should increase as the percentage of slip (creep) increases. This friction characteristics can be evaluated using “creep curves” in controlled test machines. A test method has been developed which can generate creep curves under realistic conditions of speed and contact pressure. This method was found to differentiate 11 different railway products.

Surface Engineering III

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

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

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

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

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

9 - 9:30 am
3665854: Effect of Surface Texture Pattern on Friction Anisotropy Under Insufficient Lubrication
Atsuta Harada, Kaisei Sato, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Seiya Watanabe, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan
A belt-type continuously variable transmission (CVT) is a type of transmission that enables highly efficient driving for automobiles. Since the CVT transmits torque by frictional force, high friction is required in the circumferential direction of the pulley. However, lower is required in in the radial direction to reduce friction loss. Therefore, it is important to generate friction anisotropy that satisfies both friction properties. Surface texturing is one of the effective techniques to generate friction anisotropy. In this study, various patterns of surface textures were applied to the actual CVT pulley, and friction tests were conducted under insufficient lubrication. In this presentation, we will report the results of the friction test and explain the effect of surface texture patterns on the generation of friction anisotropy.

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

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

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

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

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

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

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

3F — Northern Hemisphere A1

Seals III: Hydraulic and Two-phase Seals

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3647512: Leakage and Rotordynamic Characteristics For Two Types of Novel Hole-Pattern Seals Operating in Supercritical CO_2 Turbomachinery
Zhigang Li, Zhi Fang, Jun Li, Xi'an Jiaotong University, Xi'an, ShaanXi, China

Two novel hole-pattern seals were invented and assessed for applications at the balance piston in a 14 MW supercritical CO2 turbine, focusing on the seal leakage and rotordynamic performance. To enhance the seal net damping capability at high inlet preswirl condition, a straight swirl brake also was designed and employed at seal entrance for each type seal. Numerical results of leakage flow rates, rotordynamic force coefficients, cavity dynamic pressure and swirl velocity developments were analyzed and compared for a conventional hole-pattern seal and two novel seal designs at high positive inlet preswirl (in the direction of shaft rotation). To take into account of real gas effect with high accuracy, a table look-up procedure based on the NIST database was implemented, using an in-house code, for the fluid properties of CO2 in both supercritical and subcritical conditions.

8:30 - 9 am
3668666: Analysis of Sealing Performance of Elasto-hydrodynamic Seal for sCO_2
Jing Tang, Hanping Xu, Ultool LLC, Duluth, GA; Sevki Cesmeci, Ikenna Ejiogu, Georgia Southern University, Statesboro, GA; Jordan (Shuangbiao) Liu, Northwestern University, Evanston, IL

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

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

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

9:30 - 10 am
3647339: A Grooved Rotor-Smooth Surface Stator Seal vs. a Smooth Surface Rotor-Grooved Stator Seal: Comparison of Measured Leakage and Effective Force Coefficients
Jing Yang, Luis San Andres, Dara Childs, Texas A&M University, College Station, TX

Submersible electric pumps handling particulates feature annular seals made by a grooved rotor and a smooth surface stator (GR-SS). A seal made of a smooth surface rotor and a grooved stator (SR-GS), on the other hand, offers better dynamic stability. The presentation details measured leakage and effective direct stiffness (K_{eff}) and damping (C_{eff}) coefficients for a GR-SS seal vs. a SR-GS seal. The seals'

dimensions and operating conditions are typical of inter-stage seals: clearance/diameter=0.002, pressure drop =0.2 to 0.8 MPa, and shaft speed =2 to 8 krpm. Supplied with an ISO-VG2 fluid and a null inlet pre-swirl, the GR-SS seal leaks 10% less than the SR-GS seal. K_{eff}'s for the two seals are comparable in magnitude and decrease quickly with shaft speed. The SR-GS seal offers twice C_{eff}'s than the GR-SS seal, and not decaying as shaft speed increases. The experimental results demonstrate the SR-GS seal is preferable for its larger damping albeit imposing a minor penalty in leakage.

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

10:30 - 11 am
3652885: Fretting Wear and Tightness Assessment of Natural Gas Flange Sealing
Zheng Zhang, Deguo Wang, Yanbao Guo, China University of Petroleum, Beijing, China

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

3G — Northern Hemisphere A2

Grease III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

Lubricants and greases in industrial equipment exist to provide lubricity to vital mechanical parts and to reduce heat and stress. To evaluate lubricant and grease thermal properties thermo-analytical techniques can be utilized. There exist several applications within the ASTM literature describing the use of Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) techniques that can be used for grease analysis. TGA techniques can be used to determine the compositional analysis of a grease including the inorganic content and is routinely used to evaluate evaporative and degradation

parameters. DSC techniques have been used to evaluate the thermal stability of lubricants. In this presentation the thermal stability of several grease formulations is investigated. The resulting products are then tested using spectroscopic techniques to evaluate the grease formulations.

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

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

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

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

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

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

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

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

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

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

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

3H — Northern Hemisphere A3

Tribochemistry II

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

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

Tribochemical reactions induced in boundary lubrication conditions at the interface of steel surfaces provide the opportunity to form carbon tribofilms in-situ. The effectiveness of the tribofilm in decreasing friction and wear is influenced by the composition of the surfaces in contact and the properties of the lubricant. The tribofilm formation was evaluated with reciprocating pin-on-disk tribotests, Raman spectroscopy of the tribofilm deposit, and confocal microscopy characterization of the wear scars. The mixed elastohydrodynamic lubrication film thickness was analyzed to determine the interfacial condition of the cases studied, and molecular dynamics simulations were conducted to understand the mechanism of film formation. The catalytic activity of alloying elements was evaluated experimentally by comparing 52100 steel with other steel compositions. We determined that certain alloying elements affect the tribological performance of steel when the testing conditions are maintained.

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

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

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

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

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

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

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

Biotribology III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3J — Northern Hemisphere E1

Wear III

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30

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

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

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

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

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

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

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

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

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

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

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

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

11:30 am - 12 pm
3652075: Stress Activates Wear at Multi-Asperity Interfaces
Cyrian Leriche, Bart Weber, Steve Franklin, ARCNL, DIemen, Noord-Holland, Netherlands

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

Contact Mechanics I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30 am

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

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

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

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

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

A thorough understanding of the mechanics of asperity contact is critical to developing theories and models for analyzing rough-surface interactions. It is widely accepted that asperity contact is not a single-scale issue; however, the problem is how the scale issue should be properly handled? Since the asperity of a surface is a microscopic feature of the macroscopic body, and therefore, both should be modeled together in mechanics. The current work considers a microscopic asperity on a half-space to obtain the combined responses of the asperity and the base in both elastic and plastic regimes. The contact behavior of this asperity is numerically simulated with the finite element method (FEM), and a rough-surface contact model based on the Boussinesq half-space solution. The results are compared and discrepancies are discussed. Three stages of asperity contact are revealed: the Hertzian, non-Hertzian, and deep-contact stage where the base body also takes a part in the contact.

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

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

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

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

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

3L — Northern Hemisphere E3

Gears I

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

8 - 8:30 am
3637554: Effects on the Wear and Micro-Pitting Behavior of Nitrided External and Internal Gears
Michael Geitner, Bernd Zornek, Thomas Tobie, Karsten Stahl, Gear Research Center (FZG), Technical University of Munich, Garching bei München, Germany; Stefanie Hoja, Leibniz Institute for Materials Engineering (IWT), Bremen, Germany

Nitriding is a common surface heat treatment process, which can significantly increase the load carrying capacity of gears, compared to e.g. through hardened gears. In current research, the wear and micro-pitting behavior of gears is analyzed within theoretical and experimental investigations. Different material

pairings and structures of the nitriding zone are considered. In this publication, an overview is given by a systematic comparison of different nitriding variants regarding the material pairing and structure of the nitrided layer with through and case hardened gears. Recommendations are developed to allow an optimization of the wear and micro-pitting behavior of nitrided external and internal gears. The results enable an implementation into the existing load capacity calculation methods and can build the base for standardized rating methods regarding wear and micro-pitting, e.g. within ISO 6336.

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

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

9 - 10 am - **Invited Talk**

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

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

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

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

The effect of lubricant viscosity on dynamics of a high-precision spur gear pair with near-zero backlash is investigated under deterministic and uncertain conditions via a tribo-dynamic model. This model, for the first time, considers the backlash reduction induced by the lubricant film between meshing teeth. In general, increasing viscosity can mitigate vibration in off-line-of-action (OLOA) direction and decrease dynamic transmission error (DTE) but can hardly mitigate vibration in line-of-action (LOA) direction. Moreover, increasing viscosity can suppress the uncertainty of OLOA vibration caused by the uncertain backlash, supporting stiffness and meshing stiffness but cannot suppress the uncertainty of DTE. Therefore, gear dynamic performance can be improved by increasing lubricant viscosity. However, to what extent the gear dynamic performance can be improved depends on the operating condition and

surface roughness.

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

3M Northern Hemisphere E4

Rolling Element Bearings III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

capacitance method and frictional forces are measured in both the rolling and transverse directions. The results are presented to investigate the effect of transverse vibrations on friction, film thickness and contact damage under EHL and mixed lubrication conditions.

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

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

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

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

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

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

To predict wear in rolling bearings, it must be differentiated from normal running-in. Since this is only possible if normal running-in is fully understood, the conditions leading to it and the processes in the early operating phase are investigated in detail. For this purpose, the focus is on the role of slip in surface topography changes, which is assessed by replicating the rolling-sliding contact of a bearing in a tribometer. AISI 52100 bearing steel samples are tested in three slip conditions under mixed lubrication regime with a PAO base oil. 3-D surface relocation is employed to measure the aerial roughness during set intervals to track the rate of change of roughness and asperity conformation. In addition to this, the surface and the sub-surface of the test samples are examined under a scanning electron microscope for signs of stress. Finally, conclusions on the effect of slip on surface modifications are drawn from a comparison between the running-in period of the three tests.

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

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

4A Southern Hemisphere I

Electric Vehicles IV

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

4 - 4:30 pm - **TBD**

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

This work presents a new model for prediction of EV transmission efficiency. The model can differentiate between different lubricants in terms of their impact on transmission efficiency by use of measured rheological data at appropriate conditions to predict gear teeth losses along the path of contact. Gear loss predictions are combined with existing numerical models for bearing and gear churning losses so that overall gearbox efficiency can be predicted. Temperature changes resulting from heat generation and gearbox cooling are accounted for by representing components as nodes within a thermal network. Temperature predictions show good agreement with measurements from road tests with a real EV. Further results are shown to assess transmission losses over a range of duty cycles including the standard WLTP cycle. The model provides a computationally efficient way to compare lubricant performance as well as aspects of the mechanical design of a transmission to improve energy efficiency.

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

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

4B Southern Hemisphere II

Lubrication Fundamentals IV - Antiwear & Friction Control

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

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

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

2:30 - 3 pm
3663146: Mechanism of Synergistic and Antagonistic Interaction between TiO2 and ZDDP Under Boundary Lubrication
Pranesh Aswath, Vinay Sharma, UTA-Materials Science and Engineering, Arlington, TX; Richard Timmons, The University of Texas at Arlington, Arlington, TX; Ali Erdemir, Texas A&M University, College Station, TX

Interaction of ZDDP with TiO2 and plasma functionalized TiO2 nanoparticles was studied, under boundary lubrication using a pin on reciprocating flat configuration. Friction coefficients, wear loss and electrical contact resistance were measured. Tribofilms generated were subjected to extensive surface analysis using X-ray photoelectron spectroscopy (XPS) and X-ray absorption near edge structure spectroscopy (XANES) to determine tribochemistry. Results from tribological tests, coupled with chemical characterization of the tribofilms, suggest that both ZDDP and TiO2 nanoparticles, by themselves, form effective protective films at the rubbing surfaces. However, when used as a mix in the oil, they surprisingly behave antagonistically in terms of providing anti-wear films, resulting in severely increased wear. In order to better understand the mechanism sequential tests with different combination of additives were used to determine the impact of tribochemistry on friction and wear behavior.

3 - 4 pm – Exhibitor Appreciation Break

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

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

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

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

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

Lowering engine oil viscosity has proven to be an efficient way of reducing CO2 emissions in the passenger car sector and has the potential to do the same in the heavy duty sector. In the US, an overwhelming majority of customers with heavy-duty diesel engines still use SAE 15W-40 engine oils, with a slow adoption of more fuel efficient viscosity grades like SAE 10W-30 or SAE 5W-30 oils. More benefit could be gained by going to even lower viscosities. To optimize engine protection with these lower viscosity levels, additive packages will require a significant redesign compared to those commercially available today. Shell Lubricants Technology is eager to help OEMs reach best fuel economy possible

while still offering the same engine protection, especially against wear. In this work, we identified some bench tests that demonstrate the performance of SAE 0W-12 HDDEO oils and investigated the friction and wear protection characteristics of prototype low viscosity oils.

4C Southern Hemisphere III

Commercial Marketing Forum IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm - **The Lubrizol Corporation**

2:30 - 3 pm - **Clariant Corporation**

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

4D Southern Hemisphere IV

Tribotesting IV

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

insights from this study can drive the research towards a more alternative forms of sustainable lubricants.

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

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

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

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

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

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

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

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

Nanotribology I

Session Chair: TBD
Session Vice Chair: TBD

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

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

2:30 - 3 pm
3669446: Adhesion, Friction, and Wear Mechanisms in Si Tip and Si Substrate Indentation and Sliding
Judith Harrison, US Naval Academy, Annapolis, MD; Zachary Milne, Sandia National Laboratory, Albuquerque, NM; Robert Carpick, University of Pennsylvania, Philadelphia, PA; J. Schall, NC AT&T, Greensboro, NC

Adhesion between single crystal Si tips and Si(111) substrates was examined using molecular dynamics (MD) to model experiments of nanoscale silicon tip-tip contacts using nanoindentation coupled with TEM. Experimentally, adhesion was observed to increase by an average of nearly 20x when sliding occurred, while low adhesion was recovered when contact was made without intentional sliding. MD simulations of contact with and without sliding were performed using Si tip-substrates couples that matched experimental conditions. Various H- and OH-terminations, tip-substrate alignments, and tip shapes/heights were examined via MD. Simulation results confirm the experimental hypothesis that repassivation of the surfaces reduces adhesion. Additionally, specific wear mechanisms were elucidated as a function of hydrogen termination, sliding direction, and tip specifications.

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

4 - 4:30 pm
3644465: In Situ Atomic Force Microscopy Evaluation of Pressure-Induced Changes in Structural Morphology of Phosphonium Phosphate Ionic Liquids
Filippo Mangolini, Zixuan Li, Oscar Morales-Collazo, Robert Chrostowski, Joan Brennecke, The University of Texas at Austin, Austin, TX

Phosphonium phosphate ionic liquids (PP-ILs) have attracted considerable attention in tribology owing to their high thermal stability, good miscibility in hydrocarbon fluids, and excellent lubrication performance. However, a fundamental understanding of their nanoscale lubrication mechanism is still lacking. Here, we use atomic force microscopy (AFM) to evaluate in situ the dependence of the structural morphology of

confined PP-ILs on applied pressure. The results indicate a pressure-induced structural transition of PP-IL molecules upon sliding at a normal applied pressure up to 5.5±0.3 GPa, which leads to the generation of a lubricious, solid-like interfacial layer. The growth rate of this layer strongly increases with applied normal pressure and temperature. Based on molecular dynamics (MD) simulations of pressure-induced structural transitions in PP-ILs, a simple phenomenological model will be proposed to account for the observed morphological and nanotribological changes.

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

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

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

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

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

4H — Northern Hemisphere A3

Tribochemistry III

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

Abstract is pending internal release process. Abstract will updated in 2-3 weeks when it is cleared for release.

3 - 4 pm – Exhibitor Appreciation Break

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

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

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

Small changes to the molecular structure of lubricant additives affect their adsorption and dissociation behaviour at the nanoscale, as well as their friction and wear performance at the macroscale. Here, we show using reactive nonequilibrium MD simulations that secondary trialkylphosphates dissociate much faster than primary trialkylphosphates between sliding iron surfaces. For both molecules, dissociative chemisorption proceeds through cleavage of the carbon−oxygen bond. The rate increases exponentially with temperature and stress, which is indicative of a stress-augmented thermally activated process. When we fit the rate−temperature−stress data with the Bell model, both molecules have similar activation volumes and energies. The difference in reactivities is mostly driven by a larger pre-exponential factor. These observations are consistent with recent macroscale tribometer experiments of the antiwear additive ZDDP.

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

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

4I — Northern Hemisphere A4

Biotribology IV

Session Chair: TBD
Session Vice Chair: TBD

Session Information TBD

4J — Northern Hemisphere E1

Wear IV

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

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

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

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

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

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

4K — Northern Hemisphere E2

Contact Mechanics II

Session Chair: TBD
Session Vice Chair: TBD

2:00 pm - 2:30 pm
3669314: Under the Surface: Observing Subsurface Response Using 2D DIC
Kyle Schulze, Auburn University, Auburn, AL; Alexander McGhee, University of Wisconsin, Madison, WI; Eric McGhee, University of Florida, Gainesville, FL

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

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

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

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

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

4L — Northern Hemisphere E3

Gears II

Session Chair: TBD
Session Vice Chair: TBD

Session Information TBD

Rolling Element Bearings IV

Session Chair: TBD
Session Vice Chair: TBD

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

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

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

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

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

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

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

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

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

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

4 – 6 pm Northern Hemisphere C

Roundtable Discussions

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

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.

Lubrication Fundamentals V - New Chemistries

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

8 - 8:30 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.

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
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 oC 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.

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 Laboratory, 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**

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, Honor Powrie, University of Southampton, Southampton, United Kingdom; Zudi Lu, Southampton Statistical Sciences Research Institute (S3RI), School of Mathematical Sciences, 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
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.

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 Machine 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 8:30 am

8 - 8:30 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.

8:30 - 9 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.

9 - 9:30 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.

9:30 - 10 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.

10 - 10:30 am - Break

10:30 - 11 am
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

8 - 8:30 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)

8:30 - 9 am
3641888: Role of Interfacial Interaction and Adsorbed Water on the Tribology of Ultrathin 2D Material/Steellinterfaces
Guorui Wang, Taib Arif, Rana Sodhi, Tobin Filleter, University of Toronto, Toronto, Ontario, Canada; Guillaume Colas, Univ. Bourgogne Franche-Comte FEMTO-ST Institute CNRS/UFC/ENSMM/UTBM, Besançon, France

Lubrication of steel using two-dimensional (2D)-materials has been a growing interest in recent years at the macro/microscale for a wide range of applications including lubricating 440 C-steel for satellite and automotive components. This work takes a new approach of comparing the tribological behavior of ultrathin-graphite and ultrathin-MoS2 at varying humidity against a custom-fabricated 440 C-steel counter-surface using friction force microscopy. The presence of oxides on the 440 C-steel counter-surface is found to form stronger chemical interactions with MoS2, leading to higher friction, interfacial-shear-strength and adhesion as compared to physically interacting steel/ultrathin-graphite interface. While water increases friction and adhesion for steel/ ultrathin-graphite interface, an opposite trend is observed for steel/MoS2 interface, where water act as a temporary protective film to suppress the chemical interaction.

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**

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 - **TBA**

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 (μ ~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 μ ~0.20 to μ ~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 – **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, Oak Ridge, 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.

5K — Northern Hemisphere E2

Metalworking Fluids I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30 am

8:30 - 9 am
3647495: Using ionic Liquids as Catalysts in the Process of Biodiesel Synthesis and its Application in the Preparation of Metalworking Fluids
Roshanak Adavodi, Petro Eksir Asia, Esfahan, Islamic Republic of Iran

Metalworking fluids are used in metal removal processes such as cutting and grinding and in metal forming processes such as drawing, rolling, and stamping. Also, Metalworking fluids are used as a coolant to reduce the heat generated by the process. Bio metalworking fluid (high degradability, optimal lubrication, high viscosity index, and oxidation stability could be mentioned as advantages of bio metalworking) is introduced as an alternative to petroleum products of metalworking. These fluids can be prepare from synthetic esters which include biodiesels and fatty esters. Fatty acid esters are prepared by the reaction of fatty acids with alcohol in the presence of an acidic catalyst. In this study, ionic liquids are used as solvents and catalysts in esterification processes and the obtained esters are used as a raw material in the bio metalworking fluids producing process and their tribological properties are evaluated.

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

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

path in developing robust tank-side additives with exceptional microbial control and enhanced fluid longevity while satisfying end-user demands like operational efficiency, global regulatory compliance, and minimizing waste to reduce the environmental impact.

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

Historically, condition monitoring for microbial contamination has focused on measuring bioburdens in bulk fluid samples. However, biofilm communities create several significant metalworking fluid (MWF) management challenges. First, they are non-uniform. Samples must be collected from diagnostic, rather than representative locations. Second, biofilms are resistant to microbicide treatments. Third, biofilms readily reinfect recirculating MWF once the microbicide concentration has decreased to less than its critical concentration. Although the use of bioresistant MWF has decreased the need for microbicide tankside additions to control planktonic populations, it has not necessarily reduced the risk of bioaerosol generation. This paper will address the importance of biofilm bioburden monitoring and control, and the implications of effective control on bioaerosol exposures.

10 - 10:30 am - Break

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

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

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

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

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, 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 Analysis
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, 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

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

1:30 - 2 pm
3664147: Analysis of Engine Oils Using Modulated Thermogravimetric Analysis (mTGA)
James Browne, Waters TA Instruments, New Castle, DE

Thermogravimetric analysis (TGA) is commonly used to assess the thermal stability of materials including lubricant oils by measuring mass loss as a function of temperature or time. Modulated thermogravimetric analysis (mTGA) superimposes a sinusoidal heating rate on the linear heating rate which allows calculation of the Arrhenius parameters activation energy (ΔE) and pre-exponential (Z) in a single mTGA experiment. From these parameters we estimate time to failure using established methods at an operating temperature range and extreme temperature.
In this work we compared thermogravimetric differences between five (5) commercially available engine oils. Additionally, we gained insight into potential differences in decomposition mechanisms by numerical treatment of rate of mass loss data relating activation energy as a function of conversion.

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; 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 koc 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 RONO2, 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 – 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 - 2:30 pm - **Afton Chemical Corp**

2 - 3 pm - **Afton Chemical Corp**

6D Southern Hemisphere IV

Condition Monitoring II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 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 quantities 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

2 - 2:30 pm
3666834: Development of Oil Monitoring System for Construction Machinery
Hidecki 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 aluminum 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 FluidCare Center GmbH, Sulzbach, Saar, Germany; Stephan Leyer, University of 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**

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.

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 Inorganic Fullerene-Like Tungsten 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 – **Environmentally Friendly Fluids Business Meeting**

6H — Northern Hemisphere A3

2D Materials + Superlubricity - Materials Tribology and Nanotribology IV

Session Chair: TBD
Session Vice Chair: TBD

Session Information TBD

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
3646264: Enhancement of Lubricant Replenishment for Starved Lubrication by Laser-Induced Wettability Gradient Surface
Patrick Pat-lam Wong, City University of Hong Kong, Kowloon, Hong Kong; Chenglong Liu, F Guo, X. Li, Qingdao University of Technology, Qingdao, China

Bearings running under starved conditions are commonplace at high speeds, regardless the initial quantity of lubricant supplied. In fact, regulating the lubricant supply to a bearing can alleviate excessive viscous friction. Thus, to make the best use of the available lubricant in a bearing is continuous of interest. This paper introduces a new wettability gradient surface pattern, which can be simply manufactured using femtosecond laser ablation. We have implemented the new pattern on either side of a bearing track to intensify the oil replenishment. The unidirectional flow of oil from the two sides towards the lubrication track is actuated by the wettability gradient. The effects of the new surface pattern on lubrication are evaluated with bearing tests at limited lubricant supply conditions. Results show that lubricant replenishment is able to be enhanced by the new pattern such that the bearing friction decreases and the lubricating film thickness increases.

2:30 - 3 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.

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

3:30 - 4 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.

4 - 4:30 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.

4:30 - 5 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.

5 - 5:30 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.

5:30 - 6 pm – **Fluid Film Bearings Business Meeting**

Materials Tribology II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3668172: Tribological Evaluation of Metal Particle Filled Fluoropolymer 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, CJ Ideas, 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 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, Chagrin Falls, 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, Chair of Machine Elements - Technical 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**

Metalworking Fluids II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3669331: Optical Characterization of Metal Working Fluids (MWF) for Robust Formulations, Improved Batch Lifespan and MWF Recycling
Ravinder Elupula, Charles Nider, Formulaction, Piscataway, NJ

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

2 - 2:30 pm
3663177: The Application of Electrochemical Analysis in Metalworking Fluids (MWFs) Evaluation
Tian Zhang, Feng Jiang, Huaqiao University, Xiamen, Fujian, China

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

2:30 - 3 pm
3667018: A Novel Approach to Understanding Metalworking Fluid Distribution on Machined Surfaces
Eleanor Riches, Gordon Jones, Caitlyn Da Costa, Jeff Goshawk, Michael Jones, Waters Corporation, Wilmslow, United Kingdom

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

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

3:30 - 4 pm
3669258: Lubrication Behavior of Metalworking Fluids on Tribometer and in Cutting Process
Haichao Liu, Florian Pape, Lars Ellersick, Berend Denkena, Gerhard Poll, University of Hannover, Garbsen, Germany

For a better understanding of the lubrication action of metalworking fluids (MWFs) in cutting, the lubrication behavior of water-miscible MWFs has been tested on a model tribometer and in an orthogonal cutting. The lubricating film forming ability and the frictional property of MWFs have been tested with the model ball-on-disc tribometer. The chip formation process and the cutting forces are compared under dry and wet cutting processes for different cutting speeds. The penetration ability of MWFs into the chip-tool contact zone and the lubrication effects of MWFs in cutting are discussed.

4 - 4:30 pm
3645789: Boundary Lubricant Additive Response Comparisons on Copper Alloys Using Twist Compression Tests (TCT)
Ted McClure, Sea-Land Chemical Co. / SLC Testing Services, Westlake, OH; Alexes Morgan, Sea-Land Chemical Co., Westlake, OH

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

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, 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**

Non-Ferrous Metals I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3663048: Hybrid Formulation Impact on Copper Corrosion
Arturo Carranza, David Edwards, Joseph Remias, Huifang Shao, Brian Sears, Jose Montenegro, Afton Chemical Corporation, Richmond, VA

Hybrid vehicles represent a significant part of the engine oil market and will continue to expand on the coming years. Corrosion, especially under cold climate conditions, has been identified as a key challenge for electrified vehicles due to intrinsic water retention. Understanding limitations and advantages of lubricant components under harsh operating conditions is crucial to developing robust formulations. The present work describes corrosion kinetics for key components in the automotive industry in the presence and absence of water. The approach allows for corrosion mechanism categorization and modeling under various performance conditions. In addition, the method has been used to evaluate several hybrid lubricants out in the market.

8:30 - 9 am
3663820: Stability of Emulsions for Aluminum Hot Rolling
Ariane Viat, Constellium Technology Center, Voreppe Cedex, France

Aluminum is usually hot rolled thanks to an oil-in-water emulsion with typical oil concentration being 1-10%. The emulsion stability relies on chemical (surfactant type and concentration) and mechanical (stirring) characteristics. In this paper, different stability measurement techniques have been compared: static destabilization kinetics by light retrodiffusion, oil droplet size by laser diffraction, coulter counter and emulsion stability index (ESI). Lab experiments on "clean" emulsions showed that the different techniques converged on global stability trends, with specific indications on emulsion health with each device. Lab results were then used to understand emulsions behaviors on production hot rolling mills. It has been possible to evaluate the impact of the different following phenomena occurring on an emulsion in use: strong shearing through spray nozzles, surfactant build-up, contribution of the metallic particles on emulsion stability.

9 - 9:30 am
3668803: Investigation of Lubricity Performance of Self Emulsifying Lubricant for Aluminum MWF by Using Molecular Modelling.
Ronald Hoogendoorn, Ramesh Navaratnam, Patech Fine Chemical, Dublin, OH

To reduce energy consumption the use of light weighted metals is growing. Hence machining of these materials and the required lubricity performance of MWF lubricants become more important. In this presentation, a molecular model focusing on Self-Emulsifying Lubricant (SEL) structure and its adsorption/spreading ability on the metal surface is developed, and validated the performance in aluminum application by tapping torque test and block on ring test. Based on this model, physical/chemical characteristics of the SEL in solution and interaction phenomena on metal surface have been studied. By comparing the test results of block copolymer PAG with various self-emulsifying esters (SEE), we show how SEL structure and related solvent properties can impact lubricity performance of aluminum metalworking fluids in different application tests.

9:30 - 10 am

3668860: An Experimental Method for Comparing Relative Tendencies of Cold Rolling Base Oils to Generate VOCs
James Anglin, Allegheny Petroleum Products Co., Monroeville, PA

The tendency for a cold rolling base oil to evaporate under process conditions can impact plant emissions as well as fire risk, worker hygiene, and process consistency. Certain properties of candidate cold rolling oils can provide a qualitative indication of whether their use may impact existing stack emissions levels. These properties can include vapor pressure, flash point, and distillation curve information. In this work, an improved measure of the expected tendency to evaporate was sought using actual evaporation rates under temperature conditions relevant to coolant systems. This information may be helpful in obtaining regulatory approval for proposed base oil changes.

10 - 10:30 am - Break

10:30 - 11 am
3669196: Nuclear Magnetic Resonance Spectroscopy as a Useful Tool for Estimating Formulation Variations of Emulsions Used for Aluminum Hot Rolling
Josef Leimhofer, AMAG rolling GmbH, Ranshofen, Austria

For aluminum hot rolling, emulsions with different compositions (e.g. fatty acid based and fatty acid free) are in use. With respect to composition, the emulsifier system is investigated, as well as the addition of fatty acid to an originally fatty acid free emulsion system, using, among others, nuclear magnetic resonance spectroscopy.
The work will show the results of corresponding measurements and how they are used as additional information to judge the applicability of the modified emulsion formulations.

11 - 11:30 am
3669414: In Aluminum Rolling What Are the Effects on Surface Quality
Andrea Knopp, Constellium, Ravenswood, WV

Last year we laid out what Tramp Oils are and how they can effect Rolling Fluids. This year I want to take a much deeper dive and focus on the effects that Tramp Oils have on surface quality. This will focus on both Hot Rolling and Cold Rolling systems.

11:30 am - 12 pm
3644040: Field Performance Simulation Pilot Mill Testing for Aluminum Hot Rolling Oils
Thomas Oleksiak, Ze Feng, Bas Smeulders, Michiel van Breemen, Pablo Bakermans, Wim Filemon, Zhiming Ma, Kai Ye, Peter DeBruyne, Wenbing Jiang, Quaker Houghton, Oswego, IL

Simulating the field performance of aluminum hot rolling oils is a challenging process. It is not only difficult to simulate a contact where metal reduction is taken in a rolling/sliding contact but also the high temperatures and roll coating formation are further complicating factors. Using a pilot rolling mill, a field simulation process has been developed and tested. Performance factors include mill parameters as well as an evaluation of anodized quality. Key oil and emulsion parameters will also be reported. This field simulation was used in the final development stages of a low acid product and will be used further in new aluminum hot rolling platform developments. Comparative data of the low acid product versus traditional soap-based chemistry will be presented.

Lubrication Fundamentals VII - Measurement

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3669357: The Measurement of Tribofilm Formation Using a Combination of Visible and Infrared Light
Matthew Smeeth, Clive Hamer, PCS Instruments, London, United Kingdom

In order to study the “tribofilm” formation, rigs such as the MTM (mini-traction machine) are run under mixed sliding speed conditions, allowing antiwear additive reactions to occur. Each optical interferometry image captured is analyzed to correlate the Red, Green and Blue colors to lubricant film thickness. A unique combination of RGB pixel values will correspond to a known film thickness. Beyond a certain film thickness value however, the colors will start to repeat which can give ambiguous results. In order to overcome this, measurements have been made which combine visible light with longer wavelength infrared light, effectively giving 4 unique “colours” and therefore a far wider measurement range. The paper will discuss the details of the new technique and show how it can be applied to measured relatively thick tribofilms films formed by a variety of additives which were previously indeterminate, thereby extending the range of this powerful technique.

8:30 - 9 am
3664409: In-Situ Chemical Characterization of Degraded Lubricant During Rubbing
Bastien Bolle, Janet Wong, Pavlos Aleiferis, Imperial College London, London, United Kingdom

A Lubricant is subjected to chemical changes during its operational life. These variations affect lubricant properties and may have serious consequences its effectiveness. To investigate the link between the chemical changes and performance of a lubricant, a MTM (Mini Traction Machine) test rig with in-situ Raman spectroscopy is used to examine tribofilm formation of various chemicals during rubbing. This allows chemistry and friction of the tribofilm to be correlated directly. Specifically, the effects of shear (by varying slide-roll ratio), temperature, gas environment on degradation of base fluids will be presented. Base fluids of interest include iso-octane, hexadecane and PAO.

9 - 9:30 am
3647567: Study of Tribological Contact Condition Using the Non-Linear Behaviour of Longitudinal Ultrasonic Waves
Saeid Taghizadeh, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

When the amplitude of incident ultrasonic waves is small (linear ultrasound), waves reflected from a contact contain information about the contact state. However, it is not possible with a single measurement to distinguish between reflection from an oil film and a solid contact -i.e., whether it is mixed or hydrodynamic lubrication. This limitation can be improved using a high-power ultrasonic wave (non-linear ultrasound). The reflected wave from the contact is distorted, and higher order frequencies are generated in the wave. It this study, a new reflection coefficient (second order reflection coefficient) using non-linear ultrasound, is presented. This has a different response to a dry contact and a lubricated film. By combining both linear reflection coefficient and second order reflection coefficient they can be to independently give the lubricant thickness and tribological contact conditions.

9:30 - 10 am
3669413: The Effect of Surface Structure on Friction and Film Thickness in Running-In Phase
Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czechia

Film thickness thinning and decrease of lubricant viscosities is related with considerable decrease of surface roughness to maintain full film separation. The optimal surface roughness is affected by wear

processes that take place during running-in phase. In this phase several non trivial processes are combined, i.e. surface roughness influences elastohyrodynamic lubrication, surface features are deformed elastically or plastically, and surface structure is modified by wear. This study combines in-site and ex-site measurements of film thickness, friction, and surface topography for several various structures. Results show how different parameters of surface structures influence running-in process and stable friction. The effect of real roughness on film thickness is presented.

10 - 10:30 am - Break

10:30 - 11 am
3688903: Traction, Stribeck and Scuffing Characteristics of Lubricants in Rolling-sliding Contacts Using Twin Disc
Debdutt Patro, Sravan Josyula, Harish Prasanna, Deepak Halenahally Veeregowda, Ducom Instruments, Bangalore, India

Rolling sliding contacts are subjected to high contact pressures (1.5 to 4 GPa) and slip ratios (0 to 100%). Traction, Stribeck and scuffing characteristics of lubricants affect the efficiency and durability of the machine elements. In this work, Twin Disc Roller on Roller was used to measure the traction and scuffing performance of a commercial 20W-50 oil. After the traction tests, a peak in the coefficient of friction was observed with 40% slip with an increase in lubricant temperature. In the Stribeck tests, a transition from EHD to boundary lubrication was observed. Scuffing tests were run in co-rotation and contra-rotation. The load was increased until sharp increases in friction or vibration occurred. Post-test microscopy indicated severe material transfer and surface damage.
Such test methods can effectively and quickly screen different base oil and additive chemistries in a repeatable manner and enable development of lubricants for electric vehicles and high speed railways.

11 - 11:30 am
3646586: Novel Test Methods for Electric Transmission Fluid Development
Yungwan Kwak, Afton Chemical, Richmond, VA

Vehicle electrification is a key technology to improve vehicle fuel efficiency, reduce greenhouse gas emission, and create a healthier environment. Drivetrain lubricants in this application are different than those of conventional transmissions. Thus, an urgency to develop various new test methods exists, so that robust fluid performance under real-world operating conditions can be assured. This presentation will discuss various new tests developed for electric transmission fluid (ETF) development. Discussion topics will include 1) understanding a fluids' cooling performance, and electric motor/power electronics; 2) copper corrosion under various operating conditions, including non-electrified and electrified conditions; 3) circuit board and low voltage connector tests; 4) magnet wire compatibility, with a focus on both breakdown voltage and partial discharge; 5) plastic insulation material compatibility; and 6) electrical property of ETF under application conditions.

11:30 am - 12 pm
3665915: Structural Analysis of PFPE and MAC Space Lubricants
Gordon Jones, David Douce, Waters Corporation, Wilmslow, Cheshire, United Kingdom; Michael Buttery, Rachel Bingley, European Space Tribology Laboratory, Warrington, United Kingdom

Quadrupole Mass spectrometry combined with Atmospheric Solids Analysis Probe (ASAP-MS) is demonstrated as a technique for the structural characterization of two space lubricants, a perfluoropolyether (PFPE) and a multiply alkylated cyclopentane (MAC). Full scan negative ion mass spectra of the PFPE samples were dominated by sequences of oligomeric alkoxy fragment ions, each retaining one terminal end group of the polymeric chain. The fragmentation patterns were characterized by cleavage at the C-O bonds. Thermally aged PFPE lubricants showed similar characteristics to fresh oil but with more fragmentation. Analysis of the MAC samples, highlighted, a major peak at m/z 911.7amu in positive and m/z 942.3amu in negative ion modes, likely relating to the tris (2-octyldodecyl)-cyclopentane. Fragmentation was evident in both spectra aligning with CH3, CH2 and CH homologous series. Thermally aged MAC lubricant showed similar characteristics to the fresh oil, again with more fragmentation.

Condition Monitoring III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3669144: Condition Monitoring Method for Oxidation of Biodegradable Hydraulic Oils
Tomomi Honda, University of Fukui, Fukui, Japan

Recently, it is required to use biodegradable oil from the viewpoint of global environmental problems. On construction machines, online sensing systems have been developed, and some construction machines are beginning to use fluid property sensors. However, there are few reports on the degradation diagnosis of biodegradable hydraulic fluid using fluid property sensors. In this study, we aimed to improve the diagnostic accuracy by investigating their relationships with the parameters of the color analysis sensor and the fluid property sensor. We made oxidized biodegradable oils using the RPVOT without water and catalyst and measured color parameters, physical properties, and TAN using these sensors. As a result, it was suggested that using a combination of color analysis and fluid property sensor, we can detect the early stage of oxidation and indirectly know the value of TAN from the dielectric constant.

8:30 - 9 am
3669267: Ageing and Reconditioning of Gearbox Oils: The Tribological Perspective
Arnaud Ruellan, Aldara Naveira-Suarez, SKF Group, Gothenburg, Sweden

Imagine the benefits of being able to continuously or regularly recondition oils restoring the tribological performance levels required for a given application. A new reconditioning technology combining chemical and advanced filtering techniques has been developed to remove contaminants including submicron particles from oils, hence removing catalysts for oil degradation, and thereby extending the oil life. In this study, the tribological performance of the reconditioned industrial gearboxes have been compared to that of the fresh and used oil collected from the field by using specific tribological screening methods in combination with standard chemical analyses. While the main objective is to make sure that key lubricating properties are not altered during the reconditioning process, results also underline the importance of understanding the negative and/or positive effects of oil ageing and of defining the concept of oil life depending on the application.

9 - 9:30 am
3669316: By Lubes
Antonio Lopes, Axel Royal LLC, Panama City, Panamá, Pana, Panama

A perfect relationship between lubricants, surgically considering the secondary effects of friction, wear, and temperature. It is no longer acceptable to go beyond the industry's requirements, of the OEM of equipment, without considering the responsibility of CAPEX, which is in the hands of maintenance managers.
There is no longer saying that people without specific abilities will become lubricators as in the past. Instead, maintenance must now focus on standards under responsible, trained, and skilled technical leadership in managing resources. How much does an hour of the machine down? For unexpected maintenance? Why not invest in predictive maintenance? I will inform you how to protect your equipment in simple steps, find a better cost-benefit ratio, and create an effective cost reduction, which means COSTDOWN. Ask me how?
9:30 - 10 am
3669322: A Novel Technique Combining Automated Liquid Particle Counting and Elemental

Analysis by ICP-OES
Keith Schomburg, PerkinElmer, Magnolia, TX

Particle counting is used by in-service lubricant analysis laboratories as a standard test to determine contamination levels of in-service lubricants. Valuable information regarding the health of the equipment can be gained by knowing the size distribution of particles within the fluid. This information is often related to potential wear and life expectations of the equipment. Recently, a new instrumental technique has been developed which integrates particle counting with wear metals testing by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). For this new technique, a small volume of lubricant is diluted with solvent for normal wear metals analysis by ICP-OES. As the diluted sample is transferred to the ICP it is tested by an optical particle counting device in-line to the sample introduction system. This new integrated technique can be performed in 45 seconds per sample and provides both particle size distribution data and wear metals analyses into one analysis.

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

10:30 - 11 am
3670334: Improved Oil Condition Monitoring of Industrial Lubricating Oils
Ruediger Krethe, OilDoc GmbH, Brannenburg, Germany

Oil oxidation is the most important process in oil aging for almost all industrial lubricants. New application areas and requirements for much longer oil drain intervals lead to a strong increase in the use of fully saturated, synthetic oils. Typical test patterns like viscosity, acid content and IR oxidation are not sufficient for a reliable oil condition monitoring of synthetic oils particularly in large oil reservoirs. Therefore, the monitoring of additive depletion and of the formation of oxidation-related by-products becomes more important. The paper demonstrates the principle and application of new methods in oil condition monitoring. 1. New lab methods of Oil Condition Monitoring, 1.1 Oxidation Index, .2 Additive depletion, 1.3 Deposit potential testing 4 Examples A number of examples form different application areas demonstrate the value of the new test methods and how to interpret the test results in the context of the conventional tests.

11 - 11:30 am
3678842: A Novel Homogenizing ICP Sample Introduction Approach
Steven Twining, Elemental Scientific, Inc., Navasota, TX

Running oil samples for elemental content by Inductively Coupled Plasma Optical Emission Spectroscopy or, ICP-OES is often challenging as samples struggle to remain well mixed. Even recent use of mechanical stir mechanisms often fail to keep samples homogenized due to a time lag between the stir process and analysis. This talk covers technology that enables laboratories to analyze samples of varying viscosities reliably using a new homogenization process that occurs immediately before each sample analysis. The result is an elemental analysis that’s closer to one that is representative of the actual lubricant as it flows through the machine compartment it was designed to lubricate. This enables laboratories to provide an accurate elemental picture of the wear, additive, and potential ingress elemental content.

11:30 am - 12 pm
3671792: Determination of Nitrite Levels in Engine Coolant by UV/Vis Spectroscopy
Nicholas Lancaster, PerkinElmer, High Wycombe, Buckinghamshire, United Kingdom

Literature reports that the second major cause of engine and equipment failure behind lubricant failure, is that of the coolant. Formulations of engine coolant (also known as antifreeze) consist of glycol, water, and an additive package. These formulations of coolant can differ by their additive chemistry, but the function of such chemicals is common –to deter the deterioration of the surface of wet cylinder lines. Nitrite (NO_2^-) is a common additive to coolant formulations used to preventing pitting by creating an oxide patina on the liner exterior. The nitrite is consumed as it is in use however and as such requires frequent testing by either paper test strip or laboratory analysis. The paper test strip is a manual analysis and can prove

unreliable. Using EPA method 354.1 as a template we can develop a method to accurately determine nitrite levels in glycol based aqueous engine coolant using UV/Vis Spectroscopy alongside an autosampler for rapid sample preparation and analysis.

7E Southern Hemisphere V

Nanotribology IV

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3649988: Evaluating Fuel Lubricant Additives – Relating the Nano to the Macro Scales
David Burgess, Zhenyu Jason Zhang, Peter Fryer, University of Birmingham, Birmingham, United Kingdom; Jacqueline Reid, Ian McRobbie, Innospec, Ellesmere Port, United Kingdom

Organic friction modifiers (OFMs) as fuel lubricant additives have been researched in great detail since their discovery in the early 1920's. Industrially fuel lubricity is evaluated using rapid bench-top testing most notably the high frequency reciprocating rig (HFRR) being an ISO standard method. Some research questions the ability of these methods to evaluate, distinguish and better understand OFMs in fuel. We use a wide variety of nanotribological techniques (AFM, QCM and Langmuir trough) to develop molecular understanding of the factors affecting the OFM performance and then relating to them to more rapid macroscale testing to allow new ways of viewing the way we analyze and evaluate how OFMs work. We see there two main factors for OFM functionality: The equilibrium performance and the kinetics factors of the binding adsorption processes. By understanding ways of improving both of these factors, OFMs can be tailored to the needs of the operational environment.

8:30 - 9 am
3645202: Nanoscale Frictional Behavior on Electrochemically Corroded Hard Carbon-Based Film: Roles of Surface Topography and Vapor Environment
Chen Xiao, Fiona Elam, Feng-Chun Hsia, Bart Weber, Steve Franklin, Advanced Research Center for Nanolithography, Amsterdam, Netherlands

Hard carbon-based film has attracted extensive attention as a protective coating for tribological applications including the employment in humid and charged environments because of its superior wear resistance and chemical inertness. Here, the electrochemical properties, surface chemistry, and frictional responses (in dry air, humid air, and isopropanol vapor (IPA) environments) of two carbon-based films with different surface roughness were investigated. XPS and Raman results show evidence for surface oxidation during the electrochemical corrosion, which results in no changes to the nanoscale topography but improves surface wettability. The friction force increases upon corrosion in water vapor conditions due to the intensifying capillary condensation of the relatively more hydrophilic surface, but decreases in IPA condition due to the boundary lubrication. In addition, rougher surface results in a lower friction force in water vapor conditions, but higher friction in IPA condition.

9 - 9:30 am
3646121: In Situ Observation of ZDDP Tribofilm Growth by Changing Surface Morphology Using Atomic Force Microscopy
Kaisei Sato, Graduate School of Tokyo University of Science, Tokyo, Japan; Seiya Watanabe, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

ZDDP is known to form reaction film between sliding surfaces and protect adhesion wear. However, there are few reports about in situ observation of tribofilm formation due to difficulty in investigating the formation process in nano-scale. Recently, Gosvami et al. observed the growth process of the ZDDP

tribofilm using atomic force microscopy (AFM). In addition, they confirmed that the ZDDP formation started at scratch marks. From these backgrounds, we considered that the growing amount of tribofilm could be controlled by changing the surface morphology. In this experiment, we confirmed that a rough surface promoted the growth of tribofilm compared to a smooth surface. In addition, the formation process showed that the tribofilm grew from each asperity of tribofilm-selves and the rough surface formed more shape tribofilm. Based on the above, we consider that the promotion of tribofilm growth is due to increased contact pressure by decreasing the radius of single asperities.

9:30 - 10 am
3646517: Sintered Tribofilm Growth as a Function of Steel Substrate Microstructure
Steven Thrush, US Army DEVCOM GVSC, Warren, MI

Recent experiments confirmed that zirconia nanoparticles dispersed in oil have the ability to generate robust tribofilms in steel/oil boundary lubrication tests through nanoparticle surface capture followed by particle accumulation and tribological sintering. However, the ability of the nanoparticle to generate a tribofilm has a strong dependence on its material properties relative to the counterfaces of the tribocontact. Heat treatment of steel counterfaces allowed for control of hardness while their elastic properties remained relatively constant. More uniform tribofilm growth was found on harder steel counterfaces. In contrast, softer surfaces grew patch-like tribofilms correlative to harder steel grains. Thus, the tribofilm growth was steel microstructure dependent, isolated to the grains with sufficient hardness to permit localized tribosintering. Tribofilm growth and morphology were characterized as a function of steel microstructure.

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

10:30 - 11 am
3678885: A Study on the Formation and Characterization of Tribofilms Derived from Inorganic Nanoparticles in Boundary Lubricated Sliding Contact
Kora Farokhzadeh, Steve Papanicolaou, Bruker Nano Surfaces, San Jose, CA; Ian Armstrong, Bruker, Santa Barbara, CA; Steve Shaffer, Shaffer Tribology Consulting, San Jose, CA

Inorganic nanoparticles are introduced as lubricant additives to maintain low friction in boundary lubricated sliding contact due to their ability to enhance load bearing capacity and thermal stability. To implement model lubricants on large scale and optimize performance it is essential to understand the mechanisms of lubrication and tribofilm formation in mixed or boundary lubrication regimes. In this study, MoS_2 and CeO_2 nanoparticles were suspended in base (PAO) and formulated (10W-30) oils and tested under pin-on-flat reciprocating conditions in self-mated bearing steel surfaces. The incidence and thickness of tribofilms generated during experiments were characterized using AFM and white light interferometry. The findings were used to understand how the intrinsic properties of the nanoparticles affect tribofilm formation, friction behavior and interfacial phenomena under extreme pressure conditions.

11 - 11:30 am
3653280: Tribology of Plasma Functionalized $CaCO_3$ Nanoparticles in the Presence of Thiophosphate Antiwear Additives.
Pranesh Aswath, Kimaya Vyavhare, UTA-Materials Science and Engineering, Arlington, TX; Richard Timmons, The University of Texas at Arlington, Arlington, TX; Ali Erdemir, Texas A&M University, College Station, TX

The surface modified $CaCO_3$ nanoparticles were synthesized through plasma enhanced chemical vapor deposition (PECVD). Oil formulations were prepared with functionalized $CaCO_3$ nanoparticles in combination with ashless dialkyl dithiophosphate (DDP) and zinc dialkyl dithiophosphate (ZDDP). Tribological test results indicate synergistic interaction of functionalized $CaCO_3$ nanoparticles with ZDDP and DDP providing enhanced friction and wear performance under boundary lubrication. Improved wear protection by functionalized $CaCO_3$BM nanoparticles under boundary lubrication was attributed to the formation of Calcium and Boron-rich 50-80 nm thick tribofilms on the worn surface. XANES results indicate that the functionalized $CaCO_3$ nanoparticles interact with ZDDP and DDP and form tribofilms

either by tribochemical reactions or metal cation supply. These results indicate plasma functionalized $CaCO_3$ nano-additives can reduce concentration of harmful P-based additives in the automotive lubricants.

11:30 am - 12 pm
3647872: Presentation TBD
Pranjal Nautiyal, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Abstract Coming Soon

7G — Northern Hemisphere A2

Environmentally Friendly Fluids III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3658516: Blending with Sustainable Base Oils and Other Oils to Achieve Biodegradable Finished Lubricants – A Little Bit Goes a Long Way!
Michael Woodfall, Biosynthetic Technologies, Indianapolis, IN

Biodegradability of finished lubricants is attainable for all! Even a small percentage of biobased, sustainable base oils can transform your formulation from inherently biodegradable to readily biodegradable. This 30 minute session will be a MUST for anybody looking to develop environmentally acceptable lubricants through blending with sustainable biobased products. The speaker will provide examples of finished formulations covering: grease, hydraulic fluid and gear oils.

8:30 - 9 am
3664256: Science & Technology of Next-Generation Fuels & Lubricant Additives
Prem Pal, REDA Chemicals, Edmonton, Alberta, Canada

Fuels and lubricants are an essential part of our life. With time, our understanding of producing more efficient fuels and lubricants for complex and advanced machines has constantly been improving. In order to achieve increased performance, efficiency while still meeting the environmental regulations several types of chemical additives are mixed into base fuels and lubricants. Additives can make up from 0.1 to 30 volume percent of the finished product, depending upon the target application of the lubricant product. Additives are expensive chemicals, and creating the proper mix or formulation of additives is a complicated science. This presentation will walk us thru the basic chemistry and engineering of some of the additives, especially the next-generation environment-friendly ones, and how they are revolutionizing the fuels and lubricants industry.

9 - 9:30 am
3658810: HX-1-Approved Biobased Hydraulic Fluids
Mark Miller, Biosynthetic Technologies, Indianapolis, IN

The market for vegetable oil based hydraulic fluids has grown because of relative advantages that these fluids have, when compared with other fluid types. However many biobased hydraulic fluids do not comply with some requirements. A new category of biobased hydraulic fluids are NSF H-1 certified and comply with the European EcoLabel and USDA's BioPreferred® Program. These food-grade hydraulic fluids serve as a drop-in replacement to conventional mineral-based hydraulic fluids and offer superior lubricity, improved operational performance and lower overall environmental impact, and deliver extreme pressure and wear resistance characteristics along with biodegradability. This method of blending, will

provide hydraulic fluids that will help food companies meet environmental sustainability objectives as well as reduce the bio-hazard risks associated with accidental spills due to non-toxicity (> 100 ppm as per the OECD 201, 202, and 203) & high biodegradability (>75% by the OECD 301B).

9:30 - 10 am
3664549: Breaking the Viscosity Ceiling: Development of Readily Biodegradable High Viscosity EAL Synthetic base fluids.
Ramesh Navaratnam, Patech Fine Chemical, Dublin, OH

As the performance demand for new Environmentally Acceptable Lubricants (EAL) grows, formulators are driven to develop high viscosity Synthetic lubricants. However, highly complex molecules are either not readily biodegradable or unable to meet key performance criteria are like hydrolytic stability, hydrocarbon base oil miscibility, anti-wear/lubricity, rubber compatibility, and oxidation stability. Some of these requirements are conflicting in general perception, such as biodegradability and hydrolysis resistance. This presentation will show how such limitations were overcome, and readily biodegradable saturated complex esters with the viscosity of 1,000 and 3,000 cSt @40C were developed. In addition, we also show the estimation results of application characteristics by using unique model based on molecular perspective.

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

10:30 - 11 am
3658832: Innovations and Regulations For Biobased and Sustainable Lubricants and Additives
Mark Miller, 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). This presentation focuses on the innovations, features, benefits, strengths, and limitation of the different types of EALs and additives. It explores classification of base fluids and additives as well as the requirements of finished lubricants. It compares the performance of conventional petroleum products and biolubricants. In addition, the different definitions of environmental acceptability are explored as well as the regulatory driving forces and the requirements for each. The considerations for choosing the type of EAL that is most applicable to specific applications will be explained and finally, the best maintenance practices to ensure long fluid and equipment life will be discussed.

11 - 11:30 am
3668828: Feasibility of Bio-Lubricants Under Mixed Lubrication Conditions
Sam Davison, University of Sheffield, Sheffield, South Yorkshire, United Kingdom

A bespoke test rig which pushes journal bearings into mixed lubrication regimes has been designed and biodegradable lubricants have been put to the test under these extreme conditions. It's estimated that 50% of all of the lubricants produced are lost into the environment. Biodegradable lubricants are a necessary technology to protect the environment for future generations and also have demonstrated excellent lubricity and potential to reduce energy losses. Legislation also dictates the use of biodegradable lubricants, the highest profile being the vessel general permit VGP legislation for lubricants used in the marine sector. Confidence in biodegradable lubricants is relatively low and they're blamed for a rise in bearing failures particularly in marine stern tubes. To date, experimental comparison of the performance of lubricants has been limited to hydrodynamic testing which shows little difference between the lubricants. This work aims to fill that gap.

7H — Northern Hemisphere A3

Synthetic Lubricants and Hydraulics I

Session Chair: Ryan Fenton, BASF Corporation, Tarrytown, NY
Session Vice Chair: Lauren Huffman, Dow Chemical, Midland, MI

8 - 8:30 am
3668716: High VI Industrial Lubricants and Their Impact on Equipment Efficiency
Ricardo Gomes, Frank-Olaf Maehling, Thorsten Bartels, Lucas Voigt, Phil Hutchinson, Evonik Oil Additives, Horsham, PA

Hydraulics and pneumatics are used throughout the industry for a large variety of end uses, e.g. hydraulic excavators. Most of these applications become more and more demanding with increasing operating pressure, smaller fluid volumes and higher specific workloads. A significant amount of power is consumed by these applications. Besides robustness and reliability, energy efficiency is an aspect of increasing importance. Many end users are confronted with the need to reduce Total Costs of Ownership and like to consider every option to improve productivity and efficiency of their equipment. This is closely linked to the increased focus on sustainability. The paper will discuss the demand for more efficient operation of fluid power applications and will show how shear-stable, high-VI hydraulic fluids can improve the equipment efficiency by several percent compared to incumbent monograde fluids.

8:30 - 9 am
3668356: Modeling the Effect of Polymer Structure and Chemistry on Viscosity Index, Thickening Efficiency, and Traction Coefficient
Pawan Panwar, Ashlie Martini, University of California, Merced, Merced, CA; Emily Schweissinger, Stefan Maier, Stefan Hilf, Sofia Sirak, Evonik Industries, Hanau, Germany

The chemistry and structure of base oil and polymer additive molecules in lubricants directly affect viscosity index (VI), thickening efficiency (TE), and traction coefficient (TC). However, the relationship between molecular properties and these key performance metrics is still not fully understood, inhibiting design of fluids with potentially improved performance. This study used molecular dynamics simulations to identify structure-property-function relationships for lubricants of similar viscosity consisting of different polymers having chemistries consistent with commercially available products. Then, simulation calculated VI, TE, and TC were validated by experimental measurements. The differences in VI, TE, and TC between the fluids were investigated by simulation-calculated multiple structural properties of the polymers. Finally, simulations were used to develop simple models to rapidly predict these properties which can ultimately guide design of new lubricants or additives.

9 - 9:30 am
3644828: Quantifying Wet Brake Chatter Using Accelerometers
Michael Botkin, Caroline Mueller, Southwest Research Institute, San Antonio, TX

Wet brakes are common in off-road equipment and other high-torque applications where high levels of heat must be dispersed. Under the right conditions, wet brakes are susceptible to brake chatter caused by a stick-slip action that can result in noise and excessive vibration. Current brake chatter tests quantify brake chatter as audible noise or variations measured in torque at the brake. In the method described in this paper, an accelerometer is used to detect brake chatter and quantify its severity in an off-road axle. A Fourier Transform on the data collected during a brake engagement is used to observe the resonant frequency of the axle system. The summed area under this region of the curve is used to measure the energy of the system at the resonant frequency, and the sum is compared to a threshold value that discriminates quiet engagements from noisy engagements. This process reliably identifies brake chatter and provides a quantitative measure of its severity.

9:30 - 10 am
3648474: VI Improvers for Energy Efficient Compressor Oils
Justin Kontra, Frank-Olaf Maehling, Lucas Voigt, Bin Xu, Evonik Oil Additives, Horsham, PA

Air compressors and pneumatic systems are responsible for a significant fraction of the overall industrial power demand. These systems are required to be robust and reliable. Energy efficiency is an aspect of increasing importance and linked to the increased focus on sustainability. Approaches to improve the efficiency of positive displacement compressors have focused mostly on design, while the development of high VI fluids to boost performance remains largely underutilized. Ideal lubricants protect high wear surfaces, enhance sealing at compression interfaces, and improve overall volumetric efficiency. To measure the impact of high VI compressor oils – lubricants with synthetic high viscosity PAMA base stocks and shear stable viscosity index improvers were benchmarked against market general compressor oils, in both pneumatic and refrigerant compressors. Fluids with VIs above 165 consistently demonstrated significant efficiency gains, while maintaining oxidative and thermal stability.

10 - 10:30 am - Break

10:30 - 11 am
3670950: Metallocene Catalysts on Ethylene Propylene Oligomer as Synthetic Base Oil and Viscosity Modifier
Dianta Ginting, DL Chemical, Daejeon , Yusung Gu , Republic of Korea

The properties of Synthetic based oil design to more superior compared to a mineral base oil, such as better low-temperature performance, better oxidation stability, better viscosity index, and extended life. The advantages of metallocene catalysts are high activity, narrow MWD, wide product range, uniform molecular weight distribution, good physical performance, and good electrical properties. The advantages of metallocene catalysts are high activity, narrow MWD, wide product range, uniform molecular weight distribution, good physical performance, and good electrical properties Ethylene. Based on the metallocene catalyst, the Ethylene Propylene oligomer has good properties such as less hazy, good low-temperature properties, good shear stability, good chemical stability, good oxidation stability, and easy handling. This experiment will explores ethylene-propylene oligomer as base oil and as a viscosity modifier

11 - 11:30 am
3667495: High Viscosity Index Tractor Hydraulic Fluids that Meet Multiple OEM Specifications
Durga Prasad Chalasani, Ricardo Gomes, Justin Langston, Frank-Olaf Maehling, Evonik Oil Additives, Horsham, PA

Tractor Hydraulic Fluids (THF) are multi-purpose fluids designed to transmit power and to lubricate and protect transmissions, differentials, hydraulic components, wet brakes, among other functions. THF specifications are set by OEM's and some of the popular and commonly used specifications include those from John Deere, Massey Fergusson, ZF, CNH, among others. High Viscosity Index THF's that can meet the specifications of multiple OEM's in a single fluid offer potential benefits to both lubricant marketers and end users, such as- simplifying inventory management, reducing errors in application, lower maintenance costs and equipment interoperability. This presentation will discuss the development of such single fluid THF formulations and review the lab and performance test data.

11:30 am - 12 pm
3670662: Development of a New Fuel Efficient, Shear Stable Axle Lubricant to Meet New US GHG Requirements
Arjun Goyal, BASF Corporation, Florham Park, NJ

EPA and NHSTA on behalf of DOT have enacted rules to establish the reduction of GHG of new on-road heavy duty vehicles. This paper describes the development of a new lower viscosity, shear stable, synthetic heavy-duty axle lubricant. The lubricant consists of a unique combination of synthetic base oil and proprietary viscosity improver which results in superior low-and-high temperature properties with excellent extended-length shear stability. The new lubricant meets the SAE J2360 and leading axle manufacturers extended oil drain specification requirements. The new axle lubricant also shows fuel savings of 0.79% and axle temperature reduction of 5.2C over a fuel efficient SAE 75W-90 axle lubricant. Using EPA estimates, the use of new fuel efficient lubricant is estimated to save over $300 and reduce

carbon dioxide (CO2) by over 200 kg per truck per year. Field tests are progressing in various long-haul fleets with one fleet has accumulated over 225,000 no-drain miles with no issues

7I Northern Hemisphere A4

Fluid Film Bearings II

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3668648: Identification of the Dynamic Force and Torque Characteristic of Annular Gaps
Maximilian Kuhr, Peter Pelz, Technische Universität Darmstadt, Darmstadt, Hessen, Germany

The presented work investigates the rotordynamic force and torque characteristic of annular gaps such as seals and journal bearings. Although the dynamic influence of both components is known, the influence of the tilting and moment coefficients has been neglected in almost all experimental investigations. In order to close this knowledge gap, a worldwide unique test rig is operated at the Chair of Fluid Systems at the Technische Universität Darmstadt. Essentially consisting of two radial magnetic bearings for force measurement, excitation and displacement of the rotor, the test rig covers the relevant parameter range for turbulent and laminar flow in narrow annular gaps. In an extensive parameter study, the influence of the annulus length, a modified Reynolds number, the flow rate, the pre-swirl, and the centre of rotation on the force and torque characteristic is investigated. Furthermore, the experimental results are compared to a new and general simulation method.

8:30 - 9 am
3663212: A Bayesian Approach for Shaft Centre Localization in Journal Bearings
Christopher Lindley, Scott Beamish, Rob Dwyer-Joyce, Nikolaos Dervilis, Keith Worden, The University of Sheffield, Sheffield, United Kingdom

Ultrasonic techniques work well for online measuring of circumferential oil film thickness profile in journal bearings. However, attempts to model the oil film thickness from these measurements usually rely on deterministic approaches, which assume the observations to be true with absolute certainty. Unaccounted uncertainties of the oil film thickness may lead to a cascade of inaccurate predictions for subsequent calculations of the hydrodynamic parameters. In the present work, a probabilistic framework is proposed, and likelihood maps are constructed to display the probable location of the shaft centre given the bearing rotational speed and applied static load. The results offer the possibility to visualize the confidence of the predictions and allow the true location to be found in an area of high probability within the bearing's bore.

9 - 9:30 am
3642865: Measuring Oil Films in Dynamically Loaded Journal Bearings
Scott Beamish, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

This paper describes the design of a journal bearing test platform capable of high accuracy film thickness measurements via permanently embedded ultrasonic transducers. A bespoke hydraulic loading system with programmable valves allows the application of dynamic loads with set loading patterns, including the simulation of loading patterns found in real components. Tests under a range of rotation speeds, temperatures and lubricant types have allowed the detailed analysis of film thickness response to rapidly changing loads.
Unlike conventional methods, the ultrasonic technique offers a non-invasive direct measurement of the shaft-bearing interface, thus enabling the study of phenomena such as cavitation, bearing deformation and oil pressure effects. Results have been compared against eddy current sensors, a theoretical model, and numerical techniques. This work focuses on the rig design, refining the technique, validation and how

the system is being applied to current industrial problems.

9:30 - 10 am
3668808: CAPM – A New Model for Design of Media-Lubricated Journal Bearings Under Turbulent and Laminar Flow Conditions
Robin Robrecht, Peter Pelz, Technische Universität Darmstadt, Darmstadt, Hessen, Germany

Media-lubricated journal bearings use the process fluid of the pump as lubricant. The process fluids often have low viscosity, i.e. water or some hydrocarbons. The operation conditions of media-lubricated journal bearings are characterized by large eccentricity, significant axial flow, and moderate Reynolds numbers. The flow is mostly turbulent but can be laminar in some cases. Under these conditions, the use of typical models based on Reynolds equation or Bulk Flow Theory often leads to unreliable prediction of leakage and dynamic forces on the rotor. For this reason, the new Clearance Averaged Pressure Model (CAPM) was developed and validated for turbulent flow.
In this presentation, the CAPM is introduced and results are compared with a Reynolds equation model and CFD data for laminar operation conditions with consideration of inlet pressure losses due to the axial flow.

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

10:30 - 11 am
3668712: Simulation of the Dynamic Force and Torque Characteristics of Annular Gaps - Rotordynamic Relevance of the Tilt and Moment Coefficients
Maximilian Kuhr, Peter Pelz, Technische Universität Darmstadt, Darmstadt, Hessen, Germany

In the present work, the relevance of the rotordynamic force and torque characteristic of annular gaps such as seals and journal bearings is investigated. Although the dynamic influence of both components is known, the influence of the tilting and moment coefficients is generally neglected below an overall threshold defined by the ratio of the annular gap length to the rotor radius $L/R < 1.5$. The derivation of this threshold neglects the operating point of the annulus and any other geometric or operational parameters. To overcome this, a new and generalized simulation method is presented. The method is then used to calculate the rotordynamic force and torque coefficients over a wide range of parameters, leading to a much sharper formulation whether the tilt and moment coefficients can be neglected or must be taken into account.

11 - 11:30 am
3669020: Hybrid Fluid Film Bearings for Liquid Rocket Engine Turbopumps: Test Rig Development and Performance Prediction
Keun Ryu, Kyuman Kim, Howon Yi, Chanwoo Lee, Hyunsung Jung, Homin Lim, Seki Sin, Seungho Choi, Junwon Heo, Minsoo Wee, Hanyang University, Ansan, Gyeonggi-do, Republic of Korea

Turbopumps in reusable liquid rocket engines require compact fluid film bearings to support the large thrust and radial loads at high shaft speeds. Hybrid bearings offer significantly enhanced durability with low friction and wear while providing accurate rotor positioning as well as large load and static stiffness characteristics even working with low viscosity liquids. The current work develops multiple test rigs for measurements of the static and dynamic load performance of cryogenic fluid film bearings and identification of bearing force coefficients. Experimentally validated predictive bearing models significantly reduce time and expenses in further developments of cryogenic hybrid bearings. The work conducted is a stepping stone in a concerted effort aiming towards developing a complete bearing technology integrating cryogenic hybrid bearings for the design, prototyping, and troubleshooting of envisioned reusable rocket engine turbopumps for next-generation propulsion systems.

11:30 am - 12 pm
3639364: Non-Newtonian Couple-Stress Squeeze Film Behaviour Between Oscillating Anisotropic Porous Circular Discs with Sealed Boundary
Benyebka Bou-Saïd, INSA Lyon, Villeurbanne , France; Mustapha Lahmar, Bilal Boussaha, Guelma

University, Guelma, Algeria

We investigate theoretically the non-Newtonian couple stress squeeze film behavior between oscillating circular discs on the basis of V. K. Stokes micro-continuum theory. The lubricant squeezed out between parallel porous plates is supposed to be a concentrated suspension. The effective viscosity is determined by using the Krieger-Dougherty model. For low frequency and amplitude of sinusoidal squeezing the governing equations including the modified Reynolds equation coupled with the modified Darcy's equation are derived and solved numerically. The slip velocity at the porous-fluid interface is directly evaluated considering laminar and isothermal squeezing flow. The couple stress effects on the squeeze film characteristics are analyzed through the dimensionless couple stress parameter considering sealed and unsealed boundary of the porous disc.

7J Northern Hemisphere E1

Materials Tribology III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3645630: Experimental and Numerical Study of the Friction of Carbon Fiber Tows
Noel Brunetiere, Kiran Bhantrakuppe Narayanappa, Olga Smerdova, CNRS, Universite Poiters, ISAE-ENSMA, Chasseneuil du Poitou, France

Carbon fibers tows are used as reinforcement material in composite elements. To ensure mechanical integrity of the composite structure it is important to ensure a good positioning of the carbon fibers in the mold during the manufacturing process. The positioning of the carbon fiber tows strongly depends on the friction with the mold.
In the present work, the friction between a carbon tow placed on a cylindrical pin rubbing on a rotating glass disk is experimentally studied in dry and resin lubricated conditions on a dedicated tribometer. The tests are performed for different loading levels and sliding speeds. The results are compared to numerical simulations considering contact mechanics and lubrication. The tows are modeled using a simple elastic foundation approach coupled with the Reynolds equation when the resin flow is considered.

8:30 - 9 am
3663350: Comparison of Scuffing and Wear of Hard Materials in Four Low-Lubricity Fuels
Stephen Berkebile, Monica Ferrera, Nikhil Murthy, US DEVCOM ARL, Aberdeen Proving Ground, MD; Kelly Jacques, Maddox Dockins, Euan Cairns, Aditya Ayyagari, Diana Berman, Samir Aouadi, Andrey Voevodin, The University of North Texas, Denton, TX; Auezhan Amanov, Ruslan Karimbaev, Sun Moon University, Asan, Republic of Korea

High-pressure common-rail fuel delivery systems operate under harsh conditions due to internal lubrication with the fuel. Low viscosity of fuels, variations in fuel chemistry, and tight mechanical tolerances tend to promote high wear and scuffing that can lead to premature failure of components. Hard coatings have the potential to mitigate these failure in fuel-lubricated mechanical interfaces and increase operational life. Using several tribological methods and interface conditions, we will present and compare the wear and scuffing resistance of around 20 hard coatings in F-24 jet fuel, ethanol, decane and dodecane. The coatings fall into categories of tungsten carbides, diamond-like carbons, nitrides, and oxides with various thicknesses and surface treatments. Of the 20 coatings, at least three demonstrated lower wear in most fuels with respect to hardened AISI 52100 steel. However, we demonstrate that scuffing resistance must be considered for a full assessment of suitability.

9 - 9:30 am

3668923: Investigation of the Evolution in Chemistry and Physical Steel Contacts During the Scuffing Process
Kelly Jacques, Andrey Voevodin, Samir Aouadi, Thomas Scharf, Diana Berman, University of North Texas, Denton, TX; Rose Pesce-Rodriguez, Stephen Berkebile, US DEVCOM ARL, Aberdeen, MD

Fuel pump materials must resist wear when lubricated upon operation in hydrocarbons under conditions of dynamic fluid pressure and flow to expand fuel compatibility. Determination of new materials to implement in such systems to protect them against scuffing is impeded without a thorough understanding of scuffing initiation on currently used hardened steel surfaces. In this work, a pin-on-flat high-frequency reciprocating tribometer was used to establish an experimental method that repeatably produces scuffing events on self-mated through-hardened AISI 52100 steel. Optical microscopy, scanning electron microscopy, energy dispersive spectroscopy, profilometry, Raman spectroscopy, and Fourier transform infrared spectroscopy were used to characterize the evolution of sliding interfaces during scuffing. Overall, it was found that the chemical composition and wear behavior of AISI 52100 steel differed greatly for surfaces subjected to scuffing and those which resisted scuffing initiation.

9:30 - 10 am
3644063: High-Throughput Investigation of a High Strength Additively Manufactured Multi-Principal Element Alloy
Morgan Jones, Irene Beyerlein, University of California Santa Barbara, Santa Barbara, CA; Nicolas Argibay, Iver Anderson, Emma White, Prashant Singh, Duane Johnson, Ames Laboratory, Ames, IA; Andrew Kustas, Frank DelRio, Ping Lu, Sandia National Laboratory, Albuquerque, NM

Multi-principal element alloys (MPEAs) show great promise for use in the power generation industry due to their high melting temperatures and strength. Additive manufacturing (AM) methods enable fabrication of compositionally graded specimens and rapid exploration of composition-dependent properties. AM was paired with scratch testing techniques to determine hardness and toughness, followed by microstructural analysis to identify deformation mechanisms. Micro-scratch and nanoindentation experiments were performed on an AM MPEA specimen, which was found to have extraordinary mechanical properties. High temperature nanoindentation showed remarkable strength and thermal stability, with negligible change in strength up to 500 C. Density-functional theory calculations showed that this system favors the formation of multiple highly-thermodynamically stable phases, corroborated by transmission electron microscopy, which also revealed evidence of highly coherent phase boundaries.

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

10:30 - 11 am
3642145: Crystal Rotation Kinematics During Dry Sliding on High-Purity Copper
Christian Greiner, Christian Haug, Peter Gumbsch, Karlsruhe Institute of Technology, Karlsruhe, Germany; Dimtri Molodov, RWTH Aachen University, Aachen, Germany

During the tribological loading of metals, dislocation-mediated plasticity results in a variety of microstructural changes, including grain refinement or the formation of crystallographic textures. One key process involved therein is the reorientation of the crystal lattice, or crystal rotation. Our work sheds light on the early stage, fundamental mechanisms of tribologically induced lattice rotation kinematics. Using a high-purity copper bicrystal and a sapphire sphere, unlubricated, single-pass sliding tests were conducted. Electron backscatter diffraction (EBSD) performed directly on the wear track reveals a crystal rotation process around the transverse direction at the heart of tribologically induced lattice rotation, irrespective of sliding direction, grain orientation and normal load. A detailed analysis corroborates that surprisingly, changing the sliding direction merely alters the precise accommodation of crystal rotations, but not their fundamental nature.

11 - 11:30 am
3647024: Evolution of Surface Cracks Under Rolling Contact: 3D Crack Morphology and Influence of Material Composition
Chiara Bertuccioli, Amir Kadiric, Imperial College London, London, United Kingdom; Kenred Stadler, SKF,

Schweinfurt, Germany

This paper presents recent research into the evolution of surface initiated rolling contact fatigue cracks morphology in different stages of their growth. Rolling contact fatigue (RCF) tests were carried out on a triple-disc fatigue rig to generate surface cracks under controlled contact conditions. Tests were stopped before a large crack developed into a pit using vibration signal analysis. Roller test specimens of different materials were employed to investigate the effect of material composition. 3D shapes of cracks at different stages of their development were then obtained using a custom methodology employing FIB-SEM and other analytical techniques in combination with a series of software processing steps to obtain 3D crack coordinates. The results are presented to describe the evolution of crack morphology as crack length increases and to illustrate the pertinent effects of material composition.

11:30 am - 12 pm
3670524: Tribological Performance of Sliding Parts in Low Viscosity Fluids
Aditya Ayyagari, Maddox Dockins, Euan Cairns, Diana Berman, University of North Texas, Denton, TX; Stephen Berkebile, US DEVCOM ARL, Aberdeen Proving Ground, MD

Moving towards environmentally sustainable technologies, understanding the wear and friction behavior of industrial coatings in low viscosity and/or volatile fluids such ethanol, decane or kerosene has gained importance. While lubricity is largely governed by the fluid dynamics of the lubricant, the wear behavior of the contacting surfaces in presence of the low molecular weight hydrocarbons is also strongly dependent on the materials properties and formation of tribochemical compounds that can strongly influence the surface interactions. This study presents the mechanism defining the tribological properties of materials in alcohols and alkanes that is validated for several hard industrial coatings. The observations are complemented by detailed surface characterization techniques – mass spectrometry, Raman spectroscopy, and advanced electron microscopy.

7K — Northern Hemisphere E2

Metalworking Fluids III

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30 am

8:30 - 9 am
3645759: Metal Working Fluids Containing Hydroxyproline Rich, Natural Proteins Have Reduced Drag Out and Provide for Cleaner Machines and Workpieces.
Eric Yezdimer, Gelita USA, Sergeant Bluff, IA; Matthias Reihmann, Gelita AG, Eberbach, Germany

Multiyear use of synthetic metal working fluids containing hydroxyproline rich, natural proteins (HRPs) in multiple machine shops have found several performance improvements, including reduced drag out and cleaner machines/workpieces. Previously it was found that HRPs form dynamic, nanometer thick, hydrophilic layers on metal surfaces that improve cooling and provide lubricity. In this work, it was determined that the addition of HRPs to semi-synthetic fluids modify the net chemical adhesion profile on steel and aluminum surfaces. The use of water and oil soluble dyes, spectrophotometry and TOC measurements allowed for surface residue quantification and demonstrated HRPs reduced the adhesion of oil emulsions to the surface. Tapping torque experiments with semi-synthetics spiked with HRPs also demonstrated improved lubricity. This indicates HRPs are not negatively impacting the oil performance during machining, but post operation can act to expel undesirable oils and cracked residues.

9 - 9:30 am

3647104: Formulating Aluminum Metal Working Fluids – Which Additives Provides Essential Benefits?
Michael Stapels, Kao Chemicals GmbH, Emmerich, Germany

The significantly increased use of Aluminum in our industry has long ceased to be a secret. Neglecting the specific requirements of this material in the development of an aluminum metalworking fluid will end up in an unsatisfying situation for all people involved. Beside standard requirements like cooling and lubrification particular emphasis has to be placed on the soap formation of aluminum coolants. Another important point is to avoid the highly undesired staining of the Aluminum during machining. Key to meet all these requirements is the selection of an appropriate emulsifier chemistry. One of the most promising chemistries are ether carboxylates as - in the right combination - they are able to master the balancing act between emulsion stability as well as foam- and soap-control. Additionally they provide especially in combination with a proper amine chemistry excellent stain prevention.

9:30 - 10 am
3651204: Post Machining Cleaning – How to Pick the Right Surfactant For the Job
Ashley Milton, Stephanie Cole, Clariant, Mount Holly, NC

With the hundreds of available surfactants on the market to incorporate into a metal cleaning formulation, the task of picking the correct surfactant can be daunting. Determining whether your formulation requires emulsification or rejection of foreign oil is critical for selecting the proper surfactant in a cleaning formulation. Understanding surfactant performance with various soil types, metal types and pH stability will help the end-user achieve their desired cleanliness. The backbone of the surfactant chemistry will determine the functionality of the surfactant and its application performance. This paper will define trends associated with different surfactant chemistries and how to apply this theory to developing a cleaning formulation.

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

10:30 - 11 am
3667154: Polyglycol as Performance Wear Lubricant and Synergism with Extreme Pressure Additives on Net Oil Metalworking Fluid
Eduardo Lima, FASB - Philosophy and Sciences College, São Paulo, Brazil

To create a more robust scientific information from previous studies that considers known factors that affects wear, which brings negative aspects on metalworking process, potential damages on metal parts, unwanted wear on relative expensive tools, or debilities to create adequate and precision measures on metal parts, demands effective additive development against wear. Consequences of metal-to-metal contact is possible to be prevented by adding adequate chemistries that form a protective film between surfaces, either by physical adsorption or even by a chemical reaction. This study presents performance results exploring more from Oil Soluble Polyglycol as synthetic performance Wear Lubricant Additive proposal and covering more on synergism with Typical Extreme Pressure Additives Study on Typical Net Oil Metalworking Fluid, creating relation between: additive molecular weight relation, bubbles release, oxidation, viscosity, and fundamental extreme pressure/ low wear.

11 - 11:30 am
3669361: How Did You Come Up With That? A Comparison Study of the Different Innovation Methods Between Large Corporations and Small & Medium Sized Enterprises (SME).
E Jon Schnellbacher, Formulas & Solutions, LLC, Allen Park, MI

Metalworking fluid formulation traditionally happened in small & medium sized enterprises although recently though mergers and acquisitions has become common in larger corporations. This presentation discusses how the R&D strategies may be applied to companies according to available resources. There is a basic structure difference between large corporations with greater resources and differentiation and small to medium size enterprise (SME's) with less than 500 employees. Do they create products the same way? The North American Chemical Manufacturers Best Practices Study (NACM-BPS) indicates

otherwise. SME companies have smaller R&D staffs that fill different roles including both technical service and product development. Furthermore, they also tend to have fewer resources limiting their ability to do more innovative and radical innovation. This presentation discusses challenges and strategies between different size companies adopting the best innovation practices.

7L — Northern Hemisphere E3

Tribology of Biomaterials I

Session Chair: Alison Dunn, University of Illinois, Urbana, IL
Session Vice Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

8 - 8:30 am
3669024: Tribology of Soft Contacts Lubricated by Particulate Suspensions
Christopher Serfass, Catherine Hill, Elias Kerstein, Yug Saraswat, Lilian Hsiao, North Carolina State University, Raleigh, NC; Shravan Pradeep, University of Pennsylvania, Philadelphia, PA

The presence of suspended solid particles in consumer products such as foods and cosmetics greatly influences texture perception. This has led to increased interest in understanding the tribology of these systems. To investigate the influence of particles in lubricated tribopairs, we prepare lubricants that comprise suspensions of poly(methyl methacrylate) microparticles of various sizes ($0.4\ \mu m \leq 2a \leq 1.5\ \mu m$) and volume fractions ($0.05 \leq \varphi \leq 0.50$) in squalene and perform velocity sweep tests using a ball-on-three-plates geometry. We observe a reduction of friction in the boundary regime, the appearance of a φ-dependent plateau in the mixed regime, and a φ-dependent rate of increase in friction in the elastohydrodynamic regime. To account for the nonlinear increase in viscosity as φ increases, we use steady shear rheological testing to characterize the suspension viscosity. Our overall aim is to create a framework linking tribological and rheological behavior in colloidal suspensions.

8:30 - 9 am
3669423: Interfacial Wear of Soft Hydrogels Due to Repeated High-Speed Cavitation Events
Alexander McGhee, Jin Yang, Elizabeth Bremer, Christian Franck, University of Wisconsin-Madison, Madison, WI

Inertial microcavitation, the formation and collapse of micron to millimeter-sized bubbles, is a widely found phenomenon across engineering and life sciences. Examples include cancer ablation therapies using focused ultrasound histotripsy procedures or spontaneous formation in ballistic, blast, or directed energy events. Within these various applications, a fundamental understanding of the finite deformation behavior of the soft material (e.g., tissue) during cavitation is paramount for quantitative predictions of material failure, damage, and cellular injury for living tissues.
This study has resulted in the full-field measurement of the temporal evolution of subsurface deformation, strain, stress, pressure, and volumetric expansion of the surrounding material during repeated cavitation events at a fluid-hydrogel interface.

9 - 9:30 am
3669352: Patterned Elastomeric Materials in Lubricated Tribology
Lilian Hsiao, Yunhu Peng, Christopher Serfass, North Carolina State University, Raleigh, NC

The interfacial film thickness between two patterned surfaces strongly influence the elastohydrodynamic lubrication (EHL) friction coefficient because of its contribution to the shear and normal forces in lubrication analysis. We use a tribology accessory on a stress-controlled rheometer to examine how an interfacial fluid film, comprising a mixture of water and glycerol, separates two solid surfaces in tribological sliding conditions. Poly(dimethyl siloxane) (PDMS) materials and hydrogels are patterned using photolithography and replica molding. We combine Reynolds' equations with linear elasticity to model the

tribological behavior of soft materials, including that of robotic and human fingertips. Softer patterns bend more easily during applied deformation, which consequently decreases the EHL friction. Our results collectively show that the liquid film is a key parameter in the tribology of soft materials, and furthermore enables the design of friction in realistic environments.

9:30 - 10 am
3669442: In Situ Observation of Interface Between a Glass Syringe and Elastomer Stopper for Low Temperature Storage of Biologics
Kylie Van Meter, Pont de Claix, France; Brandon Krick, Florida State University, Tallahassee, FL; Nestor Rodriguez, Eloise Perrin, BD Medical-Pharmaceutical Systems; Avinash Tiwari, Bo Persson, Peter Grubber Institute, FZ Julich, Julich, Germany

Biologics like mRNA-based vaccines for COVID and some cell therapies require storage at temperatures of - 80°C to keep the therapeutics stable and maintain dose potency. During the freeze-thaw cycle of the vaccine, the components of a prefilled-syringe (rubber stopper, lubricant, glass body, liquid) undergo thermal, mechanical, and physical changes that can affect the integrity of the internal sealing of the syringe and the vaccine itself. In this study, freeze-and-thaw experiments were performed to study the behavior of a system comprised of a glass syringe with a butyl rubber, silicone oil lubricated stopper filled with deionized water. The contact and position of the rubber stopper and glass syringe interface was observed with in situ adaptive optics. The results revealed a complex behavior of the prefilled system during freeze-and-thaw caused by the confined and non-uniform crystallization of water and the thermal transitions occurring at the glass-lubricant-elastomer interface.

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

10:30 - 11 am
3669232: Tribological Performance of Additive Manufactured Partial Implants Sliding Against Articular Cartilage Assessed Using In Vitro Experiments
Manel Rodriguez Ripoll, Timea Varadi, Rosa Eder, Markus Kronberger, Friedrich Franek, AC2T research GmbH, Wiener Neustadt, Austria; Christoph Bauer, Stefan Nehrer, Danube University Krems, Krems, Austria

Hemiarthroplasty, a medical procedure consisting in the replacement of half of the affected joint has emerged as a less aggressive alternative to full replacement surgery. However, it has been widely observed that the remaining native cartilage left after hemiarthroplasty experiences accelerated wear when in contact against partial implants. The aim of this work is to evaluate the potential of additive manufactured materials using Laser Metal Deposition as partial implants. The additive manufactured materials are investigated under reciprocating sliding motion against bovine osteochondral plugs in controlled electrochemical conditions using a floating cell with a three-electrode set up coupled to a microtribometer. The results are benchmarked against CoCrMo in terms of friction, tribocorrosion performance and metal release. Further, the impact of implant material on cartilage damage is assessed based on the metabolic activity of chondrocytes and the expression of catabolic genes.

11 - 11:30 am
3669398: Evolution-Structure-Property Relationships of Tissues Drive Functionality in Slicing and Grinding Dentitions
Tomas Grejtak, Tomas Babuska, Lehigh University, Bethlehem, PA; Tyler Hunt, Stephen Kuhn-Hendricks, Gregory Erickson, Florida State University, Tallahassee, FL; Soumya Varma, Deeksha Kodangal, Siddhartha Pathak, Iowa State University, Ames, IA; Mark Norell, American Museum of Natural History, New York, NY; Santiago Lazarte, Brandon Krick, Florida A&M University–Florida State University, Tallahassee, FL; Manish Jain, Swiss Federal Laboratory for Materials Science and Technology, Thun, Switzerland

Teeth are biomechanical marvels that evolved over millions of years through natural selection to be functional and damage tolerant as they are crucial to the survival of the organism. Multifunctional grinding dentitions of grazers are composed of several tissues with varying mechanical properties that act together

to withstand high surface stresses over millions of loading cycles to obtain nutrients from plants covered with hard and wear promoting particles. Dental enamel is the most remarkable tissue of all. Although it is composed of ~ 95 % of brittle hydroxyapatite crystallites, it exhibits exceptional strength and toughness, properties that are typically mutually exclusive. This work aims to understand the role of individual tissues and their properties on the functional grinding dentition of mammals and the relationship between the hierarchical designs of the enamel microstructures and their exceptional properties at different scales through multiscale mechanical characterization.

7M — Northern Hemisphere E4

Rolling Element Bearings VII

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3666064: Modelling Geometrical Raceway Deviations of Roller Bearings in Multi-Body Simulation
Patrick Wingertszahn, Onur Atalay, Bernd Sauer, TU Kaiserslautern, Kaiserslautern, Germany

Even high-precision machine elements such as rolling bearings are subject to geometric deviations from the nominal shape from the manufacturing process. But components can also be deformed during assembly or operation. In the case of rolling bearings, the adjacent construction is often the cause and affects the internal geometry of the bearings. Shaft, housing and thus the bearing rings can deform due to the load situation, resulting in unwanted vibrations. In this contribution, a multi-body simulation model is used to investigate the influence of deviated internal geometries on bearing kinematics, bearing load and life. Therefore, mathematical approaches are presented that allow a consideration of roundness deviations in contact calculation. Their application is shown on the basis of some use cases. The method should provide a better understanding of the bearing vibration behavior and its causes.

8:30 - 9 am
3641287: Analysis of an Angular Contact Ball Bearing with Flexible Cage
Karine Petuya, Daniel Nelias, Univ Lyon, INSA Lyon, CNRS, LaMCoS, Villeurbanne, Rhône, France; Alexandre Leblanc, Artois University, Béthune, Pas-de-Calais, France

Aeronautical industry is currently developing ball bearings with cages made of lighter but softer materials. Such high-speed rolling element bearings experience cage deformation and stress concentration due to ball-to-pocket impacts. These are produced during acceleration and deceleration phases, and also during cruise when operating with combined thrust and radial load. However, few dynamic ball bearing models consider global and local cage elasticity, especially in 3D. This study aims at continuing Leblanc and Nelias' four contact-point quasi-static model by implementing either a rigid or an elastic cage. Besides, the system is transposed in dynamics to consider accelerations, ball-to-pocket contacts, lubrication, friction, and damping. For various ball bearing operating conditions, cage local and global deformations and cage center motion are analyzed. Particular attention is paid to critical operations as when radial-to-axial load ratio approaches one.

9 - 9:30 am
3643444: Planet Bearing Performance Analysis Focused on Potential Cage Stress and Roller Sliding Damage.
Travis Shive, SKF USA Inc, Lansdale, PA

Planetary gear designs are being utilized in electric drivetrain vehicles. Due to increased demand on speed and power in such gearboxes, it is beneficial to understand the resulting performance of planetary bearings in the gear system. Analytical tools are useful to study system designs and bearing performance especially when examining the areas of cage stress and possible skidding damage on the raceway contacts. Using internal software, cage design can be analyzed and modified to provide a further robust structure. This will be documented through various cage design comparison to represent how these cages will exhibit different stresses given the specified design. Secondary to the cage, raceway contacts will be reviewed to show areas where consideration should be taken to avoid skidding damage.

9:30 - 10 am
3640401: Minimum Energy Hypothesis in Quasi-Static Equilibrium Solutions for Angular Contact Ball Bearings
Pradeep Gupta, PKG Inc, Clifton Park, NY

The commonly used quasi-static model for angular contact bearings is enhanced by coupling the contact mechanics and bearing kinematic analyses with traction behavior in ball-to-race contacts. The points of pure rolling in the contacts are determined by minimizing the frictional dissipations based on a prescribed elastohydrodynamic traction model. Predictions of the enhanced model are in close agreement with those obtained by much more sophisticated dynamic analysis based on integration of classical differential equations of motion of bearing elements. A standalone software, containing the enhanced quasi-static model, is made freely available at www.PradeepKGuptaInc.com/AdoreQS.html. Full article: STLE Tribology Transactions, 2020, vol 63(6), 1051-1066.

10 - 10:30 am - Break

10:30 - 11 am
3667790: Simulation of Noise and Vibration of Systems with Real Rolling Bearings
Hannes Grillenberger, Schaeffler Technologies, Herzogenaurach, Germany

Noise and vibration (NVH) is becoming a more emphasized performance criteria not only for single components like rolling bearings, but also for complex systems like drive trains or gearboxes. For life and friction assessment of these systems ideal component geometries are typically used and sufficient for the design. For NVH, tolerances of the components and their interaction is much more important and cannot be neglected. For some issues single component simulations are sufficient to optimize the design for NVH. The interaction of components, impact on system level (i.e., perception of the customer) can only be assessed by system investigations. Due to the huge set of geometry parameters, tolerances and operating conditions, simulation is the only efficient way to the optimum design. The presentation shows the simulation approach to NVH design, optimization of tolerances and the impact on system level including the basic theory, plausiblization and validation examples.

11 am - 11:30 am
3666372: Vibration Isolation Strategy for Reducing Noise in Large Diameter Thin Section Ball Bearings
Joel Lawrence, Phil Jones, Jason Williams, Penn State Behrend, Erie, PA; Bryan Allison, SKF, Falconer, NY

Thin section ball bearings often are mounted to complicated mounting structures that may be dynamically excited resulting in undesirable structure borne noise. Dynamically isolating the ball bearing from adjacent mounting structures has shown promise in reducing displacement and acceleration levels within the assembly. A combination of closed form and finite element calculations are used to design elastomeric springs to achieve this isolation. Analytical and simulation models are used to show a greater than 90% reduction in supporting structure acceleration at the bearing excitation frequencies.

11:30 am - 12 pm
3669113: The Role of the Cage for Track Replenishment in Oscillating Rolling Element Bearings

Sebastian Wandel, Leibniz University Hannover, Hannover, Lower Saxony, Germany

Oscillating rolling element bearings are an important component in many applications such as in robotics or rotor blade bearings in wind turbines. In most cases, these bearings are grease-lubricated and thus susceptible to starvation. If, due to small oscillation angles, the inlet conditions cause the contact between the rolling elements and raceway to progressively dry out, resulting in a heavily starved contact, metal-to-metal contact can lead to an early bearing failure due to false brinelling. This paper shows that occasional re-lubrication cycles above a certain angle can effectively prevent wear initiation. The reason for this was found to be the ability of the cage to provide lubricant replenishment to the grease track on the rolling elements. With these findings, it is shown that a cage design optimized for oscillating applications can effectively prevent wear.

8A Southern Hemisphere I

Non-Ferrous Metals II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3651522: Structure-Performance Evaluation of Synthetic Metalworking Fluid Additives
Stephanie Cole, Tiffany Meyers, Clariant, Mount Holly, NC

Metalworking fluid chemistry is ever-evolving and changing due to the operation severity, increase in nonferrous metal production, and the need for sustainable green additives. Metalworking fluid is exposed to various conditions, and it must be able to withstand harsh conditions during manufacturing and processing of these nonferrous materials (e.g. rolling, cutting, forming, grinding). Lubricity additives can vary with shape, size, and solubility, contributing to the overall fluid performance. As improved health and safety attributes are becoming a necessity, it's essential to understand how molecular structure can impact product labeling and performance. This paper will discuss the various chemistries of additives that are compatible with a sustainable, oil-free metalworking fluid that effectively protects aluminum and, at the same time, deliver additional functionalities that help metalworking fluid formulators address today's formulation challenges.

2 - 2:30 pm
3647312: Correlating Viscosity of 2-Ethylhexyl Oleic Estolide Esters to Their Molecular Weight
Grigor Bantchev, Steven Cermak, USDA-ARS, Peoria, IL

Estolide esters, a class of lipids that are made from vegetable oil, were recently added to the market as renewable biobased lubricants. To widen their adoption as lubricants, their viscosity needs to be within tight limits. We measured the viscosity of the oleic estolide esters at different temperatures and compared the data with theoretical models. Mauro-Yue-Ellison-Gupta-Allan (MYEGA) was the best model to predict viscosity dependence on temperature and molecular weight. The models predicted well the measured viscosity data from the temperature and the average molecular weight of the estolides. These results will allow tailoring the estolide esters viscosity to specific applications by controlling the structure, allowing farm-based estolide esters to be used as engine oils, hydraulic fluids, metalworking fluids, etc.

2:30 - 3 pm
3647700: Formulating for High-Efficiency Cleaning and Protection Performance for Both Ferrous and Non-Ferrous Metal Surfaces
Clayton Cooper, ANGUS Chemical Co, Buffalo Grove, IL

Metal cleaning is an essential process used in manufacturing, metal processing and equipment maintenance. The common use of high-strength, lightweight alloys in automobiles, aerospace, electronics, food and beverage, and other industries has created opportunities and challenges for cleaner formulators to develop effective products that can clean and protect multi-metal surfaces. This presentation provides a fresh look at the performance of specialized alkanolamine chemistries used in metal cleaning formulations to provide a higher pH build that enables the reduction of other corrosion inhibitors. The multifunctionality of alkanolamines is shown to extend the operational window of metal cleaners and enable formulations to provide a broad and effective range of cleaning and protection performance for both ferrous and non-ferrous metals.

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

3:30 - 4 pm - **Non Ferrous Metals Business Meeting**

8B Southern Hemisphere II

Lubrication Fundamentals VIII - Rheology

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3641504: Effect of the Architecture of Polymeric Additives on the Rheological Response of Lubricants in the Elastohydrodynamic Lubrication Regime
Eliane Gendreau, Janet Wong, Imperial College London, London, United Kingdom; Sarah Matthews, Shell Global Solutions (UK) Ltd, London, United Kingdom

Low viscosity lubricants are increasingly needed as they are key to reduce friction losses. They must however possess a sufficiently high viscosity at high temperatures to ensure good lubrication. To improve their viscosity-temperature behaviour, viscosity modifiers (VMs) are blended in. They are polymer additives of complex and diverse chemistries and molecular architectures. In this project, we study the effect of VMs on lubricant rheology with in situ and real-time experiments in the elastohydrodynamic regime. Flow profiles and viscosity maps of lubricants in ball-on-flat tribological contacts, obtained with novel time-resolved laser spectroscopy techniques, will be presented. The effect of pressure, shear and VM specificities will be examined. The link between the polymer architecture and the rheological response of the lubricant across scales will be discussed.

2 - 2:30 pm
3645217: Impact of Flexibility and Molecular Architecture on the Shear Thinning Response of Viscosity Modifier Polymers
Amran Mohamed, Janet Wong, Imperial College London, London, United Kingdom; Sarah Matthews, Shell Global Solutions, London, United Kingdom; Luca Mare, University of Oxford, Oxford, United Kingdom

Viscosity modifier (VM) additives are used to reduce a lubricant's sensitivity to temperature. As lubricants are often subjected to high shear rates in rubbing contacts, a thorough understanding of the behavior of the VMs under shear is critical. In this study, how VMs affect lubricant rheology is examined using dissipative particle dynamics (DPD) simulation. We focus on the effect of architectures and chain stiffness of polymer VMs. Linear, star and comb shaped polymers were used; while chain stiffness was varied by constraining the bending potential between adjacent bonds. Their shear thinning responses and thickening abilities are examined. The conformational changes of polymers are quantified to understand differences in their rheological properties and hence mechanisms of shear thinning. We find that the

shear thinning behaviour of the star and comb changes with flexibility, whereas the linear polymer experiences the same shear thinning behavior irrespective of chain stiffness.

2:30 - 3 pm
3649386: Principles for Designing Very High VI Fluids
Erik Willett, Jacob Scherger, Functional Products Inc., Macedonia, OH

Viscosity index or “VI” is a key parameter in lubricant design and selection. Higher VI for a given viscosity grade means less thinning of the oil with heat and less buildup of viscosity with cooling. This flatter viscosity-temperature means the lubricant can operate optimally under a wide range of conditions. “High VI” per specifications like ASTM D6158 HV was originally 140. Yet VI 140 is now typical with current technology; specifications like AGMA 9005-16 specify VI up to 240. Top tier lube for gear, hydraulics, automotive, EAL, and more will continue rely on their reported VI to differentiate products since many consumers consider VI to be an easy metric for quality and performance. What does the average formulator need to do to keep up with these demands? This work builds on the fundamentals of viscosity index improver (“VI improver”) selection and resulting tradeoffs in performance, but also presents novel insights about subtle effects of base oil selection early into a project.

3 - 3:30 pm - Break

3:30 - 4 pm
3647712: Measuring Mid-Shear Viscosity Using Tapered Bearing Simulator Viscometer for Viscosity Maps
Gwenaelle Philibert, Priyanka Desai, Sarah Remmert, Shell Global Solutions US, Houston, TX

Lowering engine oil viscosity is an established way of reducing engine friction and fuel consumption. While kinematic viscosity at 100°C and High Temperature High Shear (HTHS) viscosity at 150°C are the key parameters that define an SAE grade, viscosity variations over the full range of temperature and shear rate in an engine allow for efficient design of viscosity targets. Seeking to select oils that generate the best fuel economy for their customers, Shell has been generating full-shear flow curve viscosity maps for many years already. The current bottleneck is the measurement of viscosity in the mid-shear rate range (104-106/s) that relies on time-consuming capillary technology. The TBS instrument that is widely used at 106/s for HTHS measurements per ASTM D4683 can be modified to generate shear rates beyond the stipulated 106/s by changing speed and rotor position. This work relates to automating a TBS to facilitate data generation of mid-shear viscosities.

4 - 4:30 pm
3669336: Predicting Processability of Engine Oils by identifying the True Rheological Behavior Using Microfluidic Rheometer
Ravinder Elupula, Charles Nider, Formulaction, Piscataway, NJ

Engine oils/lubricants provide lubrication to the engine parts that are in constant motion. By lubricating the engine properly, the engine lifetime can be greatly extended, and the higher fuel economy can be realized by the consumer. However, the high temperatures and shear conditions engine oils undergo when the engine is in action cannot be determined with traditional rheometers. Knowing these rheological values for each engine oil will help manufacturers in producing the best performing products in terms of better aging, better sealing, and optimal lubrication.
A novel Microfluidic Rheometer can mimic true shear conditions of an engine to provide accurate viscosity profiles of lubricant formulations. Rheometers extrapolate the data to guesstimate the viscosities. This technology doesn’t require any extrapolation, calibration, or special setup. Viscosities are continuously monitored in real-time by visual flow acquisition methods compared to a traditional rheometer.

4:30 - 5 pm
3669484: Electromagnetic Tuning of Friction Levels in GBLM Lubricated Tribosystems: An Experimental Investigation
Maria Victoria Granja Oramas, C. Fred Higgs III, Rice University, Houston, TX

Achieving in situ control of friction levels without removing and replacing lubricant materials situated within inaccessible confines of contact constitutes a grand challenge in Tribology. Externally applied electric or magnetic fields constitute a particularly promising means to actively, reversibly, and non-invasively adjust the performance of tribosystems in real-time. Using the principles of magnetohydrodynamics, this study aims to experimentally determine the electromagnetic tunability of Gallium-based liquid metal (GBLM), by analyzing its Stribeck behavior. GBLM does not only exhibit the MHD effect but has also been proposed as a viable candidate for lubrication in extreme environments, where conventional lubricants might break down or vaporize. The Stribeck behavior of GBLM will be determined across all lubrication regimes, under the effect of external transverse magnetic fields. The implication of these results on the degree of tunability of GBLM will be presented.

8E Southern Hemisphere V

Nanotribology V

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3646636: Sliding-induced Friction Hysteresis on Graphitic Surfaces in Solvated N-Hexadecane Layers
Prathima Nalam, Behnoosh Sattari Baboukani, SUNY University at Buffalo, Buffalo, NY; Ashutosh Pitkar, Zhijiang Ye, Miami University, Oxford, OH

Sliding-induced stick-slip behavior measured by an AFM tip on graphene and HOPG in n-hexadecane presents unique characteristics while measuring friction hysteresis and strengthening. The load-dependent friction measurements displayed higher friction during unloading compared to loading. Unlike ambient air or vacuum, the friction hysteresis occurred up to a transition load, beyond which no hysteresis behavior was observed. A strengthening of friction traces was observed independent of the slide distance but dependent on the load- and slide- history. The presence of solvation layers of n-hexadecane at the graphitic surfaces seems to contribute to the observed behaviors. MD simulations resolved the radial distributions of the carbon and hydrogen atoms in the n-hexadecane and measured the deformation of the graphene in front of the tip. The organization of n-hexadecane and the resultant interaction forces on the AFM tip during sliding enabled molecular understanding of friction behavior.

2 - 2:30 pm
3647603: Experimental Study and Numerical Modelling of Sliding Contact Wear in Nanocomposite Coatings
Zulfiqar Khan, Bournemouth University, Poole, Dorset, United Kingdom

This study involved experimental investigations of Nickel (Ni), Graphene, Zirconia (ZrO_2), Alumina (Ni/Al_2O_3) and Silicon Carbide (SiC) nanocomposite coatings. A micro-friction sliding contact bench test was employed to study the tribological performance of these coatings. Scanning Electron Microscopy (SEM) and white light interferometry were employed for surface analysis. Tribological data has been combined with surface stresses, grain size, hardness, and porosity to develop numerical models. U-shaped geometrical configuration has been employed for understanding interfacial energy distribution of coating-substrate system. This has led to the development of multidisciplinary mechanistic, mechanics and energy distribution based numerical models. Numerical solutions are in close agreement with experimental results. Comparative wear profiles of nanocomposite coatings showed that Ni-Graphene had the highest wear resistance comparing to other candidates.

2:30 - 3 pm

3668981: Understanding the Load-Dependence of Nanoscale Adhesion Using In Situ Experiments in a Transmission Electron Microscope
Tevis Jacobs, Andrew Baker, Sai Bharadwaj Vishnubhotla, University of Pittsburgh, Pittsburgh, PA; Rimei Chen, Ashlie Martini, University of California Merced, Merced, CA

Nanoscale adhesion is critical for advanced technologies, from nanoparticle catalysts to nanoscale devices. Here we discuss recent work to understand the atomic-scale physics governing nanoscale adhesion, using in situ adhesion tests performed inside of a transmission electron microscope. First, we will focus on the load-dependence of adhesion; using adhesion tests and molecular dynamics simulations to couple Angstrom-scale characterization of morphology and structure with nanonewton-scale measurements of adhesive forces. The results demonstrate the role that applied load plays in modifying the adhesive interaction, in ways not captured in traditional contact models. Second, we focus on applying this understanding of nanoscale adhesion to nanoparticles, where adhesion energy governs both stability and performance. Taken together, these results elucidate the atomic-scale interaction mechanisms at interfaces, to guide the tailoring of adhesion in nanoscale devices.

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

8G — Northern Hemisphere A2

Environmentally Friendly Fluids IV

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3667627: The Performance of Diesel Engine Oil Containing Ashless Anti-Wear Additive and Detergent
Yasunori Shimizu, Moritsugu Kasai, Idemitsu Kosan Co., Ltd, Chiba, Japan

For environmental protection from air pollution, the emission from combustion engine has been severely regulated. Due to reduction of NOx gas and PM regulations, after treatment devices such as oxidation catalyst and DPF have been installed on diesel vehicle. However, it has already reported that sulphated ash, phosphorus and sulphur (SAPS) in engine oil deteriorate these performance. According to this background, the level of sulphated ash and phosphorus in engine oil standards has been reduced. From this point of view, authors have developed the novel engine oil with ashless additives instead of ZDDP and metal detergent. The developed oil showed good valve train wear protection and piston detergency in the engine tests required in JASO DH-2 specification, and also maintained good oil properties during fleet tests.

2 - 2:30 pm
3669374: Soybean-Based Cutting-Fluid Lubricants and Emulsifiers
Albert Darling, Daniel Garbark, Battelle Memorial Institute, Columbus, OH

Previously, Battelle has demonstrated the effectiveness of soybean oil derivatives in applications such as lubricants and surfactants. The experience in these technologies have allowed for development of novel classes of soybean-based cutting-fluid lubricants and emulsifiers. The tuning of fatty acid composition as well as modifications of these fatty acids are key synthetic levers by which the rise of advantageous properties such as pour points below -30C, oxidative and hydrolytic stability, and low viscosities can be achieved. With the emergence of epoxidized high oleic soybean oil as a competitively priced vegetable oil feedstock, these newly developed lubricants are projected to exhibit efficient production economics as well as the capacity for large-scale manufacturing. This presentation will demonstrate the utility and benefits of soybean oil through testing results obtained in cutting-fluid applications.

2:30 - 3 pm
3669386: Traction Coefficient Analysis in Environmentally Friendly Fluids.
Zach Hunt, VBASE Oil Company, Pendleton, SC

This presentation will cover an analysis of various Group V base oils for traction coefficient in slide-roll contact. In particular the analysis will investigate traction coefficients for ISO VG 22-68 Group V base oils comprising vegetable oil, polyol esters, oil soluble PAG, and a new hybrid PAG-Ester. The analysis will be used to present a case for quantifying lubricant derived efficiency gains in environmentally friendly fluids when compared to similar ISO VG petroleum derived products. The goal of our work is to highlight the high-performance of these Group V fluids and not just their environmental acceptability.

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

8H — Northern Hemisphere A3

Synthetic Lubricants and Hydraulics II

Session Chair: Ryan Fenton, BASF Corporation, Tarrytown, NY
Session Vice Chair: Lauren Huffman, Dow Chemical, Midland, MI

1:30 - 2 pm
3668709: Dynamometer Testing of Hydraulic Fluids in a Simulated Backhoe Loader Trenching Cycle
Paul Michael, Milwaukee School of Engineering, Milwaukee, WI

Hydraulic fluids were evaluated in a dynamometer simulation of a backhoe loader trenching cycle. The experimental fluids were formulated with polymers that exhibit shear-dependent viscosity loss in the critical range for axial piston pumps. Permanent viscosity loss and high shear-rate viscosities were evaluated in bench-top rheological tests. Inline viscosity and density sensors monitored changes in fluid properties during dynamometer testing. The trenching cycle was replicated by controlling pump swashplate position, outlet pressure, and speed. Torque and flow measurements were collected to evaluate pump performance. The results from the dynamic duty cycle test were compared to standard steady state measurements collected via the ISO 4409 pump performance test. Differences in the flow rate and pressure were observed. The implications for the practical testing of energy efficient hydraulic fluids are discussed.

2 - 2:30 pm
3679369: Effects of Corrosion Inhibitors on Liquid Superlubricity of Water-based Lubricants
Jannat Ahmed, Q Jane Wang, Yip-wah Chung, Northwestern University, Evanston, IL; Ning Ren, Ying Yang, Roger England, Valvoline Inc., Lexington, KY

Water-based fluids show superlubricity under certain conditions; however, corrosion of the interactive surfaces is a concern. Lubricant corrosion inhibitors help reduce or prevent corrosion of the material surfaces under lubrication. In this work, we examined three types of corrosion inhibitors and their effects on the tribological behavior of the glycerol aqueous solution with a water/glycerol weight ratio of 0.2. The experiments were conducted under the Hertzian stress up to 800 MPa and sliding speed up to 0.15 m/s. The friction results were compared with previous observations of superlubricity, by which we identified factors influencing lubricant performance and achievement of superlubricity.

2:30 - 3 pm
3668663: The Unexpected Active Behaviour of Synthetic Esters as Cobase Stocks on Resistance to Oxidation

Siegfried Lucazeau, NYCO, Paris, France

Synthetic esters are well known for their excellent thermo-oxidative stability, amongst other properties. Introducing esters as components in hydrocarbon based ashless formulation results in improved resistance to oxidation and cleanliness, as showed by oxidation and coking test results on ISO VG 32 and ISO VG 100, group II and PAO based compressor oil formulations. Whilst it is somewhat expected that introducing 5 to 20% of an oxidatively stable base fluid in a formulation proportionally reduces the effects of oxidation, things may not be that simple. Further data analysis will discuss the dilution effect generated by the introduction of a stable cobase and the possible synergistic interactions between esters and anti-oxidants. Introducing performance esters in mineral or PAO based formulations appears like a cost-effective boosting technology delivering improved resistance to oxidation and cleanliness, amongst other benefits.

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

3:30 - 4 pm
3647952: Liquid Amides – Novel, High Performance Base Oils
Claire Ward, Croda, Goole, United Kingdom

This paper examines a tertiary liquid amide which has been structurally designed for use as a novel, high performance Group V base oil in industrial and automotive applications. The hydrolytic and oxidative stability benefits of the new liquid amide base oil could offer enhanced product performance and lifetime over some conventional esters in challenging high temperature environments with the potential for water ingress. Both of these stability benefits are showcased in fully formulated oils for a number of industrial applications. Inherent corrosion inhibition properties of the amide and reduced oxidative degradation deposits could also help to extend the service life of this base oil and some of the mechanical components it comes into contact with. The intrinsic differences in amide and ester polarity also expand the solubility properties of this new base oil, helping to create stable formulations with some challenging components in PAO and GTL based systems.

4 - 4:30 pm - **Synthetic Lubricants and Hydraulics Business Meeting**

8I — Northern Hemisphere A4

Fluid Film Bearings III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3641565: Fluid Film Bearing Damage Detection from Vibration Data
John Yu, Baker Hughes, Houston, TX

Fluid film bearing damage occurred during startup after an outage on a steam turbine generator. Vibration reached over full scale of 20 mil pp (508 µm pp) at generator drive end bearing and therefore tripped the unit. The major vibration component that tripped the unit was 0.5X sub-synchronous at a level of over 20 mil pp (508 µm pp). 1X synchronous vibration excursions existed at constant speed before the trip event. Abnormal shaft centerline positions were observed. Shaft bow reached 10 mil pp (254 µm pp) at low speeds during coast-down. Bearing metal temperature reading was invalid. After an in-depth vibration data review, diagnostic conclusions and recommendations were made, followed by corrective actions. Inspection and findings confirmed bearing damage and rubs. If the vibration issue had simply be treated as rub, followed by re-start without opening the casing, further catastrophic damages would have occurred.

2 - 2:30 pm
3650184: Tribology Induced Water Pump Bearing Failure
Christopher Dellacorte, Samuel Howard, NASA, Cleveland, OH

NASA's In-Space Propulsion facility recently experienced two infant mortality water pump bearing failures with unknown origin. The failure investigation included site visits, collection and examination of physical evidence and a bearing and pump design review. The pumps are large (2000 hp) vertical turbine design machines that utilize metallic sleeve bearings cooled and lubricated by the pumped fluid (water). Detailed examination of failure surfaces combined with bearing design revealed that the failure mode was thermal seizure brought on by inadequate cooling flow. An unusual contributing factor was that the use of grease as an assembly lubricant, as opposed to a fluid like oil, appears to have exacerbated the rather than alleviated the thermal runaway by blocking water flow. Resolution of the problem was achieved through the design and installation of dedicated bearing lubrication water feed system.

2:30 - 3 pm
3641442: Performance Analysis of Multirecess Hybrid Spherical Journal Bearing Operating with Power Law Lubricant
Satish Sharma, Adesh Tomar, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India

The present study investigates the influence of power law lubricant on the performance of four-pocketed hybrid spherical journal bearing system compensated with capillary restrictors. The modified Reynolds equation along with the capillary restrictor equation has been solved using Finite element method. A Matlab source code has been developed to simulate the non-Newtonian behavior of power law lubricant. The numerically simulated results reveals that the bearing performance is significantly affected by using power law lubricant. It has been observed that the non-Newtonian behavior of power law lubricant enhances the value of minimum fluid film thickness , fluid film stiffness and damping coefficients by an order of 24.07%, 12.86% and 19.68% respectively, as compared to correspondingly similar bearing operated with Newtonian lubricant. The present study is expected to be beneficial to the academia and bearing design engineers.

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

8J — Northern Hemisphere E1

Materials Tribology IV

Session Chair: TBD
Session Vice Chair: TBD

Session Information TBD

8L — Northern Hemisphere E3

Tribology of Biomaterials II

Session Chair: TBD
Session Vice Chair: TBD

Session Information TBD

Preliminary Author Index
(As of November 24, 2021)