2019 STLE Annual Meeting and Exhibition

Omni Nashville Hotel
Nashville, TN

2019 Preliminary Technical Program
as of 3/01/19

Program At A Glance

Preliminary as of 3/01/2019

Sunday, May 19, 2019

Registration
7 am – 6 pm – 2nd Level Omni Foyer

Education Course Faculty Breakfast
7 – 7:45 am – Legends D

Education Courses - 8 am - 5 pm
(Rooms Not Yet Assigned)
ABMA Bearings -
Advanced Lubrication 301 –
Advanced Tribology 310: Nanotribology –
Automotive Lubrication 201:- Diesel
Biolubricants and Biofuels -
Hydraulics 201–
Metalworking Fluids 115 –
Synthetics 203

Student Networking Reception - 6:30 – 8 pm - TBD
Restaurant and Bar

Monday, May 20, 2019

Registration
7 am – 6 pm – 2nd Level Omni Foyer

Monday Speakers Breakfast
7 – 7:45 am – Legends D

Technical Sessions - 8 am - 10 am
1A Materials Tribology I– Legends A
1B Lubricant Fundamentals I –Legends B
1C Engine and Drive Train Special Session on Electric Vehicles I – Legends C
1D Gears I – Music Row 1
1E Commercial Marketing Forum 1 –Music Row 5
1G Wind Turbine Tribology I – Music Row 3
1J Nanotribology I – Cumberland 3
1K Metalworking Fluids 1 – Cumberland 4
1L Nonferrous Metals I – Cumberland 5
1M Fluid Film Bearings I – Cumberland 6

Opening General Session - 10:30 am – 12 Noon
Keynote Address – Legends Ballroom
Jeff Hemphill, Chief Technical Officer, Americas
Schaeffler Group USA Inc.

Lunch on your own - 12 Noon – 1:30 pm

Commercial Exhibits and Student Posters -
12 Noon – 5 pm – **Broadway Ballroom**

Technical Sessions - 1:30 pm – 6 pm
2A Materials Tribology II – Legends A
2B Lubrication Fundamentals II – Legends B
2C Engine and Drive Train Special Session on Electric Vehicles II – Legends C
2D Gears II – Music Row I
2E Commercial Marketing Forum II- Music Row 5
2G Wind Turbine Tribology II – Music Row 3
2H Testing in Soft Tribology – Tribotesting & Materials Joint Session – Music Row 2
2J Nanotribology II – Cumberland 3
2K Metalworking Fluids II – Cumberland 4
2L Nonferrous Metals II – Cumberland 5
2M Fluid Film Bearing II – Cumberland 6

Beverage Break - 10 – 10:30 am – Legends Ballroom Foyer

Exhibitor Appreciation Break - 3 – 4 pm – Broadway Ballroom

Networking Reception - 6:30 – 8 pm – Legends Ballroom

Tuesday, May 21, 2019

Registration
7 am – 6 pm – 2nd Level Omni Foyer

Tuesday Speakers Breakfast
7 – 7:45 am – Legends D

Commercial Exhibits and Student Posters -
9:30 am – 12 Noon & 2 – 5:30 pm – Broadway Ballroom

Technical Sessions - 8 am – 12 Noon
3D Wear I - Music Row 1
3E Commercial Marketing Forum – Music Row 5
3F Metalworking Fluids III – Music Row 4
3G Tribotesting I – Music Row 3
3H Fluid Film Bearings III – Music Row 2
3I Engine and Drive Train I – Cumberland 1/2
3J Nanotribology III – Cumberland 3
3K Environmentally Friendly Fluids I – Cumberland 4
3L Lubrication Fundamentals III – Cumberland 5
3M 2D Materials I –Materials & Nanotribology Joint Session – Cumberland 6

President's Awards Luncheon/Business Meeting -
12 Noon - 2:00 pm – Legends Ballroom

Technical Sessions - 2 pm – 6 pm
4D Wear II – Music Row 1
4E Commercial Marketing Forum IV – Music Row 1
4F Metalworking Fluids IV – Music Row 4
4G Tribotesting II – Music Row 3
4H Materials Tribology III – Music Row 2

4I Engine and Drive Train II – Cumberland 1/2
4J Nanotribology IV – Cumberland 3
4K Environmentally Friendly Fluids II – Cumberland 4
4L Lubrication Fundamentals IV – Cumberland 5
4M 2D Materials II – Materials & Nanotribology Joint Session – Cumberland 6
4N Discussion Round Tables – Legends A

Beverage Break - 10 - 10:30 am – Broadway Ballroom

Exhibitor Appreciation Break - 3 – 4 pm Broadway Ballroom

Wednesday, May 22, 2018

Registration
7 am – 6 pm – 2nd Level Omni Foyer

Wednesday Speakers Breakfast
7 – 7:45 am – Legends D

Commercial Exhibits & Student Posters -
9:30 am – 12 Noon –Broadway Ballroom

Education Courses - 8 am - 5 pm (Rooms Not Yet Assigned)

Advanced Lubrication 302 –
Basic Lubrication 103 –
Metalworking Fluids 130 –
Synthetic Lubrication 204 –

Technical Sessions - 8 am – 12 Noon

5A Rolling Element Bearings I – Legends D
5B Wear III – Music Row 1
5C Commercial Marketing Forum V – Music Row 5
5D Joint STLE / CTI Symposium of Frontiers of Tribology Research – Music Row 4
5E Tribotesting III –Music Row 3
5F Synthetic and Hydraulic Lubricants 1 –Music Row 2
5G Engine and Drive Train III –Cumberland 1/2
5H Nanotribology V – Cumberland 3
5I Surface Engineering I – Cumberland 4
5J Lubrication Fundamentals V –Cumberland 5
5K Tribology of Biomaterials – Biotribology & Materials Joint Session –Cumberland 6

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

Technical Sessions - 1:30 pm - 6 pm

6A Rolling Element Bearings II – Legends D
6B Biotribology I – Music Row 1
6C Commercial Marketing Forum VI – Music Row 5
6D Joint STLE/CTI Symposium on Frontiers of Tribology Reseach II : Lubricant and Chemistry – Music Row 4
6E Tribochemistry – Materials & Nanotribology Joint Session – Music Row 3
6F Synthetic and Hydraulic Lubricants II – Music Row 2
6G Engine and Drive Train IV: Advanced Fuel Efficiency, Engine and Drive Train Hardware Technologies – Cumberland 1/2
6H Nanotribology VI – Cumberland 3
6I Surface Engineering II : Additive Manufacturing– Cumberland 4
6J Lubrication Fundamentals VI – Cumberland 5
6K Condition Monitoring I – Cumberland 6

Beverage Break - 10 - 10:30 am – Broadway Ballroom

Beverage Break - 3 - 3:30 pm – 2nd Level Omni Foyer

Thursday, May 23, 2018

Registration
7 am – 12 Noon -2nd Floor Omni Foyer

Thursday Speakers Breakfast
7 – 7:45 am – Legends A

Certification Exams
8:30 am – 12:30 pm – Mockingbird 2

Technical Sessions - 8 am – 12 Noon

7A Rolling Element Bearings III – Legends D
7B Biotribology II – Music Row 1
7C Power Generation I – Music Row 5
7E Tribochemistry – Materials & Nanotribology Joint Session II – Music Row 3
7F Synthetic and Hydraulic Lubricants III – Music Row 2
7G Grease I – Cumberland 1
7H Materials Tribology IV – Cumberland 2
7I Contact Mechanics I – Cumberland 3
7J Surface Engineering III : Surface Texturing –Cumberland 4
7K Lubrication Fundamentals VIII – Cumberland 5
7L Condition Monitoring II – Cumberland 6

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

Technical Sessions - 1:30 pm - 6:00 pm

8A Rolling Element Bearing IV – Legends D
8B Biotribology III – Music Row 1
8C Power Gemeration II – Music Row 5
8D Seals i – Music Row 4
8E Tribochemistry – Materials and Nanotribology Joint Session II – Music Row III
8G Grease II – Cumberland 1
8H Materials Tribology V – Cumberland 2
8I Contact Mechanics II – Cumberland 3
8J Surface Engineering IV – Cumberland 4
8K Engine and Drive Train V – Cumberland 5
8L Condition Monitoring III – Cumberland 6

Beverage Break - 10 – 10:30 am – 2nd Floor Foyer

Beverage Break - 3 – 3:30 pm - 2nd Floor Foyer

Materials Tribology I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Tribology of Polybenzimidazole-Polyetheretherketone (PBI-PEEK) Blend
Janet Wong, Imperial College London, London, United Kingdom

High performance polymers such as polybenzimidazole (PBI) and Polyetheretherketone (PEEK) are used in high temperature tribological applications. In this work, we compare the high temperature tribological performance of PBI, PEEK, PBI-PEEK and carbon-fiber reinforced PBI-PEEK when they are rubbed against steel in unlubricated conditions. In some cases, materials transfer are observed. The process of materials transfer are investigated and possible mechanisms and determining factors are discussed. The properties of transfered materials are characterised and are correlated to tribological performances of these polymers. Our results suggest that heat management at the rubbing contact may play a significant role in the friction and wear experienced by the rubbing pair.

8:30 - 9:00 am
Mechanical and Thermal Performance of Interpenetrating versus Singular Networks of Dynamically Crosslinked Polymers
Ballal Ahammed, Zhijiang Ye, Nethmi De Alwis, Dominik Konkolewicz, Mehdi Zanjani, Miami University, Oxford, OH

Dynamically crosslinked polymers and composites have received great attention recently due to their unique properties such as self-healing, malleability, and shape memory which are desirable for many tribological applications. However, it is still lack of understanding how the configurational arrangement and the nano/microstructure affect the mechanical, tribological and thermal properties. Here, we report a combined computational (Molecular Dynamics simulations) and experimental study of the mechanical and thermal properties of two main categories of self-healing polymer composites: Interpenetrating Networks (IPNs) and Single Networks (SNs). We evaluate and discuss the configurational details and structural impact on the mechanical and thermal performance. Our results show that IPNs outperform SNs in terms of their mechanical and thermal properties provided that the overall crosslinker densities are the same within the two network types.

9:00 - 9:30 am
Experimental Investigation into the Combined Effects of Roughness and Stiffness in Soft-Material Adhesion
Abhijeet Gujrati, University of Pittsburgh, Pittsburgh, PA, Siddhesh Dalvi, Ali Dhinojwala, The University of Akron, Akron, OH, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Many theoretical models predict the adhesion of soft materials on hard surfaces, but experimental validations of these models are limited. One reason is that adhesion depends on surface topography and, as most surfaces have multi-scale roughness; experimental roughness parameters vary depending on measurement size and technique. Here we performed adhesion tests using hemispherical lenses of polydimethylsiloxane with varying elastic modulus and polycrystalline diamond surfaces with varying roughness. The surface topography was characterized across length scales to calculate scalar and spectral roughness parameters. Adhesion tests were performed with in-situ optical measurements and

results were analyzed using a multi-scale mechanics model. The accuracy of the model depended on how the topography was measured and which assumptions were made. The adhesion data shows the combined effects on adhesion of the surface roughness of the hard material and the elastic modulus of the soft material.

9:30 - 10:00 am
Experimental Measurements of Roughness-Dependent Adhesion in Hard-Materials Contacts
Luke Thimons, Abhijeet Gujrati, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Adhesion in hard contacts is highly sensitive to roughness. Recent models suggest large-scale adhesion depends on topography across many length scales. In this experimental investigation, micro- to millimeter-scale spheres of alumina and steel were brought into contact with silicon and nanodiamond substrates of varying roughness. The tips and substrates were characterized across multiple length scales using stylus profilometry, AFM, and in some cases, TEM. Adhesion tests were performed and results were analyzed in light of three types of models: single-scale elasticity (e.g. extensions to the model of Greenwood and Williamson); single-scale rigid-body (e.g. the “modified Rumpf” model described by Rabinovich); and multi-scale elasticity (e.g. models by Persson). In all cases, simple scalar roughness parameters failed to capture the observed behavior. Better agreement between model predictions and experiments was achieved using spectral analysis and accounting for multi-scale roughness.

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

1B Legends B

Lubrication Fundamentals I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Friction Modification Mechanism of Surface Pores
Arman Khan, Qian Wang, Northwestern University, Evanston, IL, Zhe Li, Yuchuan Liu, Fanghui Shi, General Motors, Detroit, MI

Surface features in the form of dimples, textures, and grooves have been shown to result in friction reduction and the associated mechanisms are well established. Here, we report another mechanism referred to as “artificial slip mechanism” which could be another reason that could explain the low friction capability of these porous surfaces. Comprehensive two-phase computational fluid dynamics (CFD) simulations are conducted to study the dependence of slip performance and cavitation occurring inside the pore on the pore’s geometrical features. A transient hydrodynamic model by employing extended Reynold’s equation incorporating the slip coefficients derived from the CFD model is also presented. The study is particularly useful for the ring-liner interfaces of an IC engine.

8:30 - 9:00 am
Connecting Discontinuous and Continuous Tribological Models
Guytri Kastane, Institut Pprime, Montpellier, France, Mathieu Renouf, University of Montpellier, Montpellier, France, Noel Brunetiere, Institut Pprime, Futuroscope Chasseneuil cedex, France

Modelling mixed lubrication necessitates considering asperities contact and wear as well as fluid flow between rough surfaces. This can be done by using the discrete element method (DEM) for the solids interaction coupled with continuous lubrication models based on the Reynolds equation solutions. One key-point in this approach is the information transfer between the discontinuous and continuous models. In this first part of the coupling, we are interested in the surface topography transfer between the models .

An initial rough profile is discretized with a DEM approach. Then the profile is reconstructed from the discrete elements model using different reconstruction techniques. The error between the reconstructed and the initial rough profiles is analysed considering particles size, the surface statistical properties and the reconstruction method. The impact of this error on the solid and fluid models solutions is analyzed to define a reconstruction strategy.

9:00 - 9:30 am
On the Surface Lift-Off Transition in Rough Surface EHL Contacts
Jonny Hansen, Marcus Björling, Roland Larsson, Machine Elements, Luleå University of Technology, Luleå, Sweden

The pumping and churning losses in transmission assemblies are minimized when gears are operated in low viscosity lubricants. Therefore, in order to improve gear efficiency, it is of crucial importance to gain knowledge about the underlying mechanism that governs elastohydrodynamic (EHL) contacts ability to form a separating oil film. This study was set out to explore the necessary requirements for EHL contacts to achieve a state of full film separation. A ball on disc device, arranged for electrical contact resistance (ECR) measurement, was operated under a wide variety of heavily loaded rolling/sliding conditions. Friction and ECR-signal were simultaneously monitored to capture the contact performance until surfaces achieved lift-off by adequate surface modification due to running-in. Special emphasis was set on post-test surface analysis to reveal whether any surface roughness parameter could provide insights in the pre-requisite for surface lift to take place.

9:30 - 10:00 am
Novel Insight into Tribology of Carbon Black Soot Particles in Engine Oil
Deepak Halenahally Veeregowda, Angela Tortora, Ducom Instruments Europe B.V, Groningen, Groningen, Netherlands

In this study, we have tested the friction and wear response of carbon black (surrogate for engine soot) on different steel surfaces, using the high frequency reciprocating rig and SEM - EDX. Chemisorption of ZDDP on the steel surface prior to friction test resulted in severe wear but the shear-induced chemisorption of ZDDP on the steel surface showed the lowest wear. Changes in wear was related to the concentration of Zn and P, which represents antiwear phosphate film on the surface. Chemisorption of ZDDP encouraged the CB to remove the anti-wear phosphate films, that triggered severe micro-pitting and grooves on the disk surface. However, there were no grooves or micro pitting on steel due to shear-induced chemisorption of ZDDP. As it retained the anti-wear phosphate film against attack by CB. We confirm that preconditioning the steel has showed a profound effect on the soot wear mechanism. It can give important clues in formulating the soot wear resistant lubricants.

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

1C Legends C

Engine and Drive Train Special Program on Electric Vehicles I

Session Chair: B. Lotfi, ExxonMobil Chemical Co., Baytown, TX
Session Vice Chair: M. Webster, ExxonMobil Research & Engineering, Annandale, NJ

8:00 - 8:30 am
Efficiency and Emission of EVs in Comparison to IC Engines: A Life Cycle Analysis
Ali Erdemir, Argonne National Laboratory, Lemont, IL, Kenneth Holmberg, VTT Technical Research Centre of Finland, Helsinki, Finland

Electric vehicles (EV) are considered as the new paradigm for future transportation needs due to their higher efficiency and lower emissions than traditional internal combustion (IC) engines. While energy

losses due to rolling friction, aerodynamics, and braking are inherent in EVs as well, thermal and frictional energy losses are reduced substantially in EVs. We provide a side-by-side comparison of the energy consumption in IC vs EV cars. The energy efficiency for the IC case is about 21% while in the case of EVs, it could be 3.6 times higher (or about 77%). The friction-related losses excluding braking and rolling friction are 16.5% for the IC and only 6% for the EV car. We also carried out lifecycle analyses including not only the tank-to-wheel (mostly related to driving the vehicle), but also the well-to-tank plus the manufacturing, maintenance, and recycling stages thus providing a global picture comparing the overall efficiency and environmental impacts of both cases.

8:30 - 9:00 am
An Insight into E-Mobility
Dean Tomazic, FEV North America Inc., Auburn Hills, MI

Besides its zero emissions advantage, BEV's offer excellent drivability at superior efficiency. In contrast to ICE powertrain emissions and fuel economy challenges, BEV's have to overcome unique design and control challenges as system optimization is targeted over performance based value proposition. Hence, the BEV engineering community is developing novel solutions to optimize thermal management of batteries, E-Motors and power electronics. In this presentation, the authors will provide an insight into ongoing trends in electrified mobility including a deep dive assessment of opportunities and challenges that are ahead of the industry. The presentation will also provide an insight into how the design, controls and calibration are playing a role in BEV powertrain thermal management.

9:00 - 9:30 am
Automotive Fluids for Electrified Vehicles
Scott Halley, The Lubrizol Corp, Wickliffe, OH

The global focus on vehicle emission and greenhouse gas reductions has created an electrified vehicle spectrum ranging from traditional Internal Combustion Engines (ICE) through to Electric Vehicles; including hybrids, plug-ins, battery electric, and fuel cell powered vehicles. Driveline components and their respective fluids often receive attention as they are the integrators the propulsion system and the wheels. Fluids for these applications need to deliver the proper level of durability with electrical, thermal, and material compatibility properties in mind. Thermal management on electrified vehicles can also present some interesting challenges, particularly for engines and electrical systems. Batteries, for example, operate more efficiently when held within a narrow temperature range, while ICEs on certain electrified vehicles may operate at lower than traditional operating temperatures. Each of these systems can be enhanced using carefully selected fluid technologies.

9:30 - 10:00 am - **Open Discussion**

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

1D Music Row 1

Gears I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Complex Esters – A New Oxidatively Stable Lubricity Additive
Kevin Duncan, Croda, East Yorkshire, United Kingdom

Heavy duty applications such as automotive and industrial gear oils, and MWF's require higher viscosities with additional lubricity additives to cope with severe, hostile environments. Traditionally complex esters

have been used successfully in such applications, even with efficient lubrication a side effect on mechanical motion is heat. The presence of excessive temperature can lead to potential oxidation and subsequent breakdown of the molecule, impairing the performance and lifetime of the lubricant. Including an oxidatively stable ester in a finished lubricant gives the potential to extend life-cycles and reduce machine downtimes whilst simultaneously having no impact on properties such as elastomer compatibility and frictional performance. Croda has developed an oxidatively stable complex ester and compared it to commercially available alternative esters, in order to understand their influence in real life demanding applications, where potential oxidation could be a critical factor.

8:30 - 9:00 am
Efficiency Testing for Industrial Gearboxes
Paul Norris, Jakub Jelita Rydel, Chip Hewette, Helen Ryan, Afton Chemical, Bracknell, Berkshire, United Kingdom

Industrial gear efficiency has attracted a growing level of interest in recent years. Gearboxes are designed to be >90% efficient, so the prize is perceived to be small. However, with millions of gearboxes deployed worldwide small reductions in energy losses could yield huge cumulative energy savings globally. In order to expand on work that has already been published in the Industrial Gear efficiency space, a number of experiments were conducted utilising MTM, MPR and FZG techniques to evaluate the relative impacts of friction modifiers and thickener choice, as well as the impact of mineral base oil versus synthetic base oil. Results, conclusions and a review of work previously done in this area will be presented.

9:00 - 9:30 am
A Short Term Hot Hardness Evaluation of Advanced Aerospace Gear Steels
Cody Wassel, Aaron Isaacson, Sean McIntyre, Todd Palmer, Penn State University, Wayne, PA

The primary heat removal mechanism in rotorcraft gearboxes is the lubrication system. If lube system failure occurs and oil is no longer supplied to the gears and bearings, component temperatures can quickly exceed their design limits resulting in material property degradation. This work examines the short-term hot hardness characteristics of various carburized aerospace gear steels. Each alloy was heated in intervals of 50°C and held at temperature for 30 minutes prior to testing. Hardness tests were performed using a Rockwell test procedure with a 100 kilogram load and a 1/8-inch alumina ball indenter. The indentation depth was measured and converted to Rockwell C. For each alloy, the experimental hot hardness data is presented. Equations to predict the short-term hot hardness are discussed.

9:30 - 10:00 am
A New Thermally-Coupled Model for Prediction of Gearbox Power Losses
Kharthik Chakravarthy, Amir Kadiric, Imperial College London, London, United Kingdom

This paper presents a numerical approach for prediction of power losses in a simple dip-lubricated spur gearbox using a thermally coupled lubrication model. To provide the crucial link between the frictional heat generation in the contact and gear bulk temperatures, a multi-physics FE approach, with coupled fluid, phase and heat transport equations, is used to model the heat flows in the gearbox. The method employs a two-phase, phase field transport equation to track the interface between air and oil during the gear meshing. Churning losses are evaluated directly through viscous and pressure effects. The tooth bulk temperatures from the multi-physics model are then used in an EHL lubrication model to predict frictional losses in gear teeth contacts, while bearing losses are calculated using existing models. Gearbox efficiency predictions are compared for a range of operating conditions and different gear oils.

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

1E Music Row 5

Commercial Marketing Forum I

8:00 - 8:30 am - **Evonik Oil Additives, USA**

8:30 - 9:00 am - **Chevron Phillips Chemical Company**

9:00 - 9:30 am - **The Dow Chemical Company**

9:30 - 10:00 am - **Functional Products Inc.**

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

1G Music Row 3

Wind Turbine Tribology I

Session Chair: R. Voothaluru, The Timken Co., North Canton, OH

8:00 - 8:30 am
Comparison of Ultrasonic Load Measurements on an Operational Wind Turbine Bearing with Those Predicted by Ricardo SABR.
Benjamin Clarke, Gary Nicholas, The University of Sheffield, Sheffield, United Kingdom, Michael Wheeldon, Jonathan Wheals, Ricardo, Leamington Spa, United Kingdom, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

Bearing failures in wind turbines are amongst the most common and costly failures and cause large amounts of downtime; condition monitoring and further understanding of service conditions is therefore desirable. Ultrasonic methods for monitoring rolling element bearings have been developed in the lab and applied in the field and can monitor lubricant film thickness and contact load. This work compares ultrasonic load data from an operational wind turbine to those predicted by a SABR model of the drivetrain. A tapered roller bearing on the high speed shaft of a 600 kW turbine was monitored. SABR is a shaft, gear and bearing conception and design package based on engineering standards as well as Ricardo's experience. SABR predicted raceway loading was converted into element loading using SABR calculated loads and raceway stress distributions, along with Sjoväll's load integrals. Comparison of results showed good agreement between the ultrasound and SABR predicted loads.

8:30 - 9:00 am
Onsite Condition Monitoring for Offshore Wind Turbine Gearbox Lubricant Based on Colorimetry
Kyoko Kojima, Hitachi, Ltd., Kokubunnji, Tokyo, Japan

Lubricant condition monitoring is very effective technology for the gearbox monitoring based on the understanding of gearbox breakdown mechanism due to wear. Monitoring both oxidative degradation and contamination of the gearbox lubricant are necessary because they affect on wear and life of gearbox. We have developed a novel on-site diagnosis method for the gearbox lubricant based on colorimetry. Oxidative degradation is monitored as enhanced absorption in the blue light region. On the other hand, contamination with water, dust and wear particle is monitored as enhanced absorption of entire visible

light wavelengths. The threshold value of the oil degradation was determined by wear testing of used lubricant samples. Major economical advantage of introduction of this lubricant diagnosis technology is the extension of lubricant exchange interval.

9:00 - 9:30 am
Monitoring Load and Lubrication in a Wind Turbine Gearbox Rolling Bearing in the Field
Gary Nicholas, The University of Sheffield, Sheffield, United Kingdom, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Wind turbine gearbox bearings although having a moderate failure rate, will result in the longest downtime if failure occurred. Most of these failures are from bearing failure. Thus, monitoring these bearings will allow for better understanding of loading and lubrication condition, crucial information for bearing designers. Piezoelectric elements bonded onto the bearing surface can be used to send and receive ultrasonic signals. In this study, a high-speed shaft tapered roller bearing within an operational wind turbine was instrumented with ultrasonic sensors. The sensors were used to send ultrasonic pulses directly at rolling element - raceway contacts. When a wave is reflected from a contact, the flight path is reduced due to raceway deflection and the amplitude drops due to energy transmission into the roller. These two features were used to deduce the load and to investigate the oil film formation and then correlated with turbine operational parameters such as wind speed and power.

9:30 - 10:00 am
Characterization of White Etching Areas in Annealed AISI 52100 Processed by High Pressure Torsion Tests
Luis Wilches Peña, Ling Wang, University of Southampton, Southampton, Hampshire, United Kingdom, Alexander schwedt, RWTH , Aacheb, North Rhine-Westphalia, Germany, Brian Mellor, University of Southampton, Southampton, Hampshire, United Kingdom, Joachim Mayer, RWTH , Aacheb, North Rhine-Westphalia, Germany, Walter Holweger, Schaeffler Technologies AG & Co, Herzogenaurach, Bavaria, Germany

The study of White Etching Areas (WEAs) has mainly focused on samples those from field bearings disassembled after failure and bearings subjected to rolling contact fatigue tests in laboratories under various accelerators. This study investigated WEAs formed in annealed AISI 52100 after being processed on a High-Pressure Torsion (HPT) test rig where high strain is rapidly applied to create severe plastic deformation in materials (1) (2). Result show that WEA similar to those in bearings are formed in the annealed AISI 52100 bearing steel discs at three different locations under a range of loads and number of turns. Detailed SEM/EBSD/EDS characterisation on the WEAs both on the surface and in the subsurface of the HPT processed samples suggests that non-metallic inclusions in the material were found to interrupt the plastic flow in the samples under HTP testing, which has promoted the dissolution of carbides into the refined ferritic matrix.

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

1J Cumberland 3

Nanotribology I

Session Chair: J. Luo, Mechanical Engineering, State Key Laboratory of Tribology, Beijing, China
Session Vice Chair: J. Leong, Singapore University of Social Sciences,

8:00 - 8:30 am - **Session Starts at 8:30 am**

8:30 - 9:00 am
Development of Next Generation Coolants Using Nanofluids for Meeting Future Cooling Challenges in EV and Hybrid Vehicle Applications
Simon TUNG, Innovation Technology Consulting, Rochester Hills, MI

The development of advanced automotive technologies is hampered by a vital need for high performance cooling on electrical vehicles and power electronics. The conventional approach for enhanced cooling has reached its limits. Research using nanofluids has the high potential payoff to bring about a revolution in cooling technology. Nanofluid is a new class of heat transfer fluids created by dispersing solid particles smaller than 40 nm in oil-based fluid. The suspended nanoparticles remarkably improve thermal conductivity and heat transfer coefficient than the conventional coolants. In this investigation, experimental results show thermal conductivity and heat transfer coefficient have been enhanced. The effect of heat transfer has been measured as the volume fraction of the suspended nanoparticles. Heat transfer properties increase with the volume fraction of nanoparticles. Potential applications of nanofluids include the EV/hybrid vehicles, fuel cell, and the manufacturing operations.

9:00 - 9:30 am
Influence of Copper Oxide and Tungsten Carbide Nanoparticles on Micropitting under Boundary Lubrication
Sougata Roy, Yosef Jazaa, Sriram Sundararajan, Iowa State University, Ames, IA

This work investigates the potential of metallic nanoparticles as additives on crucial drivetrain failure mode called ‘micropitting’. Copper oxide (CuO) and tungsten carbide (WC) nanofluids were used as lubricants to observe their effect on micropitting life of AISI 8620 steel. The nanofluids consisted of 1% nanoparticles by weight and 1% by weight of oleic acid surfactant in Polyalphaolefin (PAO) base oil. Rolling contact fatigue tests were conducted using a micropitting test rig (MPR). Both the nanofluids exhibited increased micropitting life compared to the base oil (PAO). Tungsten carbide nanofluids showed significantly higher micropitting resistance behavior than the copper oxide nanofluids under the boundary lubrication regime. Post experiment surface characterization showed different mechanisms to inhibit micropitting and wear for the two nanofluids-the tungsten carbide nanofluid formed a tribofilm whereas the CuO nanofluids tended to fill surface cracks with the nanoparticles.

9:30 - 10:00 am
Synergistic Effects between Silver and Palladium Nanoparticles in Boundary Lubrication
Chanaka Kumara, Harry Meyer, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Oil-suspendable dodecanethiol-modified Ag and Pd nanoparticles (NPs) have been developed as candidate lubricant additives. The tribological performance of the NP-containing oils was evaluated using a ball-on-flat reciprocating sliding configuration at boundary lubrication at 100 ^{o}C. While either the Ag or Pd NPs by themselves possessed good friction reduction and wear protection abilities, a combination of the Ag and Pd NPs (0.10-0.25 wt% of each) exhibited promising synergistic effects by further reducing the friction (by 37%) and wear (by 80%) compared to using either alone. Morphology and chemical composition of the top and cross-section of the worn surface were characterized and revealed an Ag, Pd and S rich, ultra-thick (up to 3 µm) tribofilm. Galvanic replacement reactions between the Ag and Pd NPs have been evidenced and are believed to provide a stronger electron donation ability and consequently to enhance the lubricating performance

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

Metalworking Fluids I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Computational Study Aimed at Determining the Kinetics of Branched Esters Against Aminolysis
Mark Fennimore, Quaker Chemical , Conshohocken, PA

The performance of MWFs relies on the chemical and physical properties of esters. Esters in MWFs function primarily as lubricants; however, their behavior can influence other aspects of the fluid's performance including emulsion stability, foam and product shelf-life. As such, esters are chosen to optimized performance across as many parameters as possible to suite customer needs. Problems arise due to reactions that occur between the ester with other components in the MWF, e.g. reactions with amines producing amides. Amides have different properties compared to their ester counterparts resulting in deleterious changes to the product. Experiments have shown that aminolysis formation is strongly correlated to the structural features of the ester, particularly substitution near the active site. Computational analysis with Transition State Theory was used in the present investigation to elucidate the structural motifs that give rise to aminolysis resistance in esters relevant to MWFs..

8:30 - 9:00 am
An Innovative Edger Rolling Oil for Steel Plants
Natarajan Sivasurian, S Paul, R Mahapatra, P Bhatnagar, D Saxena, S S V Ramakumar, Indian oil Corporation Limited, Faridabad, Haryana, India

Historically water was used for hot rolling in Indian Steel Industries. This trend has changed during last few years and steel plants are using hot rolling lubricating oil dispersion in water through roll bite lubrication system. The hot rolling oil dispersion in water is being used for the Hot Strip Mill of few Steel Plants in India, where oil is contributed as lubricant and water as coolant and users are increasing. The paper deals with the development of an edger rolling lubricant for Hot Strip Mill in authors laboratory comprising combination of specialty additives having excellent lubricity, antiwear and EP characteristics and its extensive field trial for establishing the product performance in one of the most reputed Indian Steel Plant. The paper also discuss the analysis of data obtained during field trial. The developed edger rolling oil has provided reduced wear of roll with extended roll protection, defect elimination of edges, improved campaign length and energy savings.

9:00 - 9:30 am
Metalworking Fluids and Chloride Corrosion on Iron Alloys
John Burke, Alan Cross, Houghton International, Norristown, PA

Water diluted metalworking fluids are formulated to provide cooling and lubrication at the tool work piece interface, flush chips from the cut zone and fixtures, and provide interim corrosion protection. With extended reuse and recycling of fluids becoming more popular, the buildup of contaminants becomes inevitable and problematic. These contaminants can interfere with fluid performance in several ways. One type of contamination is from the chloride anion. It has been observed that as chloride levels increase, so does the corrosion on surfaces of iron alloys. The corrosion is manifested in the form of rust and pitting. This paper will demonstrate the effects of increasing corrosion effects on steel test panels with various levels of chloride contamination on different types of water diluted fluids such as synthetic, semi-synthetic and emulsifiable oils.

9:30 - 10:00 am
Polyalkylene Glycol as Performance Wear Lubricant Additive on Straight Oil
Eduardo Lima, Dow Chemical Company, São Paulo, São Paulo, Brazil

Additives typically called anti-wear or lubricity promoter's acts on preferential adsorption compounds on metal surfaces, forming a monomolecular film strongly adhered to the metal, which avoids contact between moving parts. Straight oil metalworking fluids users keep demanding higher lubricity and stability levels to attend continuous metal materials evolution proposals following developments from automotive and machinery industry. This study has shown positive results with oil soluble polyalkylene glycol use, in comparison with an elected fatty base benchmark, as making possible additive reduction up to 5 (five) times lower and with superiority results on proposed methodologies and related lab tests conditions adopted.

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

1L Cumberland 5

Nonferrous Metals I

Session Chair: R. Pruhs, Quaker Chemical,
Session Vice Chair: G. Biresaw, BOR, USDA-ARS-NCAUR-BOR, Peoria, IL

8:00 - 8:30 am
Static Multiple Light Scattering as a Tool to Characterize Stability and Size of Nonferrous Fluids
Mike Gould, Christelle Tisserand, Formulaction, Worthington, OH

Nonferrous rolling emulsions are well known systems but their formulation evolved over the years asking to the formulators to remain continually innovative to keep expected performances. Different physico-chemical factors are responsive of their efficiency like stability, droplet size. In this study, we propose to present a review of non ferrous emulsions systems and some results of physical analysis studies with Static Multiple Light Scattering technique. This method provides a non-intrusive optical characterization of a native sample without dilution. An infrared light source illuminates the sample and the backscattered and transmitted light intensity signals are collected simultaneously by two sensors over the whole samples height and repeated over time. The resulting spatial and time dependent signals T and BS are directly linked to the fundamental properties of the emulsion (particles mean size, concentration, …) as well as physical instabilities (flocculation, creaming…).

8:30 - 9:00 am
Friction Reduction on Anodized Alumina by Impregnating Ashless Fillers
Svajus Asadauskas, Tadas Matijosius, Center for Physical Sciences and Technology, Vilnius, Lithuania
Due to exceptional hardness, paintability, corrosion resistance and other advantages, anodized coatings are widely utilized on frames, casings, railings, fasteners and many other aluminum items. In many cases they are exposed to friction, which leads to severe damage, because the anodized coatings are highly porous and brittle. Frequently fluoropolymers are applied onto the anodized coating in order to reduce friction and wear. However, the procedure is labor intensive, involves heating above 300°C and requires expensive dispersions. In this study a number of ashless fillers were evaluated after impregnating them into the anodized coatings on industrial aluminum alloys. Their capability to participate in friction zone reactions resulted in dramatic reduction of wear and friction, often exceeding the performance of PTFE. A number of field tests with different final applications demonstrated excellent technological advantages of the investigated materials.

9:00 - 9:30 am
Update on Challenges in Machining Aluminum Alloys
Neil Canter, Chemical Solutions, Willow Grove, PA

Use of aluminum alloys in machining operations continues to be growing in importance in applications such as automobiles where lower vehicular weight is needed to improve fuel efficiency. This presentation will provide an update on the issues surrounding the machining of aluminum alloys with an emphasis on metal removal operations. Included in the discussion will be an update on the types of additive chemistries that are available to be used and the continuing need for better aluminum stain inhibitors. Current Health & Safety issues will also be examined as these concerns may limit the tools that formulators can use in developing suitable metal removal fluids.

9:30 - 10:00 am
Aluminum Staining: Achieving Performance without Sacrificing Fluid Longevity
Nicole Clarkson, ANGUS Chemical Company, Buffalo Grove, IL

Aluminum staining can be affected by several factors in a metalworking fluid (MWF) formulation. To name some of the more common influences, high pH and soft water have been known to negatively affect staining. However, formulating at a lower pH can incite poor fluid longevity, and water quality at the end user is almost always out of a formulator's control. To combat poor aluminum staining, chemistries such as phosphate esters, as well as other products, are utilized. But what if there's more to the story? Today's presentation focuses on other pieces of the formulation which can be adjusted to achieve aluminum staining performance without sacrificing other fluid criteria, such as fluid longevity.

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

1M Cumberland 6

Fluid Film Bearings I

Session Chair: TBD
Session Vice Chair: TBD

8:00 am - 8:30 am
On The Effect of Journal Kinematics on the Force Coefficients of a Test Squeeze Film Damper Supplied With an Air in Oil Mixture
Luis San Andrés, Xueliang Lu, Texas A&M University, College Station, TX, Wei Zhang, Tianjin University, Tianjin, China

Squeeze film dampers (SFDs) reduce vibration and enhance stability in rotating machinery. Operation at a high squeeze velocity draws air into the film to make a bubbly mixture that produces notable changes in the SFD performance. During tests an air in oil ISO VG 10 mixture of known gas volume fraction (GVF) and low pressure [0.1 barg] is supplied at the damper [c=0.3% D, L=0.36 D] top end, to atmospheric discharge at the bottom end. Single frequency loads and impact loads serve to identify force coefficients. When supplied with a liquid the SFD shows a direct dynamic stiffness (Kd) reducing with frequency. When supplied with a mixture Kd increases with frequency. The damping (C) identified from periodic loads decreases as the GVF increases from 0 to 1; C estimated from impact loads first increases with GVF to 0.4 and then drops with a further increase in GVF. Thus, the results show the kinematics of journal motion affect the force coefficients of a damper operating with air ingestion.

8:30 - 9:00 am

On the Static Load Performance of a Large Size, Heavily Loaded Spring Supported Thrust Bearing

Rasool Koosha, Luis San Andrés, Texas A&M University, College Station, TX

The paper describes a thermoelastohydrodynamic (TEHD) analysis for predictions of the static performance of a large size spring-supported thrust bearing (SSTB). The bearing pads include pockets for hydraulic lift and an internal cooling system with pipes laid out along the radial direction. Pressure induced deformations significantly enlarge the film thickness at the pads' leading and trailing edges. Pad thermal deformations are lesser, except at the pad trailing edge where cooling lines do not reach. Bearing operation transitioning from a nominal rotor speed to a low rotor speed while the bearing pads remain hot simulates a quick shut-down process. With a hot pad the predictions produce a much lesser fluid film thickness than that arising during a slow shut-down process where the bearing pads cool at a steady rate. The gradient of minimum film thickness versus rotor speed is much higher during the fast shutdown process which could lead to a sudden bearing failure.

9:00 - 9:30 am

Design of Numerical Optimization for Gap-Compensated Hydrostatic Bearing

Nenzi Wang, Yu-Wen Chen, Hsin-Yi Chen, Chang Gung University, Tao-Yuan, Taiwan

In this study, the objectives of the design of optimization are to develop an effective data sampling technique for selecting initial search population and stopping criteria at the end of the optimization. A gap-compensated hydrostatic bearing with several design variables is the design target. The goals are to minimize the bearing friction while maximizing the bearing stiffness. The particle swarm optimization method is chosen for easy implementation with high efficiency. A good sampling technique can speed up the search of the optimum design and properly-selected stopping criteria can minimize the search effort without sacrifice the solution accuracy. For a given total number of function evaluations, several cases with various population sizes and epochs are tested. The case with the best solution convergent rate can then be determined. This study illustrate the selection of an effective sampling technique for initial population and the stopping criteria of the bearing optimization.

9:30 - 10:00 am

The Performance of Small Centre Pivoted PTFE Thrust Bearings in Low to Medium Speed Applications

Stephen Dixon, John Butler, Paul Bruce, Michell Bearings Ltd, South Shields, Tyne and Wear, United Kingdom

PTFE faced thrust pads have proven to be a very robust and reliable solution for large, and sometimes problematic, hydrogenerator applications. In such applications the thrust pads can have a radial width in the order of 400-900 mm. However, there are numerous smaller machine types using hydrodynamic bearings requiring much smaller pads, typically less than 150 mm. For such applications, does PTFE also have advantages over the traditional Babbitt lining? This paper outlines recent work undertaken to assess the performance of two sizes of 'small' PTFE faced thrust pads across a speed range of 2.5-35 m/s, typical of vertical pump applications. Unlike hydrogenerators, which are predominantly unidirectional, pumps are very commonly subject to rotation reversals. For this purpose, the work focused mainly on centrally pivoted thrust pads which have the same performance characteristics in both rotation directions. Results are presented for 80 and 150 mm radial width thrust pads.

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

Materials Tribology II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:30 pm
Self-Organization in Materials Subjected to Severe Plastic Deformation: Relevance and Application to Wear Resistance of Metallic Alloys.
Pascal Bellon, Robert Averback, University of Illinois at Urbana-Champaign, Urbana, IL

Materials are often subjected to plastic deformation during their fabrication and their service life. This plastic deformation can alter phase stability and modify properties. These nonequilibrium environments can also lead to self-organization, for instance through the formation of tribolayers during wear. We will show that in alloys, severe plastic deformation can lead to chemical self-organization at the nanoscale, at temperatures where thermal diffusion is or is not significant. Experiments, modeling and atomistic simulations indicate that this nanostructuring results from competing kinetic processes with distinct characteristic length scales. This perspective will be illustrated on alloys subjected to sliding and erosion wear, or processed by ball milling, accumulative roll bonding, and high-pressure torsion. We will show that self-organization reactions leading to the formation of nanolayers can be used to design materials with improved wear resistance.

2:30 - 3:00 pm
Adhesion, Self-Welding and Static Friction Coefficient of Ni Alloys at Elevated Temperature
Md Saifur Rahman, Andreas Polycarpou, Texas A&M University, College Station, TX

Metals contacting at elevated temperature increase the complexity of explaining tribological characteristics even for the super alloys like Inconel 617 and 800H. The presence of Helium gas as coolant and impurities in the Very high Temperature Reactor (VHTR) makes the scenario more confounding. The static friction coefficient (sCOF) is being investigated for the before mentioned alloys at high temperature helium environment. Alloy 800H showed sCOF as high as 3.74 at 750 ^{o}C, whereas Inconel 617 showed 2.28 at 950 ^{o}C in helium atmosphere. The possibility of getting the materials self-welded at high temperature were also investigated to explain the high friction behavior. The samples were self-welded under high contact pressure in atmosphere controlled furnace and welding strength were measured using micro tensile stage. Presence of high adhesion force between the alloy surfaces resulted in very high static friction coefficient.

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

4:00 - 4:30 pm
Understanding the Role of Protective Metal Oxides in Nanoscale Tribocorrosion
Alex Lin, Xiao-xiang Yu, Laurence Marks, Northwestern University, Evanston, IL

Tribocorrosion is the degradation of a material due to the effects of simultaneous mechanical and chemical (corrosive or oxidative) damages. It is well-established that these modes of attack are not simply additive and that additional synergistic effects are often at work. In this study, direct observations of nanoscale tribocorrosion were conducted on NiCrMo and CoCrMo alloys. The general experimental approach is to first prepare electron transparent samples, then expose them to controlled oxidative or corrosive conditions, and finally use them as samples for in situ tribological experiments in a transmission electron microscope. By characterizing the structural and chemical changes of the protective oxide films in these alloys, fundamental changes in the adhesion of the films as a function of the growth and dissolution rates can then be revealed.

4:30 - 5:00 pm

Evaluation of Friction Performance and Wear Reduction of Boronized Steels

Brandon Wong, Philip Egberts, University of Calgary, Calgary, Alberta, Canada, Eugene Medvedovski, Endurance Technologies Inc., Calgary, Alberta, Canada

The purpose of this research is to examine the impact iron boride-based coatings obtained through thermal diffusion process for steels on the measured friction and wear coefficients under dry conditions and immersion in corrosive salt-water environments during sliding. Variables considered included the coating thickness as well as the deposition of BN-type layers as a boundary lubricant following the boronizing process. A custom-designed and constructed reciprocating tribometer with a 6-mm sapphire hemisphere countersurface and electrochemical capabilities was used for all experiments. Following the measurement of the friction coefficient, white light interferometry and optical microscopy were used to evaluate wear rates of the samples and sapphire countersurfaces. Although boronized steel samples showed increased COF, their wear rates were significantly reduced compared to bare steels due to significantly higher iron borides hardness; the BN-type boundary lubricant had minimal effect.

5:00 - 5:30 pm

Elevated Temperature Nanomechanical and Nanotribological Behaviors of Ni Alloys Surface Oxides: Part I-Experimental Study

Md Saifur Rahman, Texas A&M University, College Station, TX, Sepehr Salari, Ali Beheshti, George Mason University, Fairfax, VA, Andreas Polycarpou, Texas A&M University, College Station, TX

In this study, the nano-tribological properties of the oxide and the top most layer of super alloys, Inconel 617 and Incoloy 800H are studied using experimental and finite element analysis. Part-I presents the experimental portion of the study. Hardness, elastic modulus of the materials along with creep behavior were investigated using nanoindentation, while coefficient of friction (COF), scratch depth and elastic recovery at elevated temperature were investigated using scratch method. Constant load hold method is used to extract the creep properties with consideration of thermal drift. The oxide layer on top of Inconel 617 exhibits better scratch resistance and lower COF compared to 800H. The mechanical properties of the oxide are extracted using nanoindentation and ramp loading scratch is used to identify the critical load for breaking into the oxide layer. Both alloys display plastic deformation with pile up around the scratch, however, oxide layer shows high elastic recovery.

5:30 - 6:00 pm

Elevated Temperature Nanomechanical and Nanotribological Behaviors of Ni Alloys Surface Oxides: Part II-Finite Element Study

Sepehr Salari, Ali Beheshti, George Mason University, Fairfax, VA, Saifur Rahman, Texas A&M University, Collage station, TX

In this study, the nano-mechanical and nano-tribological properties of the oxide and the top most layer of Inconel 617 and Incoloy 800H are studied using experimental and finite element analysis. A comprehensive understanding of mechanical properties such as yield strength, creep parameters and stress-strain development is performed. Following part one of this presentation, FE analysis is used to extract the mechanical properties such as yield strength, shear strength and creep parameters of the oxide layer by a parametric study and fitting finite element results with the experimental nanoindentation values. In addition, a scratch model is built by using the extracted properties from nanoindentation simulations and validating the results with the experimental nanoscratch. The findings show that the oxide has higher hardness and elastic modulus as compared to the substrate resulting in the oxide layers to contain mainly all the stress/deformation during the scratch of the surface.

6:00 - 6:30 pm

The Wear Mechanism of Flexspline Materials Regulated by Novel Amorphous/Crystal Oxide Form Evolution on a Frictional Interface

Caixia Zhang, Zhifeng Liu, Jianhua Wang, Institute of Advanced Manufacturing and Intelligent Technology, Beijing University of Technology, Beijing, China

Flexspline wear is a key factor leading to wear failure of harmonic drives. The tribological properties of three normal flexspline materials under grease lubrication conditions were investigated. A novel wear mechanism regulated by two oxide forms (amorphous FeOOH and crystalline Fe2O3) evolving on a frictional interface was proposed and the details were confirmed based on co-analysis of XPS, TEM, AFM and SEM. The amorphous FeOOH generated during sliding assists the oxide layer, which therefore shows compact structure and better toughness, reducing friction at the interfaces, whereas the frictional crystalline Fe2O3, which tends to strip under the shear force without sufficient amorphous FeOOH around it, is the trigger for the loose and unstable oxide layer. The wear mechanism based on amorphous/crystalline oxide form evolution proposed provides novel research information for avoiding flexspline wear of harmonic drives.

2B Legends B

Lubrication Fundamentals II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Fluid Properties and Testing Parameters that Impact Lubricant Shear Stability
Sona Sivakova, Bart Schober, Lubrizol, Wickliffe, OH

Polymer shear stability is often described using the empirical value of shear stability index. For a long time, the shear stability index (SSI) of a polymer was viewed as a constant. But the shear stability index of a polymer can change based on the viscosity of the fluid being formulated and the API group of the base oil, as well as the temperature of the test. As the industry drives towards lower viscosity fluids, it has been observed that polymers blended into low viscosity fluids and highly refined or synthetic base stocks (like PAO) 'appear' more shear stable than in more conventional, higher viscosity, mineral base fluids. In this presentation/paper, we will investigate whether the perceived improvements in SSI due to trends toward lower viscosity lubricants, more refined base stocks and variations in test temperature are significant, whether they are maintained over more extended shear intervals and what this could mean for formulating durable low viscosity fluids.

2:00 - 2:30 pm
Hyperbranched Polymers for Shear Stable Viscosity Index Improvers
Lelia Cosimbescu, Pacific Northwest National Laboratory, Richland, WA, Robert Erck, Argonne Natl Lab, Lemont, IL, Deepika Malhotra, Pacific Northwest National Laboratory, Richland, WA

As fuel efficiency goals have pushed the boundaries of fluid viscosities lower and lower, well-designed VIIs that maintain lubrication and minimize friction and wear in a hot running engine are even more imperative. However, providing a high VI polymer is only part of the solution; another important parameter to consider is its shear stability. In the context of this work, the polymer's ability to resist mechanical shear-induced macromolecular degradation under shear conditions was investigated. Hyperbranched poly(alkyl methacrylate)s with and without polycaprolactone segments were designed and prepared via a core-first strategy, then evaluated with respect to their rheology, friction, wear, and shear stability performance. The focus of this work was to study the effect of architecture on mechanical shear stability, as it relates to hydraulic fluid performance. Furthermore, the effect of long versus short chain pendants on shear stability was evaluated.

2:30 - 3:00 pm
EHD Friction at Very High Pressure
Hugh Spikes, Jie Zhang, Imperial College, London, United Kingdom

A new high load minitraction machine is employed to measure the EHD friction properties of a range of

low viscosity base fluids in sliding-rolling conditions up to mean pressures in excess of 4 GPa. Measurements are made over a range of temperatures, enabling the effects of shear heating to be distinguished and separated from shear thinning. The observed isothermal shear stress versus strain rate responses are compared with the main existing equations used to describe the shear thinning of simple liquids.

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

4:00 - 4:30 pm
Development of a Refined Full Cavitation Model Considering Vapor and Air
Yan Wang, Xuesong Li, Xiaodong Ren, Chunwei Gu, Tsinghua University, Beijing, China

Cavitation is one of the most common phenomenon in the fluid lubrication. Though there are many hypothesis on the cavitation mechanism and many cavitation models, the physical mechanism of the cavitation remains controversial. There are two major form of cavitation, namely, vapor cavitation, which supposes the cavitation is the result of the oil vapor and air cavitation, which supposes the cavitation is due to the dissolved air or bearing-outside air. This paper constructs a refined full cavitation model considering both the vapor cavitation and the air cavitation and validated the bearing with the open data. The vapor and air cavitation are analyzed in details in a plain journal bearing and a squeeze film damper (SFD). Results shows that the cavitation mechanism are various in different bearings. Cavitation in the normal plain journal bearing is mainly vapor cavitation and cavitation in the SFD is mainly due to the air entrainment.

4:30 - 5:00 pm
Multi-Scale Modeling of the Lubrication between Rough Surfaces
Noel Brunetiere, Arthur Francisco, Institut Pprime, Futuroscope Chasseneuil cedex, France

In order to reduce friction during operation, many lubricated contacts work in the mixed lubrication regime. It is therefore necessary to have tools able to simulate this lubrication regime within a reasonable computation time along with enough accuracy. However, mixed lubrication involves several scales: the lateral scale of the asperities and the lateral scale of the domain as well as several scales in the through film direction. This is why a recently developed multi-scale approach is used in this paper and extended to include cavitation. The full contact domain is split in several sub-domains over which a deterministic approach is used because of its accuracy. The mass conservation between the sub-domains is ensured by a finite element macro-mesh based on the full domain scale allowing more efficient computations. As for the cavitation, the fluid is described as a homogeneous mixture of liquid and gas which density continuously varies with pressure.

5:00 - 6:00 pm
Tribo-CAS Film with Unprecedented Lubrication and Wear Performance Characteristics
Kenneth Chao, Deere & Company, Cedar Falls, IA

We all know what Tribo means but maybe few of us are familiar with complex adaptive systems or CAS. The scientific description of complex adaptive system can be found online such as Wikipedia. Tribo-CAS is the first sucessful attempt to employ the powerful CAS theory in the field of tribology with unique performance capabilities never seen before. In a nutshell, Tribo-CAS Film is a surface matrix layer composed of individual solid particulates with certain natural mild-stickness among themselves. This powder layer can be applied to ordinary steel/metal surfaces via sandblasting method or equivalent, and adhere spontaneously to the surface without using extra adhesives. Because these individual particulates are not rigidly bonded they have the freedom to move around or self-organize continuously in a matrix form consisting of particle clusters and empty voids under liquid-lubricated contact, which is radically different from traditional surface coatings with rigidly bonded texture.

Engine and Drive Train Special Program on Electric Vehicles II

Session Chair: B. Lotfi, ExxonMobil Chemical Co., Baytown, TX
Session Vice Chair: M. Webster, ExxonMobil Research & Engineering, Annandale, NJ

1:30 - 2:00 pm
Challenges and Opportunities with Lubricants for HEV/EV Vehicles
Arup Gangopadhyay, Ford Motor Company, Dearborn, MI

The projected growth of hybrid electric (HEV) and pure electric vehicles (EV) in the near future brings changes in powertrain architectures. Engine, transmission, and axles will be assisted by electric motors and in some applications electric motors will be integrated in the architecture with less or no friction clutches. The electric motors will be in contact with the lubricant and the lubricant is required to cool the motors by taking heat away from it. Therefore, lubricant for electrified powertrains needs to function as an effective coolant, provide corrosion protection to copper windings, laminates, and rare earth magnetic materials while maintaining wear and oxidation protection, and trading off friction stability. This presentation will discuss these requirements and challenge the lubricant industry to meet these.

2:00 - 2:30 pm
New Challenges for Tribologists and Lubrication Engineers From Vehicle Electrification
Chris Shamie, Schaeffler Group USA, Brighton, MI

The automotive landscape is undergoing unprecedented transformation as vehicle propulsion becomes more and more electrified. What challenges must tribologists and lubrication engineers solve as the take-rates for pure internal combustion-powered vehicles fall and hybrids or battery electric vehicles rise? The problems of lubrication from the point-of-view of the gearbox / bearing development community will be presented.

2:30 - 3:00 pm
Fuel Economy Testing Using a Prius Engine
Peter Lee, Dan Worcester, Southwest Research Institute, San Antonio, TX

A 2017 Prius Prime was instrumented and then driven to gather real world engine data and vehicle behavior. This was logged and analyzed, being used to develop engine control maps. The 2017 Prius Prime engine was then installed on a Sequence VIF fuel economy engine test stand and an electric motor installed to simulate the vehicle engine start. Results showing measurable fuel economy have been obtained and the set-up and results will be presented.

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

4:00 - 4:30 pm
Newly Developed Lubricants for the Challenges of Electric Drivetrains
Tobias Bender, Fuchs Lubricants Company, Wedel, Germany, Thomas Kraft, Gerd Jacobs, Erik Schuster, Rolf Luther, Bernhard Hagemann, Fuchs Schmierstoffe GmbH, Mannheim, Germany

After several successes with off-the-shelf fluids, FUCHS is developing a new generation of dedicated E-Motive fluids. As lubricants come into contact with many components, they must meet important requirements in terms of tribology and thermal management. With the increasing integration of electric components further special requirements arise for fluids and greases through new materials (e.g. copper, aluminum, and plastics), current-carrying components and high motor speeds. As part of the efforts in this area, FUCHS is currently working on water-based alternatives for transmission oils with a heat capacity that has been almost doubled in comparison to hydrocarbon-based lubricants. Apart from reducing the

number of fluids used in an electrical drivetrain, this approach may also cover thermal management needs of the battery while significantly increasing the drivetrain's efficiency. Recent results from the development are presented and advantages and challenges discussed.

4:30 - 5:00 pm
Challenges and Outlooks for Transmission Fluids in Electric Vehicles
Hong Gao, Shell Global Solutions, Houston, TX

Diverse and clean energy sources can contribute to meeting growing transport needs with reduced CO2 emissions. Electrification will increase significantly and play an important role in the global future transportation. The presentation will explain the drivetrain electrification technology trends and new requirements on transmission fluids. The key properties will be demonstrated to address the challenges which the transmission fluids are facing in the electric vehicle applications. The outlooks for transmission fluids will be discussed for both hybrid and electric vehicles.

5:00 - 5:30 pm
Understanding Base Oils and Lubricants for Electric Drivetrain Applications
Yungwan Kwak, Atanu Adhvaryu, Afton Chemical Corporation, Richmond, VA, Susie Hurley, Afton Chemical Limited, Bracknell, United Kingdom, Xinggao Fang, Christopher Cleveland, Afton Chemical Corporation, Richmond, VA

The penetration HEV and EV technology into automotive powertrain designs is an evolving trend resulting from global regulations intended to reduce emissions of greenhouse gases and other pollutants and to improve vehicle fuel efficiency. In many HEV and EV hardware designs, drivetrain fluids contact the integrated electric motor, which requires electrical and thermal properties to be considered in addition to traditional fluid properties. This presentation will discuss new insights gained around electric and thermal properties of drivetrain fluids, with a specific emphasis on understanding the critical impacts of base oils. The successful utilization of this knowledge is demonstrated on a proof-of-principle basis to show that fluids with appropriate electrical and thermal properties can be designed to meet critical factors for electrification such as cooling capacity and electrical conductivity, while still maintaining essential performance features for conventional driveline fluids.

5:30 - 6:00 pm - **Open Discussion**

2D Music Row 1

Gears II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Softening Mechanisms in Carburized Aerospace Gear Steels during Short Term Exposure to High Temperature
Aaron Isaacson, Penn State University, State College, PA, Cody Wassel, Sean McIntyre, Penn State Applied Research Lab, University Park, PA, Todd Palmer, Penn State University, Wayne, PA

The loss of lubrication survivability of gears operating in rotorcraft gearboxes is highly dependent on the gear steel’s resistance to softening during short term exposure to extremely high surface temperatures. The mechanism involved during the softening of a traditional carburized aerospace gear steel like AISI 9310 is quite different from that of more advanced, temper resistant steels like AMS 6308 (Pyrowear 53) and AMS 5930 (Pyrowear 675). This work examines each of these carburized materials after exposure to temperatures high enough to soften each sample below 20 Rockwell C. The softening mechanisms are identified and reasons for each are presented. Approaches to model the softening for each material

system were also investigated.

2:00 - 2:30 pm
Fatigue Calculations for Rough Surface Contacts with Measured and Synthesized Run-In Surface Roughness
Hassneen Asadi, Pwt Evans, Alastair Clarke, Kayri Sharif, Cardiff university, Cardiff, United Kingdom

A procedure was developed to synthesise the running-in process based on measured as-manufactured profiles. Surface roughness profiles obtained from transverse ground test disks were used to simulate asperity modification during running-in. The surfaces were run against each other in an EHL analysis and the radius of curvature of asperity peaks increased to synthesise plastic deformation. The process was developed by comparison with the real run-in profiles and with observed changes in asperity peak radii of curvature. The synthesised and measured run-in surfaces were compared in various ways. Their geometry was examined in terms of form and asperity peak radii of curvature. Rolling sliding EHL contact analyses were run and their behavior in terms of peak asperity pressure and direct contact was assessed. The transient mixed EHL analysis results were used to apply surface loading to the rough profiles to obtain stress histories which were the basis of the fatigue modeling carried out.

2:30 - 3:00 pm
Influence of Specific Film Thickness and Surface Roughness Properties on Micropitting Damage
Amir Kadiric, Benjamin Wainwright, Pawel Rycerz, Imperial College London, London, United Kingdom

Micropitting is a type of rolling contact fatigue damage that occurs in rolling-sliding contacts as a result of cyclic stresses on the roughness asperity level. Despite its increasing occurrence in gear applications, the mechanisms behind micropitting are not well understood. It is well established that micropitting occurs at low specific film thicknesses (L ratio). However, the key issues that need answering are how the extent of micropitting damage is affected by the actual L ratio, and whether the spatial and height characteristics of surface asperities are just as significant as the L ratio itself. This work attempts to answer the above questions through systematic studies of micropitting using a triple-disc rolling contact fatigue machine, in parallel with rough surface contact simulations. In an attempt to understand the mechanisms at play, particular attention is paid to the continuous interaction of micropitting damage with the competing mechanism of mild wear.

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

4:00 - 4:30 pm
Development of a CEC-Pitting Test Method for Gear Lubricants -
Measures to Reduce Scattering and Micropitting Generation in Gear Pitting Tests
Christopher Illenberger, Institute of Machine Elements Gear Research Centre (FZG), TU Munich, Garching, Germany

The lubrication condition in the contact zone of two meshing gears has essential influence on the pitting lifetime of oil-lubricated gears. Mechanical and chemical stresses are mainly influenced by surface texture, lubricant film thickness and chemical-physical interaction between tooth flank surface and lubricant. To determine the performance of gear lubricants regarding the pitting load carrying capacity, standardized test methods are desired. Extensive testing has shown that the generation of micropitting can strongly influence the pitting lifetime leading to increased scattering, which impedes a reliable determination of the pitting load capacity of different lubricants. This complicates the discrimination between the pitting load capacity of the investigated lubricants. Measures to reduce scattering and to improve the test reliability have been investigated within the development work for a standardized CEC-Pitting test method, which is expected to be published in the near future.

4:30 - 5:00 pm
A Model for the Formation and Wear of Oxide Tribofilms on Aerospace Steels under High-Speed Boundary Lubrication Conditions
Sean McIntyre, Penn State University, Wayne, PA, Stephen Berkebile, Nikhil Murthy, U.S. Army

Research Laboratory, Aberdeen Proving Ground, MD

A model for the formation and wear of oxide tribofilms under high-speed boundary lubrication is presented. The rate of oxide film formation is modeled using an Arrhenius equation based on the maximum temperature of the contact, as well as the maximum temperature between interacting asperities in contact. Diffusion of oxygen into the metal is modeled using an unsteady quasi one-dimensional approach, with the flux of oxygen into the metal at the surface determined by the rate of oxide film formation. A model for the temperature and friction-dependent rate of wear and its effect on the thickness of the surface of oxide films is included. The friction coefficient is modeled using the surface concentration of oxide: more surface oxide produces a relatively low friction coefficient, while less surface oxide leads to higher friction due to bare metal contact.

5:00 - 5:30 pm
A Model for Gear Life with Surface and Subsurface Survival: Tribological Effects
Guillermo Morales-Espejel, SKF, Nieuwegein, UT, Netherlands

Based on well-established methods used in dynamic load capacity of machine components a concept model for gear fatigue life is presented. It applies the Weibull's weakest link of material strength and the L-P theory for bearing dynamic load ratings. The model introduces of a well-defined separation between the risk of surface initiated failures and the traditional subsurface fatigue of the gear contact. This opens new possibilities for the use of specialized endurance models to predict surface life of a gear contact. Comparison between experimentally obtained gear endurance and L10 predicted life, using the present theory, indicates the ability of the model to account for the gear endurance and the contribution of the surface to the performance. This new approach is of advantage for future progress in gear design. It introduces a new parameter that, in case of failure, defines the probability of it happening at the surface. This could represent a new way to assess micropitting risk.

5:30 - 6:00 pm
Industrial Gear Oil Models Based on High-Viscosity Naphthenic Base Oils and Viscosity Index Improvers
Thomas Norrby, Linda Malm, Nynas AB, Nynashamn, Sweden

Naphthenic base oils for industrial lubricants offer benefits with regards to solvency and low temperature properties. Naphthenic base oils do not, however, on their own have the required Viscosity Index (VI) required in the common ISO VG grades for many industrial lubricants. In, for example, Industrial Gear Oil standards such as ISO 12925-1 and DIN 51517-3, a minimum viscosity index of 90 or 85 is required. Therefore, to be able to formulate gear oils, we have created a set of model base fluids meeting these Viscosity (KV) and Viscosity Index (VI) requirements. We made a range if ISO VG classes from NYNAS T 110, BT 150, T 400 and T 600 with the addition of Viscosity Index Improvers (VII), Viscosity Modifiers (VM) or high VI base fluids. We managed to meet KV and VI requirements for ISO VG 150, 220, 320, 460, 680 and 1000. We intent to share these results with formulator eager to explore the span of opportunities offered by Naphthenic base oils in industrial lubricant applications.

2E Music Row 5

Commercial Marketing Forum II

1:30 - 2:00 pm - **Colonial Chemical**

2:00 - 2:30 pm - **ExxonMobil Chemical Corp.**

2:30 - 3:00 pm - **Kao Chemicals GmbH**

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

4:00 - 4:30 pm - **Lanxess Corporation**

4:30 - 5:00 pm - **ANGUS Chemical Co.**

5:00 - 5:30 pm - **Evonik Oil Additives USA**

5:30 - 6:00 pm - **BASF Corporation**

2G Music Row 3

Wind Turbine Tribology II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Determining Mechanical Properties of White Etching Areas in Carburized 8620 Steel Using Spherical Nanoindentation
Jonathan Leung, Georgia Institute of Technology, Atlanta, GA, Vikram Bedekar, Rohit Voothaluru, The Timken Co., North Canton, OH, Richard Neu, Georgia Institute of Technology, Atlanta, GA

White etching areas (WEAs) are subsurface microstructural transformed regions found in bearing steels subject to rolling contact loading. Fatigue cracks are often found in conjunction with WEAs, and it has been suggested that the WEAs and fatigue cracks are related. However, the sequence of formation is still unclear. Determining the mechanical response of the WEAs through modeling and experiments is critical in providing clarity on their role in rolling contact fatigue. This work is focused on measuring the mechanical properties of WEAs using the Kalidindi-Pathak spherical nanoindentation protocols. The nanoindentation results show a significant increase in the indentation yield strength and reduction in indentation modulus. Using a “rule of mixtures” approach for closely packed nanocrystalline grains, the reduction in elastic modulus is shown to be associated with the presence of nanocrystalline grains within the WEAs.

2:00 - 2:30 pm
Evaluating the Effect of Heat and Surface Treatments on the Formation of White Etching Cracks
Benjamin Gould, Aaron Greco, Nicholaos Demas, Argonne National Laboratory, Argonne, IL

White etching cracks (WECs) have been identified as a mode of premature failure within wind turbine gearbox bearings. Though WECs have been reported in the field for over a decade, the conditions leading to these failures, and the process by which these failures culminate, are both highly debated. Because of the uncertainty regarding the formation mechanisms of WECs, multiple “solutions” have been implemented in the field. These range from heat treatments such as case carburization, to surface treatments such as black oxide coatings. The present work quantifies the effectiveness of these mitigation techniques using accelerated benchtop tests.

2:30 - 3:00 pm

Effect of Lubricant Stability on White Etching Area Evolution under Severe Dynamic Load Sliding Contact

Sreeraj Kodoor, Linto Davis, P Ramkumar, Indian Institute of Technology Madras (IITM), Chennai, India, Chennai, Tamil Nadu, India

The lubrication engineers and tribologists are facing a key challenge on wind turbine gearbox (WTG) lubricant decomposition and followed by premature bearing failure called white etching cracks (WEC). Recently a new methodology, under pure sliding condition, is successfully replicated white etching areas (WEA) using the modified dynamic load Pin-on-Disc (PoD) within 40hr using low reference lubricant mixture for real-time hydrogenation. The objective of this work investigates the effect of different lubricants such as mineral oil, PAO and PAG synthetic base oils under extreme boundary lubrication on WEA formation during pure sliding condition of bearing steel using modified dynamic load PoD tribometer. Using the modified test rig, the experiments are conducted with contact pressure of 1.4GPa, sliding speed of 0.2m/s and 270 loading cycles/minute. The WEA evolution behaviour of synthetic lubricants and mineral oil are studied in detail using various metallographic inspection techniques.

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

4:00 - 4:30 pm

The Role of Sulfur in Limiting Oil Drain Interval in Wind Turbine Main Gearbox Lubricants

Michael Blumenfeld, David Holt, Tabassumul Haque, ExxonMobil Research and Engineering, Annandale, NJ

The main gearbox lubricant is one of the most critical components of the modern geared wind turbine. These fluids are responsible for protecting gears and bearings under extremely high torque with severe and variable operating conditions. Despite its critical role, there is no industry consensus for identifying the “end of life” for a wind turbine gearbox lubricant. We conducted a review of used oil data and combined it with decades of up-tower experience to better understand the true failure modes of the main gearbox lubricant. Our results show that there is a significant lubricant failure mode that involves a reaction between certain sulfur-containing species and brass gearbox components which accelerates oil degradation in extended drain applications. In this paper, we will describe causes of lubricant failure, examine factors that influence lubricant failure timing, and present screener tests that predict lubricant failure in wind turbine gear oils.

4:30 - 5:00 pm

Initiation Mechanism of White Etching Cracks under the Influence of Electric Current

Ling Wang, Viktorija Rumpf, University of Southampton, Southampton, United Kingdom, Alexander schwedt, RWTH Aachen University, Aachen, Germany, Walter Holweger, Schaeffler Technologies, Herzogenaurach, Germany, Joachim Mayer, RWTH Aachen University, Aachen, Germany

White etching cracks (WECs) formed at different stages have been created in DGBB 6206 bearings after being tested on an L11 bearing test rig at Schaeffler Technologies lubricated by a low reference oil under the influence of electrical current. The evolution of WECs in these bearings has been revealed through microstructural analysis using SEM, TEM, EBSD and EDX techniques and published at a previous STEL conference. Subsequent in-depth analysis of the WECs formed at their pre-stages has provided more evidence of WEC initiation mechanisms under electrical influence. Complimentary WEC experiments under different test conditions such as in-situ heating of WEAs, bearing tests without electrical current, with current and a high reference oil as well as on tests on FE8 without electrical current have been conducted to verify the WEC initiation mechanisms.

5:00 - 5:30 pm

Real Scale Test of an Innovative Sensor-Set for Early Risk Detection of White Etching Cracks at a 2.7-MW Wind Turbine Gearbox

Freia Harzendorf, RWTH Aachen University, Aachen, Germany, Walter Holweger, Schaeffler AG, Herzogenaurach, Germany, Torsten Bley, Hydac Electronic GmbH, Saarbruecken, Germany, Soeren

Barteldes, QASS GmbH, Wetter, Germany, Ralf Schelenz, Georg Jacobs, RWTH Aachen University, Aachen, Germany

A common challenge in windturbine drivetrain technology are unexpected bearing failures caused by so called White Etching Cracks (WEC). Lubricant composition, presence of additional electrical exposure and mechanical loading may lead to WEC. Despite of considerable effort in research root causes for such failures are not entirely understood. An elementary aspect of improving windturbines reliability is to detect these failures or their preliminary stages as early as possible. Therefore, an innovative sensor-set has been compiled which enables monitoring these influencing factors. For real scale tests it is applied to the high-speed-shaft bearing of of a 2.7 MW windturbine gearbox. The campaigns goal is to apply WEC-critical but realistic transient operational conditions. The innovative sensor-set is tested under realistic conditions to increase its forecasting abilities. These results entail a significant step towards early WEC risk detection and windturbine technology improvement.

5:30 - 6:00 pm - **Wind Turbine Business Meeting**

2H Music Row 2

Testing in Soft Tribology - Tribotesting & Biotribology Joint Session

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Session Chair: A. Lin, Northwestern University, Evanston, IL

1:30 - 2:00 pm
Relating Sensory Perception to the Tribology of Milk
Grace Hully, Izzy Roots, Tom Welham, PCS Instruments, London, United Kingdom, United Kingdom, Philippa Cann, Marc Masen, Imperial College, London, United Kingdom

In recent years there has been rapid growth in the variety and availability of non-dairy milk alternatives, driven by consumers' ever evolving demands. It has been shown that emulating the conditions within the mouth during food oral processing, and to quantify the differences and similarities in friction between different dairy and non-dairy milks would be a valuable tool in the future development of milk alternatives. In this study, we have used a Biotribology Machine (BTM) to measure real time friction over the full reciprocating cycle. Tests were performed looking at dairy milks of differing fat content and the differences between non-dairy milks and a typical semi-skimmed dairy milk. Results will be presented that show the effect of varying fat content across dairy products, in addition to the widely varying friction traces from popular non-dairy substitutes and the importance of being able to compare instantaneous friction events at any point in the reciprocating cycle.

2:00 - 2:30 pm
Test Methods with Natural and Artificial Specimen for Biotribological Applications
Florian Rummel, Kartik Pondicherry, Anton Paar GmbH, Ostfildern, Germany

Tribological scenarios can be found in numerous biological and medical applications ranging from articular joints, catheters to the oral cavity. Understanding the behavior of such tribosystems is crucial for the development of life science and medical products. Within this study, the authors discuss as to how biotribological studies can be carried out with natural tissues, such as articular cartilage, or with the help of artificial substitutes such as polyvinyl alcohol (PVA) or artificial skin. This study covers novel test methodology which includes development of customized adapters to allow fixing of such tissues in order to evaluate their tribological behavior at low loads, covering sliding speeds from several nanometers up to around one meter per second. Results from different case studies are presented in the form of extended Stribeck curves and breakaway torque measurements.

2:30 - 3:00 pm
Finger-Pad Gripping: Understanding the Influential Factors
Raman Maiti, Wei Li, Zeng Lu, Stephen Matcher, Matt Carre, Roger Lewis, University of Sheffield, Sheffield, United Kingdom

Biomechanical properties of the human finger-pad are of great importance for research related to medical devices and sports. The aim of the paper is to understand the influence of external, topographical and physical properties on the friction of finger-pad using non-invasive optical coherence tomography (OCT) devices. Two optical devices, clinical (VivoSight®) and in-house (SDOCT), were used to measure the surface and sub-surface of the finger-pad sink. VivoSight and SDOCT system operated at an A-scan capturing rate of 20 kHz. The measured axial and lateral resolution of the SDOCT were 2.6 μm and 8 μm and VivoSight were 5μm and 7.5μm respectively. The finger-pad was dragged over a glass surface (0.2mm thickness) with the finger-pad facing upwards. The forces on the finger were measured using multi-axial force plate HE6X6 from Advanced Mechanical Technological Inc. The different factors were influential in flattening/smoothening of the surface and sub-surface of the finger-pad skin.

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

2J Cumberland 3

Nanotribology II

Session Chair: T. Jacobs, Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, PA
Session Vice Chair: Z. Ye, Miami University, Oxford, OHH. Gao, Material Science & Engineering, Universität des Saarlandes, Saarbrücken, Germany

1:30 - 2:30 pm
Molecular Behaviors in Thin Film Lubrication
Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

The behavior of liquid lubricant molecules, especially the molecules near the solid surface is very important to the property of the whole tribo-system. Thin film lubrication (TFL) has been proposed to characterize the molecular pattern in lubrication film less than hundred nanometers, which effectively bridged the gap between elastohydrodynamic lubrication (EHL) and boundary lubrication. Unfortunately, to date, the molecular model of TFL which was proposed 20 years ago has not been well proven. Recently a new method based on surface-enhanced Raman spectroscopy developed in our group allows us to access the molecular behavior in a nano-confined film, along with both the packing and orientation of the liquid molecules in TFL regime. The presentation attempts to systematically review the major developments of TFL, including the state-of-art studies on experimental technologies, researches and applications.

2:30 - 3:00 pm
Why Many Liquids Appear to Solidify during Squeeze-Out – Even When They Don't
Hongyu Gao, Martin Müser, Universität des Saarlandes, Saarbrücken, Germany

Liquid lubricants exhibit load-carrying capacity when they are squeezed by solid walls, along with layering structure as well as increase of shear viscosity. The ever-increasing molecular ordering within the confined space can substantially affect the tribological performance of the system. Molecular dynamics simulation was carried out based on a simple tip-confining model system. This work aims to establish a network between confined-liquid behavior and the corresponding bulk properties. Specifically, solvation force and local stresses were first reported as functions of confine distance (d), where stress anisotropy becomes increasingly evident as d decreases. In addition, spacing between adjacent confined layers is comparable to the decay length of bulk liquid density oscillation. It suggests that the ability of a liquid to

sustain non-isotropic stresses is not necessarily related to solidification but may be a natural consequence of liquid oscillating density correlation.

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

4:00 - 4:30 pm
Dynamic Behavior of a Droplet under Vibration Condition
Jing Xu, Jiadi Lian, GuoDong Liu, ShaoChao Fan, Jing Ni, Hangzhou Dianzi University, HangZhou City, China

A 3D laser marking machine is used to fabricate the rough substrate with micro-texture surface. The dynamic change process of droplets on the micro-texture substrate is collected by high-speed micro-camera under vibration condition. The dynamic behavior of a droplet under vibration condition the friction mechanism are studied systematically. The experimental results show that when the micro-vibration of a certain frequency is applied on the micro-texture metal surface, with the alternating change of the contact angle difference between the droplets from the left to the right, droplets produce alternating shrinkage and elastic deformation of tension.

4:30 - 5:00 pm
Effect of the Dispersion of Nanoparticle Additives on Their Lubricity for Use in Metalworking Fluids
Shilpa Beesabathuni, Yan Zhou, Yixing Philip Zhao, Houghton International, Norristown, PA

Nanoparticles are used as lubricity additives to reduce friction and wear as they can potentially outperform molecular additives, especially under high thermal and mechanical stresses. However, aggregation of the nanoparticle additives in lubricant oil adversely affects their tribological performance, because of a reduction in the effective particle concentration. In this study, we explore the effect of the dispersion of the nanoparticle additives on their tribological behavior in a base oil. A fully formulated metalworking lubricant was also applied as a comparison. The development of a well-dispersed and stable colloidal system is highly desirable to enhance the performance of nanoparticle additives.

5:00 - 5:30 pm
Interfacial Nano-Mechanics of Friction Modifiers
Kazushi Tamura, Kenji Sunahara, Hiroyuki Tatsumi, Motoharu Ishikawa, Idemitsu Kosan Co., Ltd., Ichihara, Japan, Masashi Mizukami, Kazue Kurihara, Tohoku University, Sendai, Japan

In recent years, with the tightening of environmental regulations, reducing energy loss are required in many fields of industry. Although friction modifiers (FMs) are promising lubricant additives to reduce friction and to improve energy efficiency, their mechanisms have not been fully understood. Here we analyzed the effects of FMs on shear characteristics of interfacially confined lubricants by using a surface force apparatus and resonance shear measurements. We found that interfacial confinement induced solidification of lubricant base oils and that FMs greatly inhibited this confinement-induced solidification. However, our analysis did not show substantial effects of FMs on the relationships between normal force and surface separation distance. These results suggest that inhibiting solidification plays a dominant role in FMs' friction reduction, regardless of their film-thickening ability.

5:30 - 6:00 pm
Study of the Nanoscale Wear Behaviors of Gallium Nitride Using Molecular Dynamics
P. Zhu, Beijing Jiaotong University, Beijing, China

In this work a series of molecular dynamics simulations of nanoscratching of gallium nitride (GaN) using a diamond indenter are conducted to investigate the anisotropic mechanical responses of GaN. The simulations are performed on the c-plane and m-plane GaN. Through the study of coordination and stress distribution, we explore the plastic deformation mechanisms of GaN, which are dominated by the nucleation and propagation of dislocations. We found the anisotropic deformation behaviors of c-plane and m-plane GaN in the scratching process. We also found that for a constant scratching depth, both the

average friction force and friction coefficient for the c-plane are smaller those of m-plane of GaN. These results shed light on the application of semiconductor devices with required properties.

2K Cumberland 4

Metalworking Fluids II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Comprehensive Investigations of Tribology Properties of Metalworking Fluid Chemistries on Multi-Metals
Yixing Philip Zhao, Houghton International, Norristown, PA

Presently, there is a need in the metalworking fluids market for products which can machine metals such as steel, aluminum, titanium etc. A good lubricant not only needs to reduce friction, but also is expected to extend tool life, improve surface finish and increase productivity. These performance expectations require the development of next generation products with good tribological properties and enhanced performance. Tribology is the science of friction, wear and lubrication. However, in the metalworking fluid industry we have limited means to measure friction and even fewer ways to study wear and surface quality of parts and tools. In this presentation, we will discuss some examples of comprehensive tribological tests measuring friction and surface quality of different metals using several metalworking fluid emulsions. The investigation enabled us to better understand the effect of the chemistry of the fluids on the tribological properties of different metals.

2:00 - 2:30 pm
Go Figure: Using Analytics and Statistics in Metalworking
Emil Schnellbacher, Formulas & Solutions, LLC, Allen Park, MI

Innovation and New Product Development struggles to make things better, faster, and cheaper. Is there a way to consistently formulate new products in a way that optimizes the constraints of: quality, time and money? Statistical models like Design of Experiment (DOE) are already used by some companies to optimize formulation in the laboratory phase of development. Not as many companies integrate analytics in the fuzzy-front-end of innovation to capture customer aspirations for new product selections. However, the use of analytics can assist in determining the voice-of-the-customer and developing better product specifications. By accurately determining the customer desires and needs, this minimizes guessing during the formulation and optimizes the likelihood of success during product launch. This paper presents a conceptual framework by using examples of this approach in optimizing formulation and new product development in metalworking fluids.

2:30 - 3:00 pm
Coolant Emulsion Properties and Field Performance of Metal Removal Fluids
Yixing Philip Zhao, Houghton International, Norristown, PA

Over the last two decades, the products and chemistries of water based metal removal fluids have evolved significantly. The changes were driven by both market needs and technology innovation. The industry needs coolants to provide good performance such as good lubricity, enhanced cooling, biostability/long sump life, low foam, super detergency and dispersion, corrosion protection and better chip handling. On the technology side, new chemicals, better understanding of the chemistries and the adoption of sophisticated and systematic formulation methods have enabled us to develop robust and globally compliant [DC1] products with the above properties. In this presentation, we will first review current industry coolant performance requirements. We will then focus on important properties of coolant emulsions and their correlation to their performance in metal removal applications.

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

4:00 - 4:30 pm
New Innovations in Rust Preventive Sustainability
Amelia Hadler, Jennifer Clark, Gregory Moran, Eric Rodeheaver, Britt Minch, Lubrizol Corporation, Wickliffe, OH

Traditional rust preventives have proven invaluable when it comes to providing critical corrosion performance while maintaining a near-invisible film and a stable finished product. However, growing concern surrounding the sustainability of raw materials could threaten existing rust preventive formulations. In addition, there is increasing interest in products that provide more advanced corrosion performance while simultaneously maintaining the flexibility to be used in a wide array of diluents. This talk will explore the benefits of using innovative film-forming chemistries to address these challenges. A new rust preventive based on sustainable raw materials is introduced. When compared to conventional rust preventives, this product shows superior corrosion performance as well as premium solubility in multiple diluents including Group II and higher paraffinic base oils and high-flash point solvents.

4:30 - 5:00 pm
Parts Cleaning Fundamentals - Importance of Cleaning and Rinsing
Suresh Patel, Chemetall, New Providence, NJ

To increase the effectiveness of the finish or final product/assembly, parts must be cleaned prior to the subsequent process(es). If the cleaner does not fulfill its purpose of removing unwanted soils from the substrate, subsequent processing steps will be impacted negatively e.g. not produce a uniform conversion coating, and therefore inadequately protect the metal surface from corrosion. A high-quality metal surface preparation (cleaning and rinsing) combined conversion coating and the appropriate organic coating is essential for the durability of finished products. Rinse water quality and proper rinsing are as critical, yet often-over-looked step in the metal preparation process. A well-designed, lean cleaning and rinsing process can help improve product quality, thru-put, and higher profits! This paper will focus on different cleaning technologies (mechanical & chemical primarily) and issues specific to the parts cleaning industry.

5:00 – 5:30 pm - **Metalworking Fluids Business Meeting**

2L Cumberland 5

Nonferrous Metals II

Session Chair: T. Oleksiak, Novelis
Session Vice Chair: A. King, Houghton International

1:30 - 2:00 pm
Thermal Behavior of Polyformates of Milkweed and Soybean Oils
Rogers Harry-O'kuru, USDA-ARS-NCAUR, Peoria, IL, Girma Biresaw, USDA-ARS-NCAUR-BOR, Peoria, IL, James Xu, USDA-ARS-NCAUR, Peoria, IL

Reprocessing of neat vicinal polyformate esters of milkweed, and soybean triglycerides in a silica drying column with mild heating resulted in a light reddish-orange gel formation of the column eluate on cooling. Analysis of the gel by ^{1}H- and ^{13}C-NMR showed products of possible elimination which include olefinic/aromatic moieties following possible elimination and rearrangement. A free carboxyl moiety in the gel matrix was observed. FT-IR of the gel suggested formation of olefinic species. Trial runs to reproduce the column results by heating aliquots of the neat vicinal polyformate under N_2 with and without silica gel generated a gas that discharged basic phenolphthalein solution. Further heating gave a tacky off-white polymer that was chloroform insoluble. In contrast, the vicinal polyacetate derivatives of milkweed and

soybean oils were stable under similar reaction conditions.

2:00 - 2:30 pm
Development of Novel and Safer Dt-MPM Antioxidants and McIn Multifunctional Corrosion Inhibitors for Industrial Applications
Ashok Cholli, Polnox Corporation, Lowell, MA

Lubricants and biolubricants are composed of base oil and additives. Key additives common to most formulations include additives like anti-oxidants, corrosion inhibitors, anti-wear additives, extreme pressure agents and emulsifier/demulsifier and other additives. The selection of lubricant additives is geared to address the desired lubricant performance related to the specific application and the oxidative-stability or the quality of the base stock oil used. Awareness of the toxicity issues related to the petroleum-based oils and additives that are used in the industrial lubricant products necessitated to develop and use environmentally acceptable lubricants. Polnox has been addressing the use of new and safer additives by developing novel technologies such as Dt-MPM™ antioxidants and McIn™ corrosion inhibitors for bio lubricants and lubricants without compromising their performance compared to commercial additives. Their effectiveness and benefits will be illustrated with examples.

2:30 - 3:00 pm
Effect of Isomerization on the Physical and Tribological Properties of Oleic Acid
Girma Biresaw, USDA-ARS-NCAUR-BOR, Peoria, IL, Helen Ngo, USDA-ARS-ERRC, Wyndmoore, PA, Robert Dunn, Grigor Bantchev, Rogers Harry-O'kuru, USDA-ARS-NCAUR-BOR, Peoria, IL

Isomerization is a powerful tool used by chemists to expand the physical and chemical properties of a wide range of organic molecules. Isomerization is widely applied in several industries to extend the application range of products and / or to formulate new line of products. Examples of industries that routinely apply isomerization in their product development include: lubricants, fuels, cosmetics, pharmaceuticals and food. Recently, a USDA patented procedure was used to isomerize oleic acid into iso-oleic acid. The two fatty acids are similar in the total number of carbons and double bond in their structure. However, the iso-oleic acid has a methyl substituted double bond randomly located along its chain. The effect of isomerization on the physical and tribological properties of these two fatty acids were investigated. The results of this investigation will be discussed in this paper.

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

4:00 - 4:30 pm
Scuffing Performance of Brass-Cast Iron Contact Pair in Hydraulic Fluid
M. Cinta Lorenzo Martin, Oyelayo Ajayi, Sheera Lum, George Fenske, Argonne National Laboratory, Lemont, IL, Girma Biresaw, Grigor Bantchev, Rogers Harry-O'kuru, USDA-ARS-NCAUR-BOR, Peoria, IL

Efficiency of hydraulic fluid power system can be increased by operating at higher pressures. Similarly, size reduction in the system will require higher power density and operation at higher pressures. Such operating conditions make sliding components in hydraulic pumps susceptible to scuffing failure. This paper presents scuffing performance evaluation of bronze and cast-iron sliding contact pair in fully formulated commercial hydraulic fluid and several experimental composite fluids. Using a step load increase test protocol, scuffing was observed to occur in the commercial fluid and PAO basestock. Scuffing resulted in severe plastic deformation and roughing of the bronze material contact area. In composite fluids consisting of PAO and bio-based phosphonate ester fluid, only polishing wear was observed even after very high contact loads. Results of present study suggest composite fluids are potential candidates for scuffing prevention in hydraulic pumps operating at high pressure.

4:30 - 5:00 pm
Water Soluble/Dispersible Corrosion Inhibitors for Nonferrous Metalworking Fluids
Tiffany Meyers, Clariant, Mount Holly, NC

Aluminum alloys are increasing in use in many industries to reduce weight, leading to improved energy

consumption and fuel efficiency. Corrosion inhibitors can be a valuable tool used for formulating synthetic, semi-synthetic and soluble oil fluids. These additives are effective in protecting aluminum and, at the same time, deliver additional functionalities which help metalworking fluid formulators address today's formulation challenges. During manufacturing and processing of these nonferrous materials (e.g. rolling, cutting, forming, grinding), a metalworking fluid could be exposed to components made of steel, copper or cobalt from contact with equipment and/or tools. A variety of water-soluble and water-dispersible corrosion inhibitors have been screened, evaluating performance criteria such as inhibition of staining on aluminum, steel protection, copper and cobalt leaching prevention, lubrication contribution, foaming tendency, and electrolyte stability.

5:00 - 5:30 pm
Synthesis and Detailed Characterization of Dimer and Trimer Acid Products using Acid Zeolite Catalysts
Helen Ngo, Jianwei Zhang, Alberto Nunez, Robert Moreau, USDA, Wyndmoor, PA

Dimer and trimer fatty acids are synthetic biobased products used in many applications including polyamides, polyurethanes, adhesives, and lubricants. The industrial production of dimer/trimer acids is through dimerization of fatty acids with clay catalysts. However, clay catalysts cannot be recycled, which is an environmental concern. The structures of dimer/trimer acids, which can affect the synthesis and properties of the downstream products are poorly understood and inconsistent. This paper will focus on our efforts to overcome these concerns and ambiguities. Specifically, the advantages of using the recycled zeolite catalysts for a more environmentally friendly process will be discussed. Detailed structural information on the products verified by nuclear magnetic resonance and mass spectroscopy will also be presented. Ultimately, the goal of this new approach is to lead to an improved and more consistent material quality for the dimer/trimer acid industry.

5:30 - 6:00 pm - **Nonferrous Business Meeting**

2M Cumberland 6

Fluid Film Bearings II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:30 pm - **Technical Session: Mechatronics Applied to Fluid Film Bearings**

2:30 - 3:00 pm
Dynamic Experimental Research of Controllable Squeeze Film Damper
Chao Chen, Xiaojing Wang, Nie Zhou, Jun Liu, Jiaqi Zheng, Caizhi Zhu, Shanghai University, Shanghai, China

Abstract: In order to decrease the vibration amplitude of rotor-bearing system, the concept for journal bearing with additional fluid film thickness in the bearing was proposed to alter the dynamic properties in this research. A new controllable squeeze film damper (CSFD) was brought out and the dynamic theoretical model of CSFD rotor-journal bearing system was established. Besides, the dynamic characteristics of CSFD journal bearing were studied by making use of a bearing test rig under different rotating speed, load and oil supply pressure. The experimental results demonstrate that, CSFD can suppress vibration and improve stability of rotor-bearing system. Besides, the reducing effects of the main bearing stiffness combined with CSFD were investigated which is basically consistent with the theoretical results. Under the same external condition, dynamic characteristic parameters have a positive correlation with the magnitude of the applied load.

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

4:00 - 4:30 pm
A New Test Rig to Meet Industrial Applications: Startup and Performance of a Two Lobe Journal Bearing
Jean Bouyer, Pascal Jolly, Michel Fillon, Pprime Institute, Futuroscope Chasseneuil Cedex, France

This work aims to present the first tests operated on the brand new test rig of our team from Pprime Institute. It consists in a 315mm in diameter journal bearing subjected to speed up to 2,000 rpm and static loads up to 100 kN. Several problems due to the dimensions of the test rig and the solutions which were found will be presented. First tests on a babbitted two-lobe journal bearing will be described and the performance of the bearing will be detailed in terms of pressure, temperature, torque and film thickness measurements. The presentation will point out the real capabilities of the test rig.

4:30 - 5:00 pm
Ultrasonic Oil Film Measurements in Journal Bearings
Scott Beamish, Henry Brunskill, Andrew Hunter, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

This paper describes the design and build of a journal bearing test platform which incorporates both shaft and bearing mounted ultrasonic arrays. These arrays produce high-resolution measurements of oil film thicknesses at a capture rate to 80,000Hz. Results have been validated against theoretical models, bench testing and in-line gap sensors to demonstrate accuracy. This versatile system has been designed to operate under a wide range of conditions including variable speed, load, oil type and temperature, thus making it suitable for many new and exciting applications. This work focuses on the rig design, sensor instrumentation, refining the ultrasonic measurement technique, validation and how the system is being applied to highly relevant industrial problems.
Current investigations include misalignment, vibration, start-up, and comparison of environmentally acceptable lubricants (EALs) against traditional mineral oils.

5:00 - 5:30 pm
Development of A Gaseous Cavitation Model for Oil-Film Bearing Considering Thermal Effect
Aoshuang Ding, Xuesong Li, Xiaodong Ren, Chunwei Gu, Tsinghua University, Beijing, China

Thermal effect strongly influences the lubricant viscosity in bearings. In this paper, an original isothermal gaseous cavitation model has been corrected with the energy equation included based on the mixture heat capacity. For validation, in eight different cases at 2000 and 3500 rpm, the simulation results of the gaseous cavitation model with thermal effect considered are compared with the half-Sommerfeld model, the Rayleigh–Plesset model, the isothermal gaseous cavitation model and experimental data. Among the three models, the gaseous cavitation model with thermal effect considered provides the best performance and can simulate the thermohydrodynamic characteristics and cavitation features of the journal bearing accurately. Therefore, the gaseous cavitation model with thermal effect considered is a reliable cavitation model for oil-film bearings.

5:30 - 6:00 pm
Experimental Investigations of Oil Pockets Effect on the Lubrication Regime Transition of Journal Bearings
Jaroslaw Sep, Lidia Galda, Rzeszow University of Technology, Rzeszow, Poland, Artur Olszewski, Tomasz Zochowski, Gdansk University of Technology, Gdansk, Poland

To prevent the bearing destruction the specific surface texture can be created on the sliding zones. One of the roles of surface irregularities is to keep some oil in case of its shortage. The aim of this paper is to identify the characteristic parameters such as sliding velocity, Hersey number and friction coefficient when the transition of lubrication regimes occurs for different types of journal bearings. The study shows the results achieved in experimental investigations for journal bearings with the oil pockets on journal surface mating with smooth bearing and with texture on bearing surface co-acting with standard smooth journal.

The obtained results are also compared with the tests effects of classical smoothly finished journal bearings. It was found that textured journal bearings moved from mixed to hydrodynamic lubrication faster and at lower speed in comparison to smooth journal bearings.

Wear I

Session Chair: M. Renouf, University of Montpellier, Montpellier, France
Session Vice Chair: A. Ghosh, Sentient Science

8:00 - 8:30 am
Effects of Shoe Design and Progressive Wear on Traction Performance
Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Previous research has shown variation in performance across shoes labeled as slip-resistant (SR) [1]. This research assessed how progressive shoe wear affects traction and fluid pressure measurements of SR shoes. Eight participants wore two types of SR shoes alternating every month walking a total of at least 75 km in each shoe. After each month, available coefficient of friction (ACOF) and fluid pressure measurements were recorded while each shoe was mechanically slid across a contaminated surface with embedded fluid pressure sensors. Fluid force measurements were then calculated. ACOF and fluid force were each affected by the number of months of wear ($p<.0001$, $p<.0001$), the heel type ($p=0.0443$, $p<.0001$), and the interaction between the two variables ($p<.0001$, $p<.0001$), respectively. This research shows that shoe design affects both performance at baseline and the progression of performance across the shoe's life. 1. Jones, T, et al. Applied Ergo, v70, pgs 134-135, 2018.

8:30 - 9:00 am
Methods to Study the Life of an Asperity Subjected to Tribological Contact
Arnab Bhattacharjee, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

Friction and wear are consequences of complex phenomena that occur within a buried tribological interface. Directly interrogating these phenomena often requires methods to penetrate the contact interface in real time or methods to separate the contact without disturbing the processes. Engines, and many other applications involve self-mated metals, which virtually precludes the former.. We have challenged ourselves to develop interrupted methods to study the life of an sperity in self-mated metallic contacts. The goal here was to break and recreate tribological contact with repositioning errors of 150 nm or less. Validation testing demonstrated that, with methods that are relatively easy to duplicate, contact locations can be replaced with a repositioning error of ±100 nm. Additionally, validation experiments with self-mated steel and a neat PAO lubricant demonstrate that the tribological contacts can be broken and replaced without any statistically significant effect on the wear rate.

9:00 - 9:30 am
Gait Parameters of Shoe Wear: A Case Study of the Shoe Wear Rate by Individual Gait Parameters
Erika Pliner, Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Elastomeric wear is dependent on the cyclical loading conditions. Therefore, outsole shoe wear is likely to be dependent on an individual's gait pattern (i.e. frictional shoe forces and shoe sliding distance). This study presents a case study comparing the gait patterns of two individuals with different shoe wear rates. Participants were asked to wear two pairs of shoes (Shoes A and B) in their day-to-day life until the shoes were deemed unsafe to wear. One participant's wear style is referred to as 'Fast Wear', wearing shoes A and B after 86 and 238 km, respectively. The other participant is referred to as 'Slow Wear', wearing shoes A and B after 407 and 1255 km, respectively. During gait, the Fast Wear participant had higher frictional forces (27-31%) and sliding distances (27-65%) than the Slow Wear participant. The relationship between sliding distance and wear rate is consistent with Archard's wear equation. Gait patterns may influence tread wear consistent with tribology theory.

9:30 - 10:00 am
Ash-Induced Wear on Biomass Pre-Conversion Equipment
Kyungjun Lee, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, Erik Kuhn, National Renewable Energy Laboratory, Denver, CO, James R. Keiser, Oak Ridge National Laboratory, Oak Ridge, TN, Edward Wolfrum, National Renewable Energy Laboratory, Denver, CO

There is growing interest in using biomass as a renewable energy source, however some biomass pre-processing equipment has been reported to have wear issues. In a NREL low-temperature conversion reactor, the stainless steel plug screw feeder experiences severe wear, especially in processing high-ash biomass. In this study, the wear issue was investigated by identifying the wear modes and correlating them to the biomass ash species and contents. Characterization was performed on the worn screw feeder to reveal the wear mechanism, as well as on the extrinsic ash from biomass feedstock to analyze the ash particle size distribution, particle shape, and chemical composition. To understand the ash abrasiveness, bench-scale 3-body abrasion wear tests were carried out with selected ash samples and the screw feeder material. The worn surfaces generated during the bench test were examined and the morphology and composition were correlated to those of the actual worn screw feeder.

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

10:30 - 11:00 am
Predicting Slip Risk Based on Footwear
Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

This study assessed whether the under-shoe fluid load during a simulated slip could be predicted based on the size of the worn region. Four shoes underwent an abrasive wear procedure to generate localized wear in the heel. Periodically, fluid pressure sensors embedded in the flooring recorded under-shoe fluid pressures during a simulated slip. Fluid force was then calculated. The film thickness of the contaminant was predicted using a derivation of Reynold's equation for thrust bearings [1] based on the size of the shoe wear region. Linear regression analysis showed that the fluid force was affected by predicted film thickness ($p < .0001$). Therefore, the fluid film thickness predictions based on the size of the worn shoe region were able to predict the under-shoe hydrodynamics. This model may have potential in determining when worn shoes should be replaced.
1. Proctor & Coleman. J Occup Acc, vol.9, no.4, pp.269-285, 1988

11:00 - 11:30 am
Influence of Film Structure on Vane Pump Protection
Xinggao Fang, Mark Devlin, Phillipe Ezanno, Afton Chemical Corporation, Richmond, VA

Additives play a critical role in keeping vane pumps in power transmissions from damage. A systematic study on additives that form surface films has been carried out using modified ASTM D7403 a method for indicating wear characteristics of hydraulic fluids in a constant volume vane pump. A wear mechanism has been identified. Practical fluids with balanced needs for transmission hardware protection will be discussed.

11:30 am - 12:00 pm
The Role of Counterface Roughness Orientation in the Thermal Effects on the Deposition of PEEK Transfer Films
Cris Schwartz, Mark Placette, Iowa State University, Ames, IA

Poly(ether ether ketone) exhibits excellent wear resistance against steel counterfaces, because of the deposition of a durable transfer film. This can drastically reduce polymer wear in many cases. It has been observed that PEEK will not deposit a sustained transfer film when sliding parallel to the roughness orientation of the metal. The investigators exposed a PEEK material to sliding parallel and perpendicular to the roughness direction of steel counterfaces. At steady state, PEEK exhibited considerably lower wear in perpendicular versus parallel sliding. Infrared thermography showed that the temperatures produced near the wear interface for perpendicular sliding were higher than in parallel. This was hypothesized to be

due to a greater extent of cyclic viscoelastic deformation of the surface during perpendicular sliding, and was confirmed by use of a thermal model and experimental observations of stress-cycled PEEK.

3E Music Row 5

Commercial Marketing Forum III

8:00 - 8:30 am
Vanderbilt Chemicals: New Corrosion Inhibitors and Their Application in Engine Oils
Vincent Gatto, Vanderbilt Chemicals, LLC, Bradenton, FL

Vanderbilt Chemicals, LLC provides a variety of unique corrosion inhibitors to formulators across all segments of lubrication. It is widely known, however, that effective use of any corrosion inhibitor requires a balanced formulation approach. To address some of these challenges the company is introducing a new series of corrosion inhibitors. Previously we discussed the application of these new products in industrial lubricants. In this presentation the benefits of these products for reducing copper and lead corrosion and their compatibility in engine oils will be discussed. The multi-functionality of these products can provide multiple solutions for formulations in many different applications.

8:30 - 9:00 am - **Chevron Phillips Chemical Co.**

9:00 - 9:30 am - **Sea-Land Chemical Co**

9:30 - 10:00 am - **Lockhart Chemical Co.**

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

10:30 - 11:00 am - **Croda Inc.**

11:00 - 11:30 am - **King Industries**

11:30 am - 12:00 pm - **Munzing**

3F Music Row 4

Metalworking Fluids III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Effect of Different Organic Acids in Organosilanes/Organic Acids Combo Systems as Stain/Corrosion Inhibitors in Metalworking Fluids for Application on Aluminum Alloys
Hoon Kim, Joana Costa, John Pentangelo, BASF/Chemetall, New Providence, NJ

Last year, we introduced the novel organosilane/fatty acid combo systems as new stain/corrosion inhibitors for aluminum alloy applications. The innovative inhibitor technology consists of two parts: 1. organosilane as the head group anchoring to the metal surface, 2. non-polar hydrocarbon chain of the

fatty acid functioning as barrier to prevent corrosive chemicals from accessing the metal surface and to minimize undesirable hydrolysis of the silane functional groups. Those two parts are combined either by ionic amine/acid salt formation or covalent amide bond linkage. Along this line, we investigated the effect of various acids. Diverse organosilanes/acids combo systems were prepared using different acids and applied in metalworking fluids. The anti-corrosion/staining performance was evaluated by metal compatibility test in combination with ICP elemental analysis. From this study, we were able to confirm the excellent performance and unique versatility of the novel inhibitor systems.

8:30 - 9:00 am
Substitution of Zinc Stearate in Cold Extrusion Processes
Wilhelm Rehbein, LANXESS Deutschland GmbH, Mannheim, Germany

Cold extrusion is a kind of massive forming process for the mass production of hollow or solid parts in one or more stages. Zinc stearate is widely used for the lubrication of aluminium cold extrusion processes. Because it is a powder it has to be applied on the slugs by a tumbling process. This leads to a strong dust formation that can cause respiratory irritation; the thermal decomposition of Zinc stearate forms toxic and irritating vapours. The paper presents the development of a new lubricant based on renewable raw materials. This lubricant is free of zinc or other metals. Because it is a waterbased suspension, it can be applied easily and without any dust formation. Tests which were done at the Institute for Metal Forming Technology of the University of Stuttgart and at a specialised company under manufacturing conditions prove that the new lubricant is an adequate replacement for zinc stearate powder.

9:00 - 9:30 am
A Dynamic Industry Needs Dynamic Additives – State of the Art Wetting Agents
Kai Wirz, Evonik Nutrition & Care GmbH, Essen, Germany

Machining processes in the modern industry become faster every day. During the metalworking process, the time for the liquid to get in contact with the solid surface is very short. Because of this trend the coverage of the surface, also called wetting, must be very dynamic in order to fulfill newest technology requirements. Additionally some wetting agents also improve other parameters like swarf removal and foam knockdown. The presentation will give an insight into the mechanism and application of state of the art wetting agents and how these can help to improve the overall performance of your system.

9:30 - 10:00 am
High-Oil Emulsions for MWFs Based on Heavy Naphthenic Base Oils
Thomas Norrby, Linda Malm, Nynas AB, Nynashamn, Sweden

In this study, a novel range of high-oil emulsions based on high viscosity naphthenic base oils have been created, for the purpose of building a better understanding of the properties of heavy high-oil emulsions. The naphthenic base oils utilized were Nynas T 110, Nynas T 400, Nynas T 600 and a paraffinic SN 500 (Group 1). A generic non-ionic emulsifier system based on readily available sorbitan-derived emulsifiers was employed. Emulsifier blends covering a range of HLB values were utilized to prepare a number of model emulsion systems. The emulsion particle size, and the emulsion stability as a function of time, was determined by static light scattering experiments utilizing a Malvern 3000E MasterSizer equipment. Application were heavy emulsion is found are for example mineral wool insulation spinning, and in heavy metal forming operations and metal hot rolling.

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

10:30 - 11:00 am
Foam Mechanism for Soluble Oils
Robert Golden, Pilot Chemical Company, Cincinnati, OH

Foam is an inherent property of agitated liquids, and it is of profound interest for metalworking fluids. The stability of the generated foam depends on several factors. Surfactants are a class of compounds that can stabilize foam, and the surfactants that are used to stabilize oil in water emulsions have been blamed

for the stabilization of foam in the emulsions. The generally accepted model for foam formation of surfactants at the air/liquid interface is typically invoked for the foaming of soluble oils and semi-synthetics. Recent evidence calls into question this model, and a new model for foam that does not utilize surfactants at the air/liquid interface will be proposed. Understanding the mechanisms of foam stabilization can help formulators develop inherently lower foaming systems which would require less dependency on antifoams and defoamers.

11:00 - 11:30 am
Evaluation of Performance Properties of Slideway Lubricants
John Hogan, The Lubrizol Corporation, Wickliffe, OH

Modern machine tools require slideway lubricants that minimize the potential for stick slip phenomenon during operation of the machine tool. Although there is no industry standard test to measure the frictional properties of slideway lubricants, many oil marketers rely on the Fives Cincinnati OEM approval. Fives Cincinnati relies on their internal Stick-Slip Test to demonstrate frictional performance. In this study, an adaptation of ASTM D2877-70 using the conditions of the Fives Cincinnati Stick-Slip Test is used to evaluate the frictional properties of slideway lubricants. We will present statistical analysis of our data that shows this test is suitable to differentiate frictional performance of slideway lubricants.

11:30 am - 12:00 pm
Vulnerability and the Art of Metalworking Fluid Formulation
Nicole Clarkson, Soraya Krasczcyk, Clayton Cooper, ANGUS Chemical Company, Buffalo Grove, IL

The act of opening something typically creates a certain level of vulnerability. Open wounds create opportunity for infection. Open doors a chance for theft. When we apply this concept to a formulation, the potential vulnerabilities include performance, contamination, bad parts, lost business, and more. Simply said, there is potential for failure. So, why open anything? Why create a potential for failure? Because fear of failure prevents us from taking important steps forward. This presentation focuses on areas of uncertainty, of vulnerability and, most importantly, discovery. Obtaining fluid longevity when biocides are altered. Reaching corrosion control at low treat rates. Achieving staining across multiple alloys. By highlighting performance characteristics in a multitude of formulary platforms, it becomes clear that discovering something new doesn't always mean the use of a new product, but sometimes the application of a known product to create a new opportunity.

3G — Music Row 3

Tribotesting I

Session Chair: O. Ogunsola, Shell Oil Company
Session Vice Chair: A. Lin, Northwestern University, Evanston, IL

8:00 - 8:30 am
In-Situ Measurement of Friction by Causing Nano-Scale Slip with a High-Powered Ultrasonic Wave
Rob Dwyer-Joyce, Xiangwei Li, University of Sheffield, Sheffield, United Kingdom

In this study we have investigated the use of high-powered ultrasonic waves to cause slip at an interface and so determine the friction coefficient in-situ. A high-powered shear wave when it strikes an interface can cause asperity slip. This results in non-linearity in the reflected signal that can then be used to deduce whether slip has taken place. If we know the shear stress caused by the wave and the normal pressure we can deduce the friction coefficient. Experiments were performed on a dry rough aluminium contact. Waves of increasing amplitude were incident on the interface and the non-linear reflected components recorded. Laser-vibrometry was used to estimate the deflection and shear stress induced by each wave. The most powerful waves caused deflections of 70 nm and shear stresses of 4 MPa. The experiments were conducted with a range of contact pressures. In this way we were able to build a map

of when slip occurred and the local friction coefficient.

8:30 - 9:00 am
Development of a Test Procedure, System and Process for High Throughput Tribological Testing of Used Oil Samples as Part of a Condition Monitoring Protocol
George Plint, Phoenix Tribology Ltd, Kingsclere, Select, United Kingdom

With a used lubricant, chemical elements associated with the original additive package can still be present and detected, but we do not know which compounds they are associated with and thus whether they work as originally intended. Furthermore, we do not know whether the used lubricant contains additional compounds that inhibit the action of the original additive chemistry. It is only possible to assess the tribological response by empirical observation. It follows, that if such observations are to be integrated with an established condition monitoring process, the cost per data point for the physical test must be comparable with the cost of the analytical data. The development of a test procedure, system and process for generating friction and wear data, with a target price of not more than $20 per data point and throughput of 200 samples per day, with the potential for process automation, is discussed.

9:00 - 9:30 am
Florescent Nanoparticle–Assisted Probing of Fluidic Behavior on 3D Printed Surfaces
Peter Renner, Hong Liang, Wei Dai, Texas A&M, College Station, TX

Textured surfaces have shown enormous promise in reducing friction, although the mechanisms of fluidic behavior on such surfaces have yet to be fully understood. In this research, we developed a methodology to prove fluidic behavior of water on a shark-skin-like textured surface using florescent nanodiamond particles. The surfaces were 3D printed with various morphological characteristics. Using the nanoparticles and principals of fluid dynamics, we were able to generate a viscosity map. Results reviewed that the fluid drag was reduced due to the low-velocity gradient.

9:30 - 10:00 am
Contamination Impact on Gas-Phase Synthesized Graphene and Graphene Platelets Effectiveness as a Lubricant Additives in Bio-Derived Oil and PAO
Gordon Krauss, Albert Dato, Harvey Mudd College, Claremont, CA, Matthew Siniawski, Loyola Marymount University, Los Angeles, CA

Suspended graphene additives (.01 and .1% by mass) are investigated as friction and wear modifiers. This work compares gas-phase synthesized graphene to graphene platelets suspended in rapeseed oil and poly alpha olefin (PAO) during pin-on-disk testing. Previous studies have found a benefit to processing of flat graphene such that it is morphologically changed into a “crumpled” shape. Gas-phase synthesized graphene is crumpled as a result of the gas synthesis process. As a result, GSG consists of folded and randomly oriented graphene structures. The wear and sliding friction of a 52100 steel ball counter-surface is measured during testing in neat rapeseed oil and PAO, in different concentrations. Significant difference is noted with respect to wear at even the low concentrations. Friction differences are not apparent over the conditions tested. The influence of water contamination on wear and friction are observed in both oils with different types of graphene (GSG and platelet).

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

10:30 - 11:00 am
The Influence of Operating Parameters and Viscometrics in Energy Efficiency in Rolling Sliding Concentrated Contacts
Mukesh Dubey, R Mahapatra, Ajay Harinarain, Indian Oil Corporation Limited,R&D Centre, Faridabad, Haryana, India, Sarita Seth, Sarita Garg, Deepak Saxena, S S V Ramakumar, Indian Oil Corporation Ltd, R&D Centre, Faridabad, Haryana, India

Overall efficiency of engines is affected by the frictional losses between several components (bearings, valve train, cam followers-camshaft, piston ring liner etc) working under different combinations of rolling

sliding and varying loads. The function of the lubricating oil used in this is to ensure proper film formation to reduce the wear and friction existing in these engines. The losses in energy due to friction between these components could be as high as 10-15% which offers a good potential for reduction by careful optimization of the design of the oils used in these engines. This study evaluates the effect of various lubricant formulations on the frictional characteristics under different regimes of lubrication simulated in bench top tribometers. Experimental test were performed on ball on disc configuration at wide range of temperature, operating parameters in rolling /sliding concentrated contact to study the energy efficiency aspect of the different lubricants.

11:00 - 11:30 am
Testing the Wear Life of Sandpaper
Kenneth Budinski, Bud Labs, Rochester, NY

The original purpose of this study was to compare the useful life of a new type of sandpaper on a metal support with the traditional silicon carbide and alumina sandpapers. However, the study ended up in the development of a new test method to rank the life of fixed abrasives. The abrasive material (sandpaper etc.) to be tested is affixed to a slowly–rotating horizontal platen and the desired rider (wood cylinder in this case) is reciprocated on the rotating platen. Rider (wood) wear volume is the test metric and it is determined from length change of the rider. These studies indicated that the feature sandpaper had lower removal rates than the competitive sandpapers. However, tests were continued to compare silicon carbide with alumina, and to rank the “sandability” of a spectrum of woods: soft pine to ebony.

11:30 am - 12:00 pm
Insoluble Residues from Thin Films of Hydraulic Fluids and Engine Oils after Prolonged Heating
Svajus Asadauskas, Dalia Brazinskiene, Asta Griguceviciene, Center for Physical Sciences and Technology, Vilnius, Lithuania

Hydraulic fluids, engine oils and many other lubricants often produce thin films, which reside on heated surfaces. Severe exposure to air, humidity, combustion gases and other aggressive factors, makes degradation proceed much faster than in bulk oils. In this study certified high quality engine, hydraulic, gear and generator lubricants were tested as 200 µm thick films for up to 3000 hrs at 120 to 150°C. After heating, which resembled micro-oxidation, severely degraded thin films were soaked in fresh lubricants to observe whether nearly solid residues still dissolve in original oil. Results showed major differences among the same type of commercial lubricants. Such thin film methodology can predict long-term ageing tendencies for basestocks, formulated lubricants and biofuel blends, greatly reducing the need of expensive testing. The project COSMOS has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 645405.

3H Music Row 2

Fluid Film Bearings III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Dynamic Performance Analysis of Hydrostatic Oil Film Considering Oil Pad Damage under Extreme Working Conditions
Zhifeng Liu, Yongsheng Zhao, Qiang Cheng, Congbin Yang, Institute of Advanced Manufacturing and Intelligent Technology, Beijing University of Technology, Beijing, China

Hydrostatic oil pad is an important part of heavy-duty hydrostatic turntable. Due to the influence of long-term and heavy load, hydrostatic oil pad will be damaged to a certain extent. Oil pad damage will directly affect the load-bearing safety of oil film, thus affecting the performance of turntable. In this paper, the

influence of the loading position of the workpiece on the inclination of the turntable is studied when the damage degree of the oil pad is coupled with the loading force. Considering the influence of inclination and rotational speed on the stability of oil pad, the influence of the damage degree of oil pad on the fluctuation of oil film is studied. Finally, a method is proposed to find the maximum reasonable rotational speed under the condition of determining the tilt angle of the turntable, and the oil film fluctuation is controlled within the preset range.

8:30 - 9:00 am
TEHD Analysis of Dynamic Behavior of a Planetary Star Gearbox Journal Bearing Due to Misalignment Torque
Balint Pap, Safran Transmission Systems, Colombes, France, Michel Fillon, Institut Pprime, Chasseneuil-du-Poitou, France, Alexis Dombek, Patrice Gedin, Ludwig Biadalla, Safran Transmission Systems, Colombes, France

In the transmission systems of next generation civil aircraft gas turbines, to achieve a high reduction ratio in a relatively small volume planetary gearboxes may be used. In planetary gearboxes a sun gear transmits its power to the planet carrier through (usually 3-5) planet gears mounted on the fix planet carrier, which transmit then the power to the ring gear. A journal bearing is often used to support the planet gears on the shafts of the carrier. During the aircraft maneuvers (pitch, yaw and roll) a gyroscopic torque is generated by the rotating planet gear, which is balanced by the pressure of the fluid film bearing. The present work details the influence of the gyroscopic torque on the various planet gears at different positions (relative to the load direction) in the reduction gearbox. The simulations are performed under hydrodynamic (HD), elastohydrodynamic (EHD) and thermoelastohydrodynamic (TEHD) regimes.

9:00 - 9:30 am
Comparison of CFD-FSI and Reynolds Equation Based Approaches in the Prediction of Dynamic Coefficients of a Convergent-Divergent Slider Bearing with an Eeforming Liner
Troy Snyder, Minel Braun, University of Akron, Talmadge, OH

Paramount to the design of the rotordynamic systems in which elastomer-lined bearings are installed is characterization of the static load-carrying capacity and the dynamicproperties of the bearings. In this paper, the convergent-divergent slider geometry is investigated as the template geometry for a single-stave within a full elastomer-lined, marine bearing. Linearized dynamic coefficients are predicted using a CFD-FSI approach with a linear elastic model for the bearing liner and compared to a Reynolds equation (hyrodynamic lubrication) based model coupled to a thin elastic liner model for the bearing deformation. A parametric study varying sliding speed, perturbation frequency, liner material, and liner thickness of the bearing is performed to reveal differences in the predicted dynamic coefficients.

9:30 - 10:00 am
Thermal Characteristics of a Vertical Hydrostatic Guideway System with Ballscrew Drive of Precision Milling Machines
Hua-Chih Huang, National Kaohsiung University of Science and Technology, Kaohsiung City , Taiwan, Wen-Hao Yang, Hiwin Technologies Corp, Taichung, Taiwan

This paper simulates the thermal characteristics of a vertical hydrostatic guideway using ANSYS/Fluent in precision milling machine applications by considering the oil film friction of hydrostatic bearings in operational feed speed and heat generation in ballscrew nut . A thermal characteristic experiment of this vertical guideway system at different feed speeds will be tested to verify the correctness of boundary conditions of Ansys model. Temperature rise in individual hydrostatic bearing due to different supply pressure, feed speed, and oil viscosity will also be analyzed, and the thermal displacement of the center point of worktable can be predicted in case of thermal deformation.

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

10:30 - 11:00 am

Numerical and Experimental Investigations of the Performance of Pocketed Thrust Bearings Operating in Micro-Electro-Mechanical Systems

Peng Wang, Thomas Reddyhoff, Daniele Dini, Francisco Profito, Imperial College London, London, United Kingdom

The high frictional torque and sever wear has prevented the development of Micro-electro-mechanical systems (MEMS) that include sliding and rotating parts for a long time. Micro-scale hydrodynamic bearings are potential to provide low friction and reduce wear at the small-scale contacts, but appropriate design is required to optimize its performance. In this study, a pocketed 1-mm diameter hydrodynamic parallel thrust bearing has been investigated both numerically and experimentally with concentration on factors affecting its load capacity and friction coefficient. Results from experiments on a custom-built MEMS tribometer demonstrated that the small-scale bearings can bear applied load up to 0.05 N and the measured friction coefficient is below 0.05 when lubricated with low viscosity liquids. An FVM model considering mass conservation, inertia effects of liquids and capillary pressure is developed to better understand the bearing working mechanism and optimize the bearing design.

11:00 - 11:30 am

Determination of Inducer Shape Influence on Acoustic Levitation Characteristics

Bartosz Bastian, Michal Wodtke, Gdansk University of Technology, Gdansk, Pomorskie, Poland

The paper presents results of theoretical research for near field acoustic levitation. The principle of the system is based on a rigid vibrating plane which under specific frequency and amplitude of vibration allows for the creation of an air squeeze film supporting a freely suspended body. CFD-based calculation method allowed for consideration of the interaction between the air film flow (described by Navier-Stokes equations) and the dynamic of the levitating object. The goal of the research was to study the effect of the levitating object shape on near-field levitation parameters. Comparison between various dimension ratio of rectangular and oval shape was investigated. The impact of dimension ratio on load carrying possibilities is presented. Results of analysis (e.g. film thickness, oscillation amplitude) allow to determine the most favourable excitation parameters for the specific shape of the levitating object

11:30 am - 12:00 pm

Multiphase Fluid-Structure Interaction (FSI) Computational Fluid Dynamics (CFD) Analysis of An Elliptical Journal Bearing with Varying Supply Rate: A Look at Starvation

Cori Watson, Minhui He, University of Virginia , Charlottesville , VA, Scan DeCamillo, Kingsbury, Inc., Philadelphia, PA, Roger Fittro, Houston Wood, University of Virginia , Charlottesville , VA

Fluid film bearings are used in a wide range of rotating machinery to support a load during rotation. This study looks at starvation of fixed geometry two pad elliptic journal bearings using multiphase computational fluid dynamics (CFD) and fluid-structure interaction (FSI) techniques. The bearing is modeled in ANSYS CFX using FSI to find the loaded journal position and convection boundary conditions are used between the solid and the lubricant; deformation is ignored. The supply pressure is varied and starvation is analyzed through the pressure, thermal and oil volume fraction distributions. The results show that the shape of the starved region does not match the “straight line” assumption of many thermoelastohydrodynamic (TEHD) codes. The results also show that the elliptical bearing modeled is always somewhat starved regardless of supply pressure. Finally, the influence of starvation on minimum film thickness, peak temperature and peak temperature location are also discussed herein.

Engine & Drive Train I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
DD13 Liners – Batch Consistency and Scuffing Initiation
Peter Lee, Carlos Sanchez, Jose Starling, Southwest Research Institute, San Antonio, TX

The DD13 scuffing test was developed as part of the new PC-11 oil specification. It uses the Detroit Diesel 12.8L in-line 6 diesel engine running with controlled batch liners and uncoated top rings. The test operates at 1800rpm throughout the test at 50% load for 30hrs before stepping to 100% load for the remainder of the test. If the engine scuffs, it normally scuffs not too long after the higher load set point is reached. However, repeatability of the test is dependent upon the liner batch. This presentation will explore the differences found in the liner batches and these differences may be driving the test.

8:30 - 9:00 am
Real Time Wear Mapping of a 2.0L Turbocharged Gasoline Direct Injection Engine
Peter Lee, Craig Wileman, Gregory Hansen, Southwest Research Institute, San Antonio, TX

A 2.0L turbocharged direct injection gasoline engine was disassembled, measured and parts irradiated to create measureable radio nuclides. The engine was then reassembled and operated through a range of test conditions in an engine test cell. As the engine was operated, the lubricant was pumped through a radio nuclide detector to measure, in real time, the wear taking place in the engine. This presentation will discuss the results obtained from this work.

9:00 - 9:30 am
Effect of Surface Textures on Fuel Economy
Stephen Hsu, Govindaiah Patakamuri, George Washington University, Washington DC, DC, Timothy Cushing, GMC, Warren, MI

Micro-surface textures have been used in seals successfully since early 2000s. Application attempts to automotive engines to improve fuel economy have been attempted. Despite friction reduction demonstrated at the bench test level, engine performance data have been elusive. One of the issues is how to measure friction reduction of a single engine component in an engine test, while there are many sliding components operating at the same time. Other parameters such as temperature, engine built, duty cycle, tolerance etc all affect the final fuel economy. This study uses an disassembled engine and fabricate textures on most of the sliding surfaces. Then ran engine fuel economy test in an engine chassis dynomometer to measure fuel economy, which was measured by metered fuel pump and by tail pipe carbon analysis and balance. Results of such tests will be reported in this presentation.

9:30 - 10:00 am
Experimental Research on the Tribological Performance of Laser Textured Cylinder Liner
Bifeng Yin, Bo Xu, Hekun Jia, Huiqin Zhou, Xin Kuang, School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, China

Due to the hydrodynamic effects of surface texture on improving lubrication property of sliding surfaces, it has great application potential in the Cylinder Liner-Piston Ring(CL-PR) system. In this research, the Laser Surface Texturing(LST) technology is used to process micro-dimples(diameter 50μm, deepth 8μm; area ratio 10%) on the cylinder liner surface. Then by conducting the reciprocating friction tests on a friction-wear tester, the instantaneous friction force of ring/liner pair is measured. The testing results indicate that laser texturing liner could reduce the friction force, especially the peak friction value around

the stroke ends of CL-PR under different lubrication conditions. Compared with the honing processed liner, the average friction coefficient of the laser textured liner can be reduced effectively under hydrodynamic lubrication state, while the average friction coefficient decreasing rate narrows under mixed lubrication state.

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

10:30 - 11:00 am
A Comparison of Tribosystems, Wear Mechanism and Lubricant Effects in Silent and Roller Timing Chains
Ramoun Mourhatch, Shelby Skelton, Seyedeh Mahboobeh Hosseini, Chevron Oronite LLC, Richmond, CA

Silent and roller timing chains are the two most common torque transfer elements between the crankshaft and the camshaft in modern IC engines. While silent chain consists of a series of link plates, connected by pivot pins, the roller chain consists of a series of connected journal bearings that actuate as they enter and leave the sprockets. Wear in both types of chains results in chain elongation and engine timing deviation. The presence of soot in modern passenger car engines due to widespread adoption of gasoline and diesel turbocharged direct injection technologies can lead to accelerated chain wear. The purpose of this study is to map the tribosystems and lubrication regimes in both types of timing chain and establish the primary wear mechanisms in each case. For that end, the authors analyzed silent and roller timing chains from controlled engine tests. The effects of material (e.g., coatings) and lubricant parameters on wear rate and mechanism were examined for each system.

11:00 - 11:30 am
Friction and Wear Investigations on Chain Joints of Timing Chains
Andre Becker, Sauer Bernd, Institute of Machine Elements, Gears, and Transmissions, University of Kaiserslautern, Kaiserslautern, Germany

The lifetime of timing chains is determined by the wear in the chain joints. Due to contact forces and sliding motion, the pin and the bush of the chain joints are worn out. The influences on the chain wear are highly complex, from basic aspects like the chain geometry and the lubrication up to the surface treatment. In order to investigate these influences systematically, a home-made test rig, the so-called chain joint tribometer, was developed and realized. This tool allows for friction and wear investigations on one single chain joint. Therefore, the real contact situation is reproduced using batch production components. The load curves, in particular the contact force and the relative motion, are determined from a MBS model of a real chain drive and applied to the test chain joint with highly dynamic actuators. The chain joint Tribometer is presented together with different measurement methods and results from wear and friction investigation.

11:30 am - 12:00 pm
Real-Time Measurements of Piston Ring and Liner Lubrication in a Marine Diesel Engine Using Ultrasound
Xiangwei Li, Henry Brunskill, Leonardo Centre for Tribology, Sheffield, United Kingdom, Matthias Stark, Winterthur Gas & Diesel, Winterthur, Switzerland, Rob Dwyer-Joyce, Leonardo Centre for Tribology, Sheffield, United Kingdom

The lubricant film thickness between the piston ring and the engine liner is a critical parameter that has a significant effect on operating efficiency. Breakdown of lubrication film results in metal-metal contact and scuffing. This can result in severe damage on interior surface of liner and reduce engine efficiency. Real-time monitoring of liner lubricant film and detection of scuffing would facilitate how operating parameters affect engine performance at the critical location. A non-invasive ultrasonic measurement system has been implemented on a test engine to monitor the lubrication in-situ. Longitudinal and shear polarised sensors were mounted on the liner at Top Dead Centre. Low-frequency ultrasound was transmitted to strike the contact interface between engine liner and piston rings. Test results found the returning signals changed with engine operating conditions which suggests that lubrication characteristics can be

monitored in real-time using this ultrasonic tool.

3J Cumberland 3

Nanotribology III

Session Chair: I. Szlufarska, Materials Science & Engineering, University of Wisconsin, Madison, WI
Session Vice Chair: P. Egberts, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada

8:00 - 8:30 am
Block Copolymer Nanoparticles Prepared via Polymerisation-Induced Self Assembly for Use as a Friction Modifier in Motor Oils
Liam Pratt, Rob Dwyer-Joyce, Steve Armes, University of Sheffield, Sheffield, United Kingdom

Poly(stearyl methacrylate)-Poly(benzyl methacrylate) (PSMA-PBzMA) diblock copolymers were synthesised via RAFT dispersion polymerisation in mineral oil by a one-pot protocol. These copolymer chains self-assemble in situ to produce sterically-stabilised spherical nanoparticles with the soluble PSMA acting as the stabiliser block and the insoluble PBzMA forming the nanoparticle cores. Stribeck curves obtained via MTM (0.5 wt%, 100°C, 10-2500 mm s^{-1}, 35 N) show that 20-60 nm diameter nanoparticles lower the friction coefficient across all rolling speeds compared to mineral oil alone, with a 46% reduction being achieved in the boundary lubrication regime. Unlike most friction modifiers, no ‘running-in’ period was required. This suggests a ‘nanoparticle entrapment’ mechanism, rather than the thin film mechanism that characterises most friction modifiers. If this is correct, it may indicate a universal lubrication mechanism.

8:30 - 9:00 am
Scale Dependent Tribological Behavior of Steel on MoS_2 Co-Deposited Commercial Lubricants with Macroscopic and Nanoscale Contacts
Peter Serles, The University of Toronto, Toronto, Ontario, Canada, Guillaume Colas, Institut FEMTO-ST, Besançon, France, Aurélien Saulot, INSA Lyon, Lyon, France, Tobin Filleter, The University of Toronto, Toronto, Ontario, Canada

While many commercial solid lubricant coatings are able to boast superlubricious properties, the reliability and fundamental understanding of their tribological performance including wear, 3rd body creation, and velocity accommodation remains largely unknown. Macroscale tribometers are able to best replicate application conditions but offer a limited understanding of the evolutionary nature of the lubricant response [1]. By matching the macroscale contact conditions to the nanoscale using friction force microscopy with custom steel-beaded cantilevers, high-resolution application-specific testing has been achieved. In the present study, three commercial 1 µm thick MoS_2 co-deposited solid lubricant coatings have been tested on macroscale and nanoscale tribological testers with contact diameters of 2 mm and 200 nm respectively. It was found that coefficient of friction does not change across scales while wear characteristics and third body circuit scale proportionally to the contact size.

9:00 - 9:30 am
Experimental Investigation of Friction and Wear Behavior of 52100 Steel Against Nano-Coated Mild Steel Subject to Refrigerant Lubrication
Zulfiqar Khan, Muhammad Bhutta, Bournemouth University, Bournemouth, Dorset, United Kingdom

Refrigerants have significant impact on friction and wear behaviours of interacting components in several industrial applications such as compressors. Refrigerant industry has been proactive in terms of introducing new and environmentally friendly refrigerants as a response to major environmental concerns arising from previously employed thermo-fluids. Hydrofluoroethers (HFEs) are promising environmentally friendly refrigerants with good thermodynamic properties. HFEs have zero ozone depleting potential and

a lower global warming potential as compared to previous generation of refrigerants. Apart from having the knowledge of the thermodynamic properties of a thermo-fluid, it is imperative to fully understand the tribological properties of thermo-fluids as lubricants in tribo-systems within the context of sustainable development. This paper presents a study of friction and wear properties of Nano-coated interacting parts with HFEs as lubricants.

9:30 - 10:00 am
A Direct Experimental Link between Atomic-Scale and Macro-Scale Friction
Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

While it is well-established that fundamental atomic-scale interactions govern the friction coefficients and wear rates observed macroscopically, atomic scale and macroscale friction coefficient measurements are quantitatively disconnected for reasons that remain unclear. Macroscale friction is insensitive to external factors like environment and material, while nanoscale friction coefficients can vary from extremely large to extremely small. We propose to begin bridging this knowledge gap by bridging the length scale gap between nano and macroscale tribometry. We will describe how we modified these methods to enable friction coefficient measurements of a model system involving single-crystal MoS_2 under the same conditions using instruments traditionally used to probe nanoscale and macrioscale friction. Eliminating this experimental 'dead-zone' between nanoscale and macroscale measurements will provide the means for when 'nanoscale' friction becomes 'macroscale' friction and why.

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

10:30 - 11:30 am
Nanotribology of Tunable Polymer Coatings
Marina Ruths, University of Massachusetts Lowell, Lowell, MA

Structuring in polymer and polyelectrolyte films can be induced and controlled by modifying solution conditions or annealing procedures. These phenomena are of interest for controlling adhesion, friction, and lubrication of surfaces in biomedical applications. For example, changes in the solvent quality and the presence of multivalent ions in polyelectrolyte systems cause aggregation and strongly influence the normal and frictional forces between interacting layers. Some of these changes can be reversible upon changing the solution conditions and enable evaluation of the contributions to aggregation from solvent quality and electrostatic bridging of polyelectrolytes. To illustrate these phenomena, examples will be shown of structure formation observed with AFM and its effects on normal and friction forces as studied with the SFA.

11:30 am - 12:00 pm
Improved Parameter Estimation for Nanoindentation Measurements
John Despard, Rice University, Houston, TX, Hamid Ghaednia, Harvard Medical School, Boston, MA, Matthew Brake, Rice University, Houston, TX

Nanoindentation measurements are an attractive approach for accurately characterizing the material properties of a test specimen. However, due to the complexities in the loading phase of an indentation contact, only the unloading phase of the force-deformation graph is used to calculate, by Hertzian theory, the effective modulus of elasticity, which accounts for Poisson's ratio effect. In this work, the feasibility of material properties measurement using the recent contact models for the loading phase of an indentation curve is investigated. This is accomplished by fitting an empirical formulation proposed by Ghaednia, et al. (2019) on nanoindentation data. The strain hardening effect has been included in the modeling to account for the scale effect issues. Comparisons are made to properties computed by current Hertzian methods and experimentally verified yield strength and elastic modulus. Conclusions are drawn concerning the accuracy of the model fit for several structural metals.

Environmentally Friendly Fluids I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Positive Effects of Mono-Unsaturation on Hydraulic Fluid Performance
Svajus Asadauskas, Linas Labanauskas, Center for Physical Sciences and Technology, Vilnius, Lithuania, Jean Couturier, Jean Dubois, Arkema, Europe, France

Basestocks from vegetable oils are vulnerable to degradation due to the abundance of double bonds. Nevertheless, mono-unsaturation might bring many positive aspects, such as high Viscosity Index, low volatility, good cold fluidity, biodegradability etc. In this study viscometric, oxidative and hydrolytic stability, vaporization, additive compatibility and other tests were carried out to compare mineral, vegetable and synthetic basestocks to systematically synthesized polyol esters and dibasic esters with or without unsaturation. Results show that highly mono-unsaturated esters, such as oleates, gondoates or erucates, approach the stability of synthetic basestocks with other properties being similar or better. Careful selection of basestocks can minimize the need for high performance additives and improve wear resistance. The project COSMOS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 645405.

8:30 - 9:00 am
Ecolabel 2018 and VGP2018 II. Changes and Challenges in 2019
Paula Vettel, Novvi LLC, Emeryville, CA

The EU Ecolabel specification is the premium approval to be obtained for environmentally acceptable lubricants (EAL). The EPA Vessel General Permit (VGP) 2013 requires that all ships over 79 feet use EAL lubricants in all ship-sea interfaces. EAL lubricants must meet requirements for biodegradability, non-bioaccumulation, low toxicity, and previously, renewable content for Ecolabel. Both Ecolabel and VGP have been renewed and updated in 2018. This presentation will review the updated information about these specifications and discuss the changes and challenges from the formulator's point of view.

9:00 - 9:30 am
Soybean Oil: Lubricating Performance
Robert Brentin, Omni Tech International, Midland, MI

Soy-based lubricants is one of the oldest and newest categories. Vegetable oils were one of the first materials used to lubricate. New advances in chemical modifications and soybean agriculture are leading to more effective soy-based lubricants. Recent development of soybeans with an increased proportion of oleic acid and low content of polyunsaturated fatty acids provides an oil with higher oxidative stability. Soybean oil has high lubricity, a polar nature, high viscosity index, high flash point / low evaporation rate, and is biodegradable and non-toxic. These properties make it a favored candidate for use in passenger car motor oil, two-cycle engine oil, greases, cable lubricants, hydraulic fluids, and metalworking fluids while having an environmentally acceptable footprint. This presentation will discuss the performance factors that make soybean oil a leading lubricant material in the biobased and vegetable oil category.

9:30 - 10:00 am
Evaluation of Water Soluble Polymers for Aqueous Lubricants
Erik Willett, Functional Products Inc, Macedonia, OH

Water based lubricants reduce the need for petroleum derivatives and offer greater fire safety over hydrocarbon alternatives. The challenge with water arises from the low starting viscosity and its potential

for freezing and evaporation. Six water soluble polymer chemistries were evaluated for thickening efficiency and viscosity index improvement from ISO 22 to 680 in pure water. Evaluation was continued to screen for inherent corrosion inhibition, lubricity, water retention, and anti-freeze behavior in water. Drawbacks like haze, foaming tendency, and surface films were observed in certain chemistries which were mitigated through additives. Water soluble AW and EP additives were formulated into the polymer/water blends to identify useful additive chemistries and verify if polar polymers hinder the function of surface-active additives on metal surfaces.

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

10:30 - 11:00 am
Performance Comparison of Hydraulic Oil Blends Made with Vegetable-Based Fluids; Evaluations of High Oleic, Low Oleic Vegetable Oils as Well as a Mineral Oil Blend
Doug Adams, RSC Bio Solutions, Indian Trail, NC

The importance of Environmentally Acceptable Lubricants (EAL) has led to improvements in the quality of vegetable-based fluids. The base fluids used in this study are high oleic soy bean oil, low oleic soy bean oil, high oleic canola oil and a mineral oil blend. To determine the level of improvements, hydraulic fluids were made with an established additive combination in the commercially available base fluids previously described. These fully formulated hydraulic fluids will be evaluated using tests that are typically used to measure the quality of hydraulic fluids. Some of the performance characteristics of the fully formulated hydraulic fluids that will be evaluated include corrosion protection, RPVOT, Pour Point, Four Ball Wear, Water separation and air entrainment.

11:00 - 11:30 am
Bio-Based Base Oils for Performance Lubricants
Basudeb Saha, University of Delaware, Newark, DE

Synthesis of bio-based base oils for high performance lubricants are desirable for operation optimization, modular equipment, environmental ecosystems and future energy security. We have developed next generation enabling technology to produce bio-based base-oils from inexpensive, abundantly supplied, and sustainably sourced feedstock (non-food biomass, natural oils and/or waste cooking oils). Our technology innovation, based on energy-efficient and atom-economic catalytic coupling and deoxygenation reactions, offers the flexibility to produce base-oils with tailored molecular architecture (carbon number, molecular size, branching, number of branching, and distance between branched chain) and tunable specifications for a wide range of existing high-performance applications. This presentation will illustrate the core technology innovation and specification comparison of products with those of commercial synthetic and mineral base oils.

11:30 am - 12:00 pm
Estolides - The Latest in High Viscosity Biosynthetic Base Oils
Jakob Bredsguard, Biosynthetic Technologies, Rancho Santa Margarita, CA

Estolides are an environmentally acceptable base oil that is sometimes referred to as a “biosynthetic.” Over the last few years, they have gained recognition for their performance and environmental qualities, allowing lubricant companies to formulate quality products that are seen as environmentally friendly. They are synthesized from vegetable oils so they have high renewable content. They are also biodegradable and nontoxic, yet have strong performance characteristics. Recent developments in biosynthetic base oils have led to a high viscosity base oil (ISO VG 680) that is both bio-based and biodegradable. The product is based on the estolide technology giving the oil the expected high viscosity index and low volatility common to other estolide oils. The product is expected to be ideal for use in grease and gear oils, offering formulators a new quality option when developing performance and/or environmentally friendly products.

Lubrication Fundamentals III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Towards a Fundamental Understanding of Organic Friction Modifier Additives
Sophie Campen, Janet Wong, Imperial College London, London, United Kingdom

Organic friction modifiers play an important role in reducing friction and wear in lubricated systems. To gain a fundamental understanding of organic friction modifier behaviour, it is necessary to investigate their friction and film-forming abilities. Organic friction modifiers adsorb onto surfaces forming self-assembled monolayers, however there is evidence that an applied shear stress can promote boundary film formation or alter the adsorbed film morphology. Here we combine friction-testing and adsorption experiments to better understand their behaviour. Quartz crystal microbalance with dissipation monitoring (QCM-D) is used to monitor organic friction modifier adsorption and atomic force microscopy (AFM) is used to probe the morphology of adsorbed and 'rubbed' friction films. Under certain conditions, friction modifiers exhibit very-low boundary friction for steel surfaces (friction coefficient < 0.02). A thin (< 2 nm) low-friction film is observed on the friction surface.

8:30 - 9:00 am
Research on Polyalkylene Glycols Superlubricity System
Wenrui Liu, Yuhong Liu, Tsinghua University, Beijing, China

Superlubricity with an ultralow friction coefficient is uneasy to achieve under macroscopic conditions. In this study, we broaden the scope of polyalkylene glycols (PAGs) superlubricity system with different molecular weights (MWs). Remarkably, the threshold concentration, where superior load-bearing capacity is achieved, for such superlubric behavior decreased with increasing MW. Both molecular-level adsorption and shear rheology of the lubricants are demonstrated to play a synergistic and complementary role in achieving superlubricity with PAG aqueous solutions. Furthermore, by introducing organic acids to such polymer aqueous solutions, the running-in time is decreased and the load-bearing capacity is significantly improved, while inorganic acids have no effects. This phenomenon is considered to be attributed to tribochemical reactions during the frictional process. This work enriches the investigation about tribological behaviours of water-based polymer lubricants at interface.

9:00 - 9:30 am
Influence of the Oil Additives and Their Molecular Structure on the Wetting and Friction Performance
Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Although it is obvious that wettability is an important characteristic in tribology, there is still no information on how additives and their different molecular structure change the wetting behaviour of oil, if at all. This work reports the influence of some simple organic friction modifiers like fatty acids, amides, alcohols and amines on static and dynamic wetting of oil. The influence of additive molecular structure was investigated by varying the number of additive polar head groups, chain length, polarity and saturation. The results show strong effect of all these additives properties on wetting of oil. Moreover, important effect on EHD friction is also reported and discussed.

9:30 - 10:00 am
Traction Curves and Rheological Properties of Some Lubricating Fluids
Robert Erck, Argonne National Laboratory, Lemont, IL

Traction curves were obtained for 20 fluids using a traction testing device which slid a disk against a ball. The traction coefficient τ was measured as a function of bulk fluid temperature and slide-to-roll ratio (SRR). Fluids were bio-based, PAO, mineral, polyol, polyalkylene glycol, and diester. Some fluids were fully formulated. The device used was a PCS brand “mini traction machine.” At a mean speed of 3 m/s, and temperatures of 25-50 °C, full-film lubrication was attained. SRR values were + 60 to -60%. The 37 N load produced a maximum contact pressure of 1 GPa, and the conditions were such that in all cases, three regions of behavior were measured: near-linear regime for small SRR, increasing to a maximum traction coefficient τ_{max} at 20 to 40% SRR, followed by a decrease in τ due to thermal effects in the contact area. Values of τ are correlated with regime and type of fluid and temperature.

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

10:30 - 11:00 am
Effect of Different Running-In Stages on Fatigue Life of Mixed-Lubricated Circular Contacted Machine Elements
Hui Cao, Yonggang Meng, Tsinghua University, Beijing, China

An appropriate running-in process can prolong the life time of mechanical components. During running-in, the microstructure of contacting surfaces evolves continuously, the details of which have not been fully explored. In this study, the morphology evolution and the corresponding coefficient of friction variation of a ball-on-disc pair in sliding-to-rolling process were numerically simulated. Meanwhile, the fatigue lives of the disc with different running-in durations were calculated and compared. The results have indicated that the running-in state significantly affects the surface fatigue life while the influence on the spalling fatigue life is relatively slight. In addition, the running-in parameters were optimized for the friction pairs to be operated in different working conditions.

11:00 - 11:30 am
Prediction of Friction in EHL Point Contacts Operating under Mixed Lubrication Conditions
Marcus Björling, Andreas Almqvist, Luleå University of Technology, Luleå, Sweden

In an EHL contact operating under mixed conditions the lubricated conjunction exhibit dissipation within the fluid film as well as the asperity contacts between the opposing surfaces. In this paper, we present a model for friction prediction in rolling-sliding EHL point contacts operating under mixed conditions. The main objective is to enable systematic investigation of the effects of surface roughness. This calls for an ultra-fast solution procedure and to this end we develop a semi-analytical low number of degrees of freedom model. To assess and justify the feasibility of the model, the friction predictions are compared against friction measurements obtained with a ball-on-disc machine.

11:30 am - 12:00 pm
The Role of Fatty Amine Chemistry in Friction Reduction
Toby Stein, Nouryon, Stenungsund, Sweden

The role of additives to enhance performance in lubricants is long established. This paper builds on one particular chemistry, that of fatty amines. We will look to discuss the history, the current role and the choices that are available. The process of evaluating fatty amines shows different levels of friction modification can be achieved and will be shown. Evaluations are carried out using MTM to try to establish structural performance relationships. A core part of the use of fatty amine chemistry is the central Nitrogen atom and the options this provides to synthetic chemists to create unique properties at a molecular level for any individual lubricant formulation or scenario. The paper will discuss how these transformations can be carried out and lessons learned.

2D Materials - Materials Tribology and Nanotribology Joint Session

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Friction on 2D Materials: Friction Contrast between Graphene, MoS_2 and Graphene-MoS_2 Heterostructures
Mohammad Rasool Vazirisereshk, University of California Merced, Merced, CA, Han Ye, University of Pennsylvania, Philadelphia, PA, Zhijiang Ye, Miami University, Oxford, OH, Mengqiang Zhao, A.T. Charlie Johnson, Robert Carpick, University of Pennsylvania, Philadelphia, PA, Ashlie Martini, University of California Merced, Merced, CA

Two-dimensional (2D) materials, including graphene and molybdenum disulfide (MoS_2), are promising candidates for the next generation of solid lubricants in oil-free systems and as functional materials for flexible electronics. The adhesion and friction behavior of 2D materials is therefore important. To understand these properties, we characterized the nanotribological properties of graphene and MoS_2 monolayers, both transferred onto a single silicon sample, establishing three structures: graphene on silicon, MoS_2 on silicon, and a graphene on MoS_2 heterostructure on silicon. This approach enabled direct comparison between friction at different loads on these three surfaces using atomic force microscopy experiments and molecular dynamics simulations. The simulations reveal the origins of the friction contrast on graphene, MoS_2 as well as the graphene-MoS_2 heterostructure. Ultimately this investigation helps provide a comprehensive understanding of contact and sliding of 2D materials.

8:30 - 9:00 am
Interlayer Friction and Superlubricity in Single-Crystalline Contact Enabled by 2D Flake-Wrapped AFM Tips
Yanmin Liu, Tianbao Ma, State Key Laboratory of Tribology, Beijing, China

Interlayer friction between 2D materials and heterostructures is a promising probe of the physics in their interlayer couplings and superlubricity. We propose a TAMET method to fabricate various 2D flake-wrapped AFM tips and to directly measure the interlayer friction between 2D flakes in single crystalline contact. First, superlubricity between different 2D-flakes and layered bulk materials is achieved with the friction coefficient as low as 10^{-4}. The rotation angle dependence of superlubricity is observed for friction between graphite layers, whereas it is not observed between graphite and h-BN because of the incommensurate contact of the mismatched lattices. Second, the interlayer lateral force map between ReS_2 layers is measured with atomic resolution, showing hexagonal patterns, as further verified by theoretical simulations. The tribological system constructed here offers an experimental platform to study interlayer couplings and friction between 2D flakes and layered materials.

9:00 - 9:30 am
Pressure- Induced Friction Collapse of Graphite Flake Sliding on Muscovite Surfaces
Bingtong Liu, Jin Wang, Ming Ma, Tsinghua University, Beijing, China

In this paper, the dependence of friction on normal load for monocrystalline van der Waals (vdW) heterojunctions composed of microscale graphite flake and millimeter-sized mica are investigated. The experimental results show that the friction can be reduced by applying a normal load with the slope in a magnitude of -0.01 during both loading and unloading processes, which deviates from the Amonton law. The negative friction coefficient is robust at different temperatures. Mechanisms are revealed using molecular dynamics simulations. The results for normal load-induced friction collapse enriches our fundamental understanding about friction and offers a route to achieve nearly frictionless sliding interfaces.

9:30 - 10:00 am
Robust Microscale Superlubricity in Graphite/Hexagonal Boron Nitride Layered Heterojunctions
Yiming Song, Tsinghua University, Beijing, China, Davide Mandelli, Oded Hod, Michael Urbakh, Tel Aviv University, Tel Aviv, Italy, Ming Ma, Quanshui Zheng, Tsinghua University, Beijing, China

Structural superlubricity is a fascinating tribological phenomenon, in which the lateral interactions between two incommensurate contacting surfaces are effectively cancelled resulting in ultralow sliding friction. Here we report the experimental realization of robust superlubricity in microscale monocrystalline heterojunctions. The results for interfaces between graphite and hexagonal boron nitride clearly demonstrate that structural superlubricity persists even when the aligned contact sustains external loads under ambient conditions. The observed frictional anisotropy in the heterojunctions is found to be orders of magnitude smaller than that measured for their homogeneous counterparts. Atomistic simulations reveal that the underlying frictional mechanisms in the two cases originate from completely different dynamical regimes. Our results are expected to be of a general nature and should be applicable to other van der Waals heterostructures.

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

10:30 - 11:00 am
Raman Spectroscopy as an Effective Tool to Detect Interaction on 2D Material Interfaces
Xiang Zhou, Dameng Liu, Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

By performing low-frequency Raman measurements and adopting a linear chain model, we obtain interlayer force constant in a new material – $SnSe_2$. The lateral force constant is lower than many other 2D materials such as MoS_2 and black phosphorus. The same strategy is also used to study twisted MoS_2. We find that the vertical component of the force constant on twisted (incommensurate-stacking) interface decreases remarkably, and that thickness, which to some extent reflects rigidity, of the component layers may also affect the strength of interlayer interaction. The force constant we obtain is more of an intrinsic characteristic of the material than a measurement of frictional or adhesive force, but it helps deeply understand tribological phenomenon concerning interlayer interaction such as solid-state superlubriciy. Our method can act as a conventional method for measuring interaction on the interface in 2D materials, as well as their homo- or hetero-structures.

11:00 - 11:30 am
Friction Modulation on Graphene: Underlying Substrate, Atomic Roughness, Defects, and Beyond
Jun Liu, The university of akron, Akron, OH, Qunyang Li, Xi-qiao Feng, Tsinghua University, Beijing, China, Zengfeng Di, Chinese Academy of Sciences, Beijing, China, Wen Yue, China University of Geosciences, Beijing, China, Chang Ye, Yalin Dong, The University of Akron, Akron, OH

It has been recognized that graphene offers excellent anti-friction and anti-wear properties. Being produced by exfoliated or epitaxial method, the friction behaviors of graphene are significantly influenced by the underlying substrate and structural defects in graphene that may develop during growth or processing. Using molecular dynamics simulation, we reveal that moiré pattern formed between graphene and supporting substrate modulates the lateral force, which arises from geometric undulation of graphene due to its different stacking states on the substrate. The presences of chemical adsorbents and vacancies increase friction in varying degrees. The Schwoebel barrier, the chemical reactivity, as well as the roughening induced by adsorbents contribute to the friction enhancement. We provides a friction-mechanism map that correlates frictional behavior to various atomic scale mechanisms, which is useful for understanding the nanoscale friction of graphene.

11:30 am - 12:00 pm
Eliminating Delamination of Graphite Sliding on Diamond Like Carbon
Yujie Gongyang, Tsinghua University, Beijing, China

Delamination is one of the major issues which cause the failure of two-dimensional layered-material based superlubric friction pairs. Using graphite mesas with single crystalline surfaces sliding on a

diamond-like carbon film as an example, here we show experimentally that the delamination of graphite can be eliminated after proper annealing. With a combined approach of careful X-ray photoelectron spectroscopy analysis, force measurement and quantitative theoretical estimation, we find the variation in the chemical states of graphite edges and the desorption of water accounts for the absence of delamination. Our result provides a new concept for tuning the frictional properties of superlubric graphite mesas and the design of delamination-free layered-material based friction pairs.

4D Music Row 1

Wear II

Session Chair: C. Wang, Cummins
Session Vice Chair: G. Molina, Dept of Mechanical Engineering, Georgia Southern University, Statesboro, GA

2:00 - 2:30 pm
Effects of Unevenly Worn Cage Pockets on the Service Life of a Solid Lubricated Rolling Bearing
Rahul Dahiwal, Sascha Pörsch, Sauer Bernd, University of Kaiserslautern , Kaiserslautern, Rheinland Palatinate, Germany

Solid lubricated rolling bearings use a polymeric cage endowed with Molybdenum Disulfide (MoS_2) particles as a reservoir of lubricant, increasing their service life significantly. During the bearing's operation, solid lubricant from the cage is transferred onto the raceways replenishing the initial lubricant coating of the raceways. Experiments have shown that uneven wear of the individual cage pockets can occur that causes the pockets to possess different diameters. This results in an effect on the bearing's service life. To analyze the real wear process, a four-bearing-vacuum-test-rig is used. Cage pockets with intentionally enlarged pocket diameters of solid-lubricating material are considered. In order to understand the effects of enlarged pocket geometries on the bearing's dynamic, a multi-body simulation model (MBS) is utilized. Furthermore, the first outcome shows that an increase of the pocket diameter results in a decrease of the pocket wear and thus the lubrication interval.

2:30 - 3:00 pm
Modeling of Low Wear of Rough Disc in Sliding Contact with Flat Ring
Pawel Pawlus, Andrzej Dzierwa, Wieslaw Zelasko, Rzeszow University of Technology, Rzeszow, Poland, Rafal Reizer, University of Rzeszow, Rzeszow, Poland

The experiments were carried our using a ring-on-disc tribological tester under dry friction condition for a conformal contact at ambient temperature. The linear speed of disc was 0.27 m/s, the sliding distance was 320 m, the normal force was 210 N. Steel discs of smaller hardness (20 HRC) were put in contact with a steel ring of higher hardness (45 HRC). Disc samples were prepared using various machining processes in order to obtain various surface topographies. It was found that disc volumetric wear was proportional to standard deviation of surface roughness height. The average coefficient of friction was proportional to disc wear. In modeling of disc wear the contact of equivalent rough surface with smooth flat surface was analysed using a numerical FFT method. In each step wear was proportional to the contact pressure. High correlation was obtained between measured and simulated disc wear levels.

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

4:00 - 4:30 pm
Impact of Wear Models on the Local Behavior of Railroad Brake Pad
Mathieu Renouf, University of Montpellier, Montpellier, France, Eric Chapteuil, Yves Berthier, INSA Lyon, Villeurbanne, France

Material used for railroad brake pad are usually composed of several constituents such as copper,

graphite, etc. In view to optimize their tribological performance in terms of friction coefficient or wear rate, it is crucial to have an accurate view of their tribological behavior. Indeed, as experimental investigations are quite impossible on a real brake, numerical simulations appear as unavoidable to understand their local behavior. In this sense, a multi-physical approach based on the discrete element framework is proposed to account for, mechanical, thermal and electrical feature during the sliding of a brake pad shoe. Numerical samples derive from tomography snapshots obtained on real brake pad shoe. Their are submitted to tribological solicitations and different wear models whch represents different operating conditions. Their behavior is then analyzed and discussed according to the different local models used in the simulation.

4:30 - 5:00 pm
Surface Damage from Micro-Slip: Analytical vs. F.E.M. Approach
Iyabo Lawal, Matthew Brake, Rice University, Houston, TX

The dynamic behavior at the jointed interface of structures produce complex loading that creates a unique tribosystem. A major contributor to surface damage comes from micro-slip events that can cause significant adhesive and/or abrasive wear of the interface. For mission critical sub-structures subjected to high-cycle fatigue events, this surface damage can affect structural stability and can lead to adverse dynamic performance. A comparison study of two modeling techniques for surface damage will be done to quantify the merits of each approach. The first approach uses statistical summation and contact mechanics principles. The second approach is based on a commercially available FEA tool. Both approaches will be validated with experimental data collected for 304 SS materials from sphere on flat tribology studies. The results will be used to continue development of a fretting fatigue modeling and will also help in understanding how experimental data can inform numerical models.

5:00 - 5:30 pm
Evolution of the Contact Interface: Towards the Introduction of a Tribological Circuit in a Multi-Scale and Multi-Physics Modeling
Vincent Magnier, yassine waddad, Philippe Dufrenoy, University of Lille, Villeneuve d'Ascq, France

In this paper, we propose a multi-scale and multi-physics numerical approach to the contact problem. Indeed, in a model representing a system, enrichment at the interface is proposed including roughness. At this interface, tribological evolution are integrated to model the mechanisms of wear, adhesion and trapping on the scale of roughness. This information is then reinjected into the macroscopic model leading to a large change in contact distribution over time. The strategy put in place is based on a theoretical enrichment of a finite element model allowing in addition to obtain a fast resolution. A comparison is made with a friction material having a flat surface.

5:30 - 6:00 pm - **Wear Business Meeting**

4E Music Row 5

Commercial Marketing Forum IV

2:00 - 2:30 pm - **Afton Chemical Corporation**

2:30 - 3:00 pm - **Afton Chemical Corporation**

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

4:00 - 4:30 pm - **Lanxess Corporation**

4:30 - 5:00 pm - **Eastman Chemical Co.**

5:00 - 5:30 pm - **Evonik Oil Additives USA**

5:30 - 6:00 pm - **BASF Corporation**

4F Music Row 4

Metalworking Fluids IV

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
A New Generation of Anti-Wear Solutions and Staining Inhibitors for Metalworking Fluids
Claude Hedoire, solvay, Aubervilliers, France

Phosphate-esters are multi-functional additives providing anti-wear performance and staining inhibition. However the current generation of phosphate-esters has some limitations. They are quite foaming additives and they tend to generate soaps when hard water is used. Soaps help to control foam but leave deposits on metal surfaces and pipes that are sometimes difficult to remove. Besides they are toxic (causes serious eye damage) and eco-toxic (harmful to aquatic organisms). Solvay is actively working on developing new solutions for metal working fluids with enhanced performance and better classification. We will present a new generation composed of several new phosphate-esters providing the following benefits: anti-wear performance, staining inhibition, emulsion stability, low soap formation, foam control, low toxicity and eco-toxicity. We will also present some formulation guidelines to get the best performance balance combining these new phosphate-esters.

2:30 - 3:00 pm
Application of Predictive Safety Screening Tools in GHS Labeling and TSCA New Chemical Notifications: A Small Company Perspective

Pamela Spencer, University of Michigan, Buffalo Grove, IL
Strong initiatives are underway to move from animal to non-animal test methods to evaluate and classify chemical hazards. For example, under the new Lautenberg Chemical Safety Act (LCSA), unless EPA restricts a PMN substance, it is required to make an affirmative finding that the substance is not likely to present an unreasonable risk of injury to health or the environment before non-exempt commercial manufacture can begin. In doing so, EPA must consider using non-animal test methods first to fulfill information needs. As a small company, with limited toxicology expertise, we have created a modified stage-gate process to inform early GHS classifications to guide safe handling/disposal of new chemicals while improving the successful outcome of a PMN under LCSA. The approach incorporates a well-defined, tiered use of new approach methodologies (NAMs) to provide early screening level safety information that can serve as a model for other small chemical companies.

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

4:00 - 4:30 pm
Boundary Lubricant Additive Response Comparisons on Aluminum Alloys Using Twist Compression Tests (TCT)
Ted McClure, 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 friction performance of metalworking lubricants. This presentation is an extension of work presented at STLE in 2017 and 2018. Increasing use of aluminum alloys is one practice automotive lightweighting initiatives can be supported. In this work, TCT is used to compare additive responses on a series of aluminum alloys. Boundary lubricants evaluated include polymers, esters, phosphorus bearing additives, and combinations. The aim is to provide useful data for formulation of lubricants for severe applications with these materials.

4:30 - 5:00 pm
Tribological and Anti-Corrosion Property of IF–WS_2 Particle in Aqueous System
Girija Chaubey, George Diloyan, Nanotech Industrial Solutions, Avenel, NJ

Nano size inorganic fullerene like tungsten disulfide (IF-WS_2) particles are known to be high performing friction reducer, anti-wear and extreme pressure additive for lubricant applications. They are not only suitable for conventional lubrication conditions rather can be used in extremely harsh conditions such as high / low temperature and high pressure. Surface engineering of the nanoparticles using appropriate surfactants / dispersion is important for stability and performance. This work present that IF-WS_2 base nano fluid can significant improve AW/AF/EP properties of synthetic and semi-synthetic metalworking fluids. Our extended experiments further showed that particles not only improve the tribological properties and cooling efficiency rather it reduces the corrosive properties of water as well. A systematic studies on anti-corrosion performance of particles was conducted. There is an ongoing research to explore the additional properties of IF–WS_2 particle along with tribological.

5:00 - 5:30 pm
Surface Integrity Analysis of the Hardened Bearing Steel Ground under Different Cooling-Lubrication and Cutting Conditions
Rosemar Da Silva, Bruno Abrão, Mayara Pereira, Raphael De Paiva, Antonio De Mello, Federal University of Uberlandia, Uberlandia, Minas Gerais, Brazil, Emmanuel Ezugwu, Air Force Institute of Technology, Kaduna, Nigeria
During grinding process, most of mechanic energy is converted into heat, which is concentrated in the grinding zone. Because of low thermal conductivity of conventional abrasive wheels and small sections of chips, the workpiece is heated to high temperatures what can cause several thermal damages, thereby, compromising component surface integrity, especially of hardened bearing steels. Thus, cutting fluid is indispensable for cooling of the workpiece, as well as the correct coolant delivery form can represent economic and environmental benefits. This present work presents a study of the cooling-lubrication technique (conventional and MQL) and cutting conditions in grinding of the hardened bearing steel. Surface integrity was evaluated in terms of surface roughness and texture of ground surfaces. Results showed that machining with the MQL technique provided the lowest roughness and more uniform texture.

5:30 - 6:00 pm
Tribological Approach of Grinding Stainless Steel with Semi Synthetic-Based Cutting Fluid
Rosemar Da Silva, Mayara Pereira, Bruno Abrão, Antonio De Mello, Federal University of Uberlandia, Uberlandia, Minas Gerais, Brazil, Alisson Machado, Mechanical Engineering Graduate Program, Pontifícia Universidade Católica do Paraná – PUC-PR, Curitiba, Paraná, Brazil, Rodolfo De Oliveira, Saint-Gobain do Brasil Produtos Industriais e para Construção Ltda, Sao Paulo, Sao Paulo, Brazil

Tribological analysis in grinding process is very important to understand chip formation and wear of abrasive wheel, thus to guarantee manufacturing of components free of thermal damages and to achieve the highest machining efficiency. Since grinding requires very high energy input per unit of volume of material removal, if cutting parameters are not proper selected, workpiece will be subjected to thermal damages, what can adversely affect its functionality. In this work, quality of surfaces of a martensitic stainless steel was evaluated in terms of surface roughness, Ra and Rt parameters. SEM images of the ground surfaces were also obtained. Tests were carried out with white aluminum oxide wheel, two radial depth of cut values and with a semi synthetic-based coolant. Results showed that the highest roughness values as well as more concentration of adhered material and deeper grooves on the machined surfaces

were found after grinding under severest cutting conditions

4G Music Row 3

Tribotesting II

Session Chair: G. Krauss, Engineering, Harvey Mudd College, Claremont, CA
Session Vice Chair: A. Lin, Northwestern University, Evanston, IL

2:00 - 2:30 pm
A New High Resolution Ultra-High Vacuum Tribometer Based on a Unique 6-Axis Force Sensor
Julien Fontaine, Matthieu Guibert, Thierry Le Mogne, CNRS / Ecole Centrale de Lyon, Ecully cedex, France, Thibaut Durand, Ecole Centrale de Lyon, Ecully, France, Jules Galipaud, CNRS / Ecole Centrale de Lyon, Ecully cedex, France, Sophie Pavan, Ecole Centrale de Lyon, Ecully, France

Tribometry inside an ultra-high vacuum chamber is a useful tool, not only for fundamental understanding of solid lubrication process, but also to study the effect of environment on the tribological response of materials. For instance, MoS_2 or hydrogenated amorphous carbon coatings may exhibit friction coefficients below 0.01. However, the main challenge to measure such low friction coefficients inside a vacuum chamber is to have a perfect alignment between the actual tangential and normal forces applied on the contact and the corresponding measuring sensors. In order to solve this issue, we have developed a unique six-axis force sensor, allowing the measurements of all forces and torques between the two counterfaces. This sensor not only allows more accurate measurements, but it also permits various type of experiments. We have performed friction experiments at different temperatures, as well as indentation and scratching with a diamond tip, or fracture experiments.

2:30 - 3:00 pm
New Developments in Non-Invasive Ultrasonic Lubricant Film Thickness, Viscosity, and Cavitation Sensors - A Review Of Case Studies.
Henry Brunskill, Peak to Peak Measurement Solutions / University of Sheffield, Sheffield , United Kingdom, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Active ultrasonics has been used for measuring lubricated interfaces for the last 20 years. It is only recently that the technology has really developed into a robust enough tool to be used in field applications. This body of work looks at the next generation ultrasonic lubricant sensors that are being employed in the field today to perform film thickness, viscosity, and cavitation measurements in-situ none-invasively. These installations are allowing engineers to understand the interfacial lubricant conditions in real-time thus allowing them to relate these conditions to operating parameters. Numerous case studies are given including numerous combustion engine, marine, power generation and aerospace applications.

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

4:00 - 4:30 pm
Scuffing Performance of Low-Viscosity Gear Oil Containing ZrO2 Nanocrystals
Nicholaos Demas, Benjamin Gould, Aaron Greco, Argonne National Laboratory, Argonne, IL

Low-viscosity oils can reduce viscous drag losses and improve fuel economy at low temperatures, but require long-life additive technology that will protect surfaces at high temperatures. One application where low viscosity oil can be beneficial is the lubrication of the hypoid gear used in the rear axles of vehicles. In this work, a test protocol was developed based on gear calculations and guided by the ASTM D5182 standard, to evaluate different gear oil formulations and their ability to prolong scuffing. Lab-scale tribological experiments using a commercially available gear oil formulated with ZrO_2 nanocrystals were performed using the three ring-on-roller contact configuration to simulate the most severe region of gear tooth contact.

4:30 - 5:00 pm
Do You Count Water and Antifoam as Containment Particles or Not?
Thomas Canty, J.M.canty Inc, Lockport, NY

The ASTM D8072 standard classification provides users of imaging the ability to report contamination data down to 1 micron without interference of water or antifoam droplets. It also reports water as a separate ppm value in the classifications. It also allows you to use the standard ISO 4408 codes with or without counts “soft” particles-water and anti-foam. This paper will present the case of how to move forward with the correct classification of particles and water while maintaining your historical data. The paper will explain how counting soft particle in the ISO 4406 or ASTM D8072 can lead to strange non-repeatable results since the mixing effect of the sample impacts the size and count of water and antifoam particles. In addition imaging technology lends itself to lab and inline analysis since it doesn’t count bubbles.

5:00 - 5:30 pm
Low Temperature Testing of Greases
Kartik Pondicherry, Florian Rummel, Georg Krenn, Anton Paar GmbH, Graz, Austria

The current study focusses on a newly developed setup which enables tribological testing of greases over a broad range of temperatures, including temperatures as low as – 80°C. The greases were tested with the roller bearing attachment for the MCR Tribometer, which was equipped with a convection temperature device (CTD) for temperature control. The tests include extended Stribeck curves and break-away torque measurements, with the latter in both rotational and oscillatory modes. In addition to the tribological tests, rheological investigations were also carried out on the greases to find a correlation between rheological and tribological properties, especially in the static regime and during the transition of the system into the kinetic regime. Also, tests were carried out with the ball-on-three-plates configuration to be able to characterize the effect of greases at the contact with the help of surface analysis using microscopic techniques.

5:30 - 6:00 pm - **Tribotesting Business Meeting**

4H Music Row 2

Materials Tribology III

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
Synthesis of a Self-lubricating Composite by in situ Formation of Graphene in Alumina Matrix During Ball Milling
Ashish Kasar, Arjun Manoj, Pradeep Menezes, University of Nevada, Reno, Reno, NV

In situ formation of graphene was carried out during wet ball milling to synthesize the self-lubricating .alumina based composite. Graphite platelets were exfoliated into graphene during ball milling in a liquid medium N, N-dimethylformamide (DMF) in the presence of micron size alumina balls. The milling was optimized at 300 rpm to avoid any destruction of graphitic sheet and promote the shear force dominating mill to exfoliate graphite. After milling, the products were characterized by FTIR to confirm the graphene formation. Subsequently, further alumina was added to prepare the composite with desired composition. Four different compositions were prepared by compaction and sintering at 1200 °C in vacuum. Tribological properties of the prepared composites were measured by sliding tests against alumina ball. The addition of graphene resulted in lower friction. The friction and wear mechanisms are discussed.

2:30 - 3:00 pm
Out of Thin Air: In-situ Formation of Diamond-like Nanocomposite Films
Morgan Jones, Nicolas Argibay, Sandia National Laboratories, Albuquerque, NM, Tomas Babuska, Lehigh University, Bethlehem, PA, John Curry, Sandia National Laboratory, Albuquerque, NM, Michael Dugger, ping lu, david adams, Brendan Nation, Barney Doyle, mi pham, adam pimentel, curtis mowry, Adam Hinkle, Michael Chandross, Sandia National Laboratories, Albuquerque, NM

Diamond like carbon (DLC) is a well-known family of solid lubricants used in a variety of different applications and environments. Experiments demonstrated it is possible to tribochemically form DLC films on highly wear resistant nanocrystalline Pt-Au thin films in the presence of ambient hydrocarbons. Sapphire counterfaces were run against Pt-Au films at different loads in various environments for up to 100k cycles. During sliding, it was observed that thick (50-200nm) films of hydrogenated DLC with interspersed Pt-Au nanoparticles readily formed – as confirmed by Raman, elastic recoil detection analysis (ERDA) and TEM. The inclusion of Pt-Au nanoparticles in the DLC matrix implies that these films may exhibit favorable electrical properties as a possible low friction, wear resistant sliding electrical contact. Further investigations into the tribological properties of these films are employed to better understand formation mechanisms and other aspects of this DLC nanocomposite.

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

4:00 - 4:30 pm
Tribological Behavior of Self-lubricating Alumina Composites with In situ Formation of Boron Nitride and Aluminum Borate
Pradeep Menezes, Ashish Kasar, University of Nevada, Reno, Reno, NV

The formation of self-lubricating in situ phase (BN) and utilization of this phase as effective reinforcements for alumina composite is investigated. Alumina, aluminum nitride and boric acid powder were used to synthesize the composite by conventional powder metallurgy route. Based on thermodynamic calculation, boron nitride and aluminum borate were formed during sintering. Friction and wear behavior of the composites were measured by scratch tests against alumina and steel balls. The hardness of the composites increased with increase in aluminum borate concentration while the wear volume decreased. However, friction behavior was dependent on counterpart. More specifically, lowest coefficient of friction was observed for the composites with maximum BN and minimum aluminum borate concentrations against alumina ball. For the steel ball, a complete opposite trend was observed. The mechanisms responsible for friction and wear performance are discussed.

4:30 - 5:00 pm
Novel Composite Lubricant for Reducing Wear and Friction Under Extreme Contact Pressure and Long Duration
Arman Ahmadi, Jialiang Tang, Vilas Pol, Farshid Sadeghi, Purdue University, West Lafayette, IN, Kuldeep Mistry, The Timken Company, North Canton, OH

This paper describes the development of a new thermally cured polymer-graphene zinc oxide-based solid lubricant that reduces friction and wear significantly during the sliding wear of bearing steel under high contact pressure and long duration. The dry solid coating was made from a mixture of graphene, zinc oxide, and a specific binder including butanone and isopropanol, and then laminated on the contact surface of 52100 steel disks. Tribological properties of the coating was examined using a ball-on-disk apparatus with the Hertzian pressure of 1 GPa and a sliding distance of 500 m. After ~3000 cycles, the 15 µm thick coating of the lubricant created a significant reduction in the steel's coefficient of friction (approximately 82%) and wear loss compared to the uncoated surfaces. Scanning electron microscopy, energy dispersive X-ray spectroscopy, X-ray diffraction, and Raman spectroscopy were conducted to determine the topography and morphology of the coating and resultant wear scars.

5:00 - 5:30 pm
Graphite Nanoplatelets as Reinforcement in the self-lubricating nanocomposites
Emad Omrani, University of Nevada - Reno, Hillsboro, OR, Pradeep Menezes, University of Nevada,

Reno, Reno, NV, Pradeep Rohatgi, University of Wisconsin - Milwaukee, Milwaukee, WI

In the present work, we studied the tribological properties of graphite nanoplatelets are studied in the Al composites. The coefficient of friction decreased in Al/GNP composites at 3% wt. of GNPs. Raman analysis shows the increase in the defects in the platelets after milling and wear tests. XRD and SEM analysis reveal the presence of GNPs at the worn surface after the tribology tests. The hardness of the Al/GNPs composites increased and the wear rate decreased with the increase of the content of GNPs up to 1 wt.%. Addition of GNPs above 1 wt.% resulted in the decrease of hardness. The addition of Al_2O_3 further decreased the wear rate of the composites and increased their hardness. Al/GNPs/Al_2O_3 composites had lower wear rate and more hardness as compared to Al/GNPs composites. The hardness increased from 74.8 HRB for pure aluminum to 94 HRB for Al/1GNPs/Al_2O_3 composite and the wear rate decreased.

5:30 - 6:00 pm
Tribological Considerations of Fouling in Air-cathode Assisted Iron-Electrocoagulation (ACAIE)
Arkadeep Kumar, Lawrence Berkeley National Lab, Berkeley, CA, Siva RS Bandaru, Mohit Nahata, UC Berkeley, Berkeley, CA, Nate Hohman, Ashok Gadgil, Lawrence Berkeley National Lab, Berkeley, CA

Air-cathode assisted iron electrocoagulation (ACAIE) can remove contaminants such as arsenic in groundwater used for drinking, or produced water in oil industry. However, long-term operation is challenging due to surface fouling. We have demonstrated efficient removal of arsenic below the maximum contaminant levels (MCL) in representative electrolyte compositions in short-term experiments. We present here long-term performance of ACAIE which remains unexplored in literature. When operated continuously over 100 hours, we see a steady reduction in H_2O_2 production which negatively affects contaminant removal. We present the tribological aspects of surface fouling of air-cathodes, which show deposition of Fe(III)(oxyhydr)oxides along with other salts, which we hypothesize as reason for reduction in chemical reactions for H_2O_2 production. We analyze the surface using contact angle (hydrophobicity), SEM, Raman, XRD, and XPS to investigate the nature of chemicals species causing fouling.

4I Cumberland 1/2

Engine & Drive Train II

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
Effects of Ionic Liquids on Micropitting Behavior for Rear Axle Lubrication
Sougata Roy, Oak Ridge National Laboratory, Oak Ridge, TN, Lake Speed Jr., Driven Racing Oil, Olive Branch, MS, Michael Viola, General Motors, Pontiac, MI, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

In present study, ionic liquids (ILs) additized lubricants were studied for rear axle lubrication. Screening sliding tests were first carried out on a series of lubricants without and with ILs. The ILs' lubricating performance largely depends on their chemistry and oil formulation. Based on preliminary results, specific lubricant formulations were designed for the top-performing IL and then evaluated using a 2M-cycle rolling-sliding test protocol and the performance was compared against that of baseline commercial gear oils. The lubricants with this IL showed a significant reduction in friction coefficient, micropitting severity and wear volume. Another IL caught our interest by providing the best protection of micropitting but generating abnormally high vibration. The worn surface showed a combination of smooth and rough regions instead of uniform morphology as observed in other lubricants. Tribofilms produced by both ILs were characterized to understand the influencing mechanisms.

2:30 - 3:00 pm
Compatibility between Ionic Liquids and Friction Modifiers
Weimin Li, Lanzhou institute of chemical physics, Chinese Academy of Science, Lanzhou, China, Chanaka Kumara, Harry M Meyer III, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Tribological performances of engine oils are largely dominated by the friction modifier (FM) and anti-wear additives (AWs) in the formulation. While oil-soluble ionic liquids (ILs) have recently demonstrated promising AW functionality, their compatibility with FMs is little known. Here, we report the latest results for several selected ILs when used together with two commercial FMs (OFM and MoDTC). Tribological results showed either synergistic or antagonistic effects depending on the IL chemistry of AWs as well as the contact materials. Aprotic ILs seemed to degrade the FMs' lubricating performance because of competition of interactions with the contact surface. In contrast, a protic ionic liquid showed strong synergistic effect with both the OFM and MoDTC, yielding ultra-low friction coefficients of 0.02-0.04 and very low wear rates under boundary lubrication. The mechanisms will be discussed based on surface characterization and modeling results.

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

4:00 - 4:30 pm
Alloy-Dependence of the Antagonistic Effects between Soot and ZDDP
Jun Qu, Chanaka Kumara, Harry Meyer, Oak Ridge National Laboratory, Oak Ridge, TN

While soot, when suspended in an engine oil, is known to accelerate the wear of diesel and GDCI engines, there is a lack of consensus on the wear mechanism. Some recent literature reported antagonistic effects between soot and ZDDP but others did not. Our study found that the antagonism is alloy dependent. Four alloys, 52100 bearing steel, and A2, M2, and M50 tool steels in different rubbing pairs were tested in lubricants containing carbon black (CB, used as a soot surrogate) only, ZDDP only, and CB+ZDDP. Adding the CB alone to the oil increased the wear rate for all four steel alloys as expected. However, when ZDDP was introduced to the CB-containing oil, distinct wear behavior was observed: the three tool steels surprisingly suffered wear increases by 2-5 times, while the 52100 steel experienced a significant wear reduction. The major difference in composition is the high Mo contents in the tool steels, which is hypothesized to be vulnerable to CB-catalyzed tribocorrosion by ZDDP.

4:30 - 5:00 pm
Impact of Amine-Based Friction Modifiers on ZDDP Tribofilms
Joanna Dawczyk, Imperial College London, London, United Kingdom, Hugh Spikes, Imperial College, London, United Kingdom

ZDDP additives are extremely effective at reducing scuffing and wear. However they can also increase friction in both boundary and mixed lubrication conditions. One way to address this problem is by the use of friction modifier additives, and in particular organic friction modifiers. However such additives have to be selected with care since it has been shown that some can damage ZDDP tribofilms. Here we present a study of the influence of a range of alkoxylated amines on the friction and durability of ZDDP tribofilms. It is shown that this impact is strongly dependent on molecular structure of the alkoxylated amine. The origins of this are discussed.

5:00 - 5:30 pm
New Organic Friction Modifiers for Wet-Clutch Motorcycle Engine Oils
David Gillespie, Croda, Cowick Hall, United Kingdom

Most high-performance motorcycles use a multiplate lubricated clutch. The main reasons for the lubrication are cooling, and to protect the steel and friction plates from excessive wear. Selecting a friction modifier for use in an automatic transmission fluid is not difficult, generally compounds that; raise the friction, ensure friction increases with sliding speed, and increase the lifetime of the fluid are chosen. However, for a motorcycle the choice becomes more complex. This is because the same reservoir

supplies lubricant to the engine, transmission and gears. It is often the case that if a FM reduces friction in a steel/steel contact it will also reduce friction in a steel/friction material contact to at least some extent. We show that by the correct choice of organic friction modifier (OFM) it is possible to reduce friction in steel/steel contacts whilst maintaining efficient clutch performance.

4J Cumberland 3

Nanotribology IV

Session Chair: M. Ruths, Department of Chemistry, University of Massachusetts Lowell, Lowell, MA
Session Vice Chair: Z. Khan, Bournemouth, Dorset, United Kingdom

2:00 - 3:00 pm
Evolution of Tribological Contacts by Multiscale Simulations
Izabela Szlufarska, Zhuohan Li, University of Wisconsin, Madison, WI, Hubin Luo, Ningo Institute of Materials Technology and Engineering, Ningbo, China

At present there is a limited understanding of how the contact interface and the contacting materials evolve during sliding. This evolution may include chemical reactions, grain growth and refinement, evolution of dislocation networks, etc. All these phenomena can contribute to friction and wear. In this talk, I will discuss results of our multiscale simulations of materials evolution in sliding contacts. First, I will focus on chemical evolution of frictional interfaces, a phenomenon referred to as chemical aging. Specifically, I will discuss the combined effects of interface chemistry and surface roughness on the origin of static friction and on velocity dependence of friction. Secondly, I will summarize our developments of multiscale models of microstructural evolution of polycrystalline metals subject to mechanical loads. I will also discuss specific predictions from our models regarding the effects of grain size on mechanical response of metal alloys.

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

4:00 - 4:30 pm
Nanotribology of Graphene in Hexadecane

Prathima Nalam, Behnoosh Sattari Baboukani, University at Buffalo, Buffalo, NY, Zhijiang Ye, Nethmi De Alwis, Miami University, Oxford, OH

Two-dimensional materials such as graphene are new emerging friction-reducing additives in transmission fluids and oils to enhance the service life of sliding metallic components. Here in this work, we investigate the dissipative mechanisms of single–layer graphene sheet in presence of hexadecane solution (a major component in base oil). We employ atomic force microscopy to measure interfacial friction of mechanically- exfoliated graphene on silica substrate as a function of hexadecane immersion time. We observe intercalation and diffusion of non-polar hexadecane molecules between the two hydrophobic surfaces i.e., oxidized silica and graphene. Further, a non-linear dependence, i.e. a decrease and then increase, in friction and adhesion forces was measured as a function of immersion time. The origins for this behavior is explored by studying the quality of the contact (net pinning forces) and the conformational ordering of the confined fluid.

4:30 - 5:00 pm
Tuning Friction at Material-Nanoparticle-Liquid Interfaces with an External Electric Field
Jacqueline Krim, Biplav Acharya, Caitlin Seed, Donald Brenner, Alex Smirnov, NC State University, Raleigh, NC

We report the use of electrophoretic forces to tune friction at material-nanoparticle-liquid interfaces with static or low frequency (0.6 – 50 mHz) electric fields. Negatively charged TiO_2 or positively charged Al_2O_3

nanoparticles suspended in water were repositioned relative to a planar platinum surface of a quartz crystal microbalance, which was then used to monitor friction levels. Active electro-tunable control of friction was achieved, and investigated as a function of electric field frequency. Kinetic effects corresponding to nanoparticle repositioning at the solid interface were discovered to occur at glass-like time scales. The studies also reveal that nanoparticles manipulated by electric fields can act as "cantilever-free" atomic force probes capable of “tapping mode” exploration of interfacial properties and nanoscale interactions in geometries inaccessible to optical and micromechanical probes.

5:00 - 5:30 pm
Sliding over 10,000 Times Faster: QCM Integrated Microtribometry to Probe Friction Fundamentals via Single-Crystal MoS_2
Nikolay Garabedian, University of Delaware, Newark, DE, Raymond Wieser, Gabriel McAndrews, Brian Borovsky, St. Olaf College, Northfield, MN, David Burris, University of Delaware, Newark, DE

Friction is independent of sliding speed according to Coulomb’s Friction Law, and yet the Prandtl-Tomlinson model with thermal activation (PTT) predicts increasing friction with increasing sliding speed. This study lays the foundation for a collaborative effort to clarify speed-dependent friction, particularly for multi-asperity tribological interactions. We integrated a traditional microtribometer with a high-speed quartz crystal microbalance (QCM) system; the quartz crystal (~ 1 m/s, 0-50 nm displacement) was placed between the tribometer’s lateral piezo stage (<0.1 mm/s, 0.01-800 µm range) and the sliding interface, so that by solely turning the QCM system on or off, friction experiments were possible at either high or low speeds without breaking the contact. This hybrid approach enables simultaneous and independent frictional characterization based on beam deflections and analysis of QCM resonance curves, which provide contact area, contact pressure and static friction data.

5:30 - 6:00 pm
Tribofilm Growth Mechanisms of ZrO_2 Nanoparticle Additives in a Fully Formulated Low Viscosity Gear Oil
Meagan Elinski, Zachary Milne, University of Pennsylvania, Philadelphia, PA, Lei Zheng, Pixelligent Technologies, Baltimore, MD, Andrew Jackson, University of Pennsylvania, Philadelphia, PA, Robert Wiacek, Pixelligent Technologies, Baltimore, MD, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Low viscosity (LV) lubricants can improve automotive efficiency by minimizing viscous losses, but the resulting thinner lubricating films risk increased boundary contact. Zirconium oxide (ZrO_2) nanoparticle (NP) additives form tribofilms that offer surface protection against boundary contact. However, how co-additives in a formulated LV gear oil impact the growth mechanisms and frictional properties of the tribofilms is unknown. To understand NP interactions with other additives, a mini-traction machine (MTM) was used to evaluate tribofilm growth and traction performance over all lubrication regimes. As well, *in situ* atomic force microscopy (AFM) tribofilm generation experiments helped assess NP/co-additive interactions. Cross-sectional transmission electron microscopy (TEM) characterized the structure of ZrO_2 tribofilms. We will discuss how understanding ZrO_2 NP behavior in a LV gear oil addresses improving vehicle efficiency while maintaining component durability.

4K Cumberland 4

Environmentally Friendly Fluids II

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
High Viscosity Esters to Boost Lubricant Performance Profile
Matthias Hof, Emery Oleochemiclas GmbH, Monheim, NRW, Germany

Today, lubricant fluids require higher performance levels and broader applicability coming from the base stock system and the additives. Trends both in industrial and automotive applications are targeted towards future solutions that fulfill not only the technical performance level but also some environmental properties. Ester chemistry has been established as a very versatile technology to supply the formulating industry with products inheriting a broad usability. These products can be used as base stocks, co-solvents and solubilizers as well as additives. This paper provides an overview of new ester technology developments with high viscosity profiles. These new esters, synthesized for a broad application profile, address one of the most demanding applications in the industry: reduction of friction combined with equipment protection. An environmental profile superior to other technologies was also achieved.

2:30 - 3:00 pm
A Peculiar Observation of "Gelling" in Bio-Derived Phosphonate Ester
M. Cinta Lorenzo Martin, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL, Grigor Bantchev, Girma Biresaw, Rogers Harry-O'kuru, USDA-ARS-NCAUR-BOR, Peoria, IL

Because of their excellent tribological performance and environmental benefit, bio-based lubricants are subject of studies and development, as well as commercial activities. One of the common basefluids used in lubricant formulation is phosphonate ester. Recently, we observed gelling of palm oil derived ester during multiple viscosity measurements at 100°C. This observation is assumed to be linked to the presence of residual di-butyl phosphite used in the synthesis of the ester fluid. This gelling behavior can have an impact on the tribological performance of the final lubricant. Studies are in progress to assess the effect of this phenomenon on tribological performance of the fluid. It is imperative that development of bio-based esters should be done in manner to avoid the gelling phenomenon.

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

4:00 - 4:30 pm
New Class of Biolubricants Based on the Unique Fatty Acid Structure of Chinese Violet Seed Oil
Diana Berman, Asghar Shirani, Kent Chapman, University of North Texas, Denton, TX, Edgar Cahoon, University of Nebraska Lincoln, Lincoln, NE

Our search for a better friction and wear reduction solution leads us to design a new class of bio lubricants that are safer, more environmentally friendly, and cost-effective in comparison to conventional ones. Recently, we discovered a unique structure of the oil extracted from the seeds of Orychophragmus violaceus. The oil demonstrated excellent lubricative properties and thermal stability. Specifically, coefficient of friction of the sliding steel pairs lubricated by Ov oil was 3-4 times lower than the one for traditionally used castor oil. In contrast to other plant-based lubricants, performance of the Ov oil is stable in the temperature range from room temperature up to 350C. This effect is attributed to the unique structure of the unusual long chain of dihydroxy fatty acids found in the oil. These findings provide a direct pathway for designing a new class of plant-based lubricants that are more effective and environmentally friendly than widely used synthetic oils.

4:30 - 5:00 pm
The Issues Facing the EAL Industry: The Stability of Oil and the Eco-Friendliness
Ashok Cholli, Polnox Corporation, Lowell, MA

The key ssue for lubricants based on bio-oil and bio-based products is to improve their oxidative stability for greater acceptance in the market. Oxidative stability of lubricants derived from bio-resources is inferior compared to fossil fuels and presents a key issue to the industry. Existing commercial antioxidants are not effective to stabilize plant/animal-derived biolubricants. There is a real need to look for a new antioxidant technology to make biolubricants as viable alternate products in a wide range of applications helping alternate sources for oil are sustainable and cost effective. A new class of safer antioxidants

possessing superior oxidative resistance has been developed by Polnox to provide extended useful life of a wide range of materials. Compared to current industry antioxidants, these novel antioxidants significantly improve material protection, due to enhanced antioxidant activity and higher thermal stability. Their effectiveness will be illustrated with examples.

5:00 - 5:30 pm - **EFF Business Meeting**

4L Cumberland 5

Lubrication Fundamentals IV

Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
Fatty Acid Ionic Liquids (FAILs): Anion Effect on Physicochemical, Environmental and Tribological Properties
David Blanco, Noelia Rivera, Javier Faes, Paula Oulego, Rubén González, Antolín Hernández-Battez, University of Oviedo, Gijón, Asturias, Spain

Two novel ionic liquids (ILs), methyltrioctylammonium octanoate $[N_{1888}][C_8]$ and methyltrioctylammonium estearate $[N_{1888}][C_{18}]$, were synthesized from natural sources using a salt metathesis reaction. One commercial ionic liquid, methyltrioctylammonium bis(trifluoromethylsulfonyl)imide $[N_{1888}][NTf_2]$, was used as comparison sample. Traction measurements (at different speeds and temperatures) and film forming tests were made in a mini traction machine. Physicochemical and environmental characterizations of the ILs were performed. The $[N_{1888}][C_8]$ exhibited the higher viscosity values; meanwhile, the $[N_{1888}][NTf_2]$ had the best thermal behavior. No signs of corrosion on steel were found after 30 days of exposure. Both FAILs exhibited moderate biodegradability and $[N_{1888}][NTf_2]$ was poorly biodegradable. Vibrio fischeri bacterial toxicity results showed that both FAILs were around 5 times less toxic than $[N_{1888}][NTf_2]$. $[N_{1888}][C_{18}]$ IL showed the best antifriction and film forming properties.

2:30 - 3:00 pm
Exploration of Macroscale Superlubricity Enabled by Hydrated Ions
Tianyi Han, Chenhui Zhang, Jianbin Luo, Tsinghua University, Beijing, China

Here we demonstrate that macroscale superlubricity based on hydrated alkali metal ions (Li^+, Na^+, K^+) can be realized for the first time under high contact pressure between the Si_3N_4 ball and sapphire disc. The ultralow friction coefficients of 0.005 are obtained under average contact pressure up to 0.25 GPa by a universal micro tribometer after a running-in period with acid solutions. The running-in stage can not only make the worn region smoother, but can generate a silica layer easy to shear which provides excellent boundary lubrication. The results show that the contribution of fluid effect is weak, and the realization of superlubricity relies more on hydration effect. The hydration superlubricity originates because hydration shells surrounding the alkali metal ions could generate the hydration repulsive force to sustain a large normal load and have a fluid response to shear simultaneously.

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

4:00 - 4:30 pm
Lubricating Titanium Using a Vegetable Oil Containing Ionic Liquids
Haitao Duan, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China

Here we report the results of a recent study on titanium lubrication using a vegetable oil containing various ionic liquids (ILs). An oxygen diffusion (OD) case-hardening process was applied to Ti-6Al-4V to improve its wear resistance. Test lubricants were made by mixing four different ILs at treat rates around 1

wt.% into a vegetable oil. Ball-on-flat reciprocating sliding tests were carried out using a steel ball rubbing against the OD-treated Ti flat in the IL-containing oils. The addition of the protic IL improved the frictional behavior and wear protection but the aprotic ILs seemed to degraded the lubricating performance of the vegetable oil. It was observed that the aprotic ILs accelerated the ageing process (decomposition and oxidation) of the vegetable oil to various extents because of the ILs' catalytical effects.

4:30 - 5:00 pm
Impacts of Glyceride and Ionic Liquid Additives on Tribological Properties of Water-Based Drilling Mud
Min Ji, Shuhai Liu, Huaping Xiao, China University of Petroleum-Beijing, Beijing, China

Water-based lubricant additive of drilling mud plays a significant role in lubrication in the drilling operation. In this study, impacts of glyceride and ionic liquid (IL) additives on properties of water-based drilling mud were evaluated using a ball-on-disk tribometer. For glyceride, the experimental results indicate that carbon chain length, level of unsaturation, and polar groups of additives are three key factors which determine friction reduction and anti-wear behaviors of the drilling mud. Under the lubrication of IL, good tribological performance and improved load capacity with increasing concentration were obtained which is related to the adsorption of the tribofilm on the contact surface.

5:00 - 5:30 pm
Evaluation of Greases Used in Rail Journal Bearings
Kuldeep Mistry, Daniel Blasko, Alan Buchanan, The Timken Company, North Canton, OH

Pre-greased and sealed packaged double row tapered roller bearings are used commonly as axle journal bearings on railway vehicles. They directly affect the vehicle's running stability, and the performance of both freight and passenger car journal bearings are closely monitored in the field due to ensure high reliability. The service life of journal bearings is dependent on the type of grease, and the grease requirements vary based on the geographical site location. Rail journal bearings are expected to meet many requirements such as being able to operate in wide moisture and temperature ranges, as well as to maintain mechanical stability under high vibration conditions. This presentation shares results from an investigation of rail journal bearing grease characteristics using a variety of relevant industry standardized tests.

4M — Cumberland 6

2D Materials - Materials Tribology and Nanotribology Joint Session

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Session Chair: TBD
Session Vice Chair: TBD

2:00 - 2:30 pm
Run-in Behaviors of Solid Lubricants
John Curry, Sandia National Laboratories, Albuquerque, NM, Tomas Babuska, Lehigh University , Bethlehem, PA, Brendan Nation, Adam Hinkle, Sandia National Laboratories, Albuquerque, NM, Brandon Krick, Lehigh University , Bethlehem, PA, Michael Dugger, Michael Chandross, Nicolas Argibay, Sandia National Laboratories, Albuquerque, NM

Run-in (initial friction) of solid lubricant films is one of the more stochastic aspects of the friction behavior over the life of a test. A wealth of factors such as environment, microstructure, contact conditions and tribochemical interactions can all play a role in the magnitude and duration of run-in. This talk focuses on how these various factors serve to alter run-in behavior on MoS2 and DLC films through experiments in ambient and UHV conditions with accompanying molecular dynamics simulations.

2:30 - 3:00 pm
Modified Molybdenum Disulfide for Improved Wear Resistance in Antifriction Coatings
Melissa Mushrush, Gary Weber, DowDupont, Auburn, MI

Antifriction coatings based on polymeric resins and solid lubricants are commonly sprayed and cured/dried as thin coatings in applications to reduce friction in metal-metal contacts. Commonly used solid lubricants such as graphite and molybdenum disulfide (MoS2) enhance the wear resistance of such coatings, but applications continue to demand improvement. A known wear mechanism for MoS2 is its slow oxidation; for this reason MoS2 is the lubricant of choice for space / vacuum applications. In order to improve its stability towards oxidation, and thus increase the wear resistance of the antifriction coatings containing it, our group has chemically modified the MoS2. A patent application is currently in draft, and once it has published this abstract will be replaced with fuller details showing the chemistry and the resulting stability and wear test data.

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

4:00 - 4:30 pm
Superlubricity at Macroscale in Oil-Free Rolling/Sliding Contacts
Kalyan Mutyala, Argonne National Laboratory, Lemont, IL, Gary Doll, The University of Akron, Akron, OH, Jianguo Wen, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Green technology initiatives call for the development of advanced lubrication strategies to minimize oil usage without compromising durability and reliability of components. Recent demonstration of atomically thin two dimensional (2D) materials ability to withstand high contact pressures at the tribological interface enabling low friction and wear opened new paths for exploration. Bearings and gears are critical components of a typical mechanical system such as a wind turbine and an automotive transmission system and subject to rolling/sliding at the interface. In this study, we demonstrated macroscale superlubricity in a rolling/sliding contact for the first time using material pairs that are coated with diamond-like carbon in an oil-free contact using 2D materials combined with nanodiamond as a solid lubricant under dry nitrogen environment. We have shown that achieving superlubricity (COF 0.003) is possible through formation of carbon rich superlubric tribolayer at the interface.

4:30 - 5:00 pm
Simultaneous In-Situ Formation of MoS_2 and Carbon-Containing Tribofilms
Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria, Bernhard Kohlhauser, TU Wien, Vienna, Austria, Sara Spiller, AC2T research GmbH, Wiener Neustadt, Austria, Carsten Gachot, TU Wien, Vienna, Austria

We study the in-situ formation of MoS_2 during sliding in the presence of sulphur-containing extreme pressure (EP) lubricant additives. The MoS_2-containing tribofilms are formed via a tribochemical reaction between the EP additive and molybdenum-containing substrates. The chemical composition and morphology of the tribofilms was studied using Raman spectroscopy and transmission electron microscopy. The tribochemical mechanisms that lead to the formation of MoS_2 are discussed as function of EP additive concentration, lubricant temperature and counterbody material. Under certain testing conditions, the in-situ tribochemical formation of MoS_2 is accompanied by the presence of oil derived carbon tribofilms. Further, the synergies and antagonisms of the in-situ formed MoS_2 tribofilms with anti-wear and dispersants co-additives is addressed. Special emphasis is set on highlighting the similitudes and differences with MoS_2 tribofilms derived from lubricants containing MoS_2 nanoparticles.

5:00 - 5:30 pm
Calcuations of Energy Barriers to Sliding Friction in MoS_2 in the Presence of Water and Oxygen
Adam Hinkle, Michael Chandross, Sandia National Laboratories, Albuquerque, NM

A model for the temperature-dependence of the friction in MoS2 has been developed which relies upon the heights of energy barriers to characterize the molecular pathways of MoS2-flake sliding . Here we present atomistic calculations that show changes to these barriers in the presence of water and oxygen,

two major environmental contaminants affecting the friction.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

5:30 - 6:00 pm
Tribological Properties of Different Nano-Sized Layered double hydroxides as Oil-Based Lubricant Additives
Hongdong Wang, Jianbin Luo, Tsinghua University, Beijing, China

Layered double hydroxides (LDHs) are a class of naturally-occurring inorganic minerals which are composed of divalent and trivalent metal cations. In this study, we chose a micro-emulsification method to synthesize the LDH nanoplatelets whose size was controlled by changing the crystallization time. As lubricant additives, their tribological properties in base oil were evaluated using a ball-on-disk reciprocating tribometer under three different loads. Under contact pressures of up 2.16 GPa, not only did the friction coefficient (COF) decrease by about 10% after nano-LDHs were added, but also the wear performance improved substantially. These improvements resulted from a protective tribofilm formed on the contact interface, as revealed by detailed surface and structure analytical studies. In particular, cross-sectional TEM images revealed that the larger size nanoplatelets (NiAl-24h), rather than the smaller ones (NiAl-6h), showed the best and most stable tribological performance.

6:00 - 6:30 pm - **Material Tribology Business Meeting**

4N Legends A

Discussion Round Tables

Session Starts at 4:00 pm

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.

DISCUSSION ROUND TABLES

Host: Daniel Merk
Host Company: Schaeffler Technologies AG
Title: The influence of electrical current and water intrusion on the failure mode of Surface Initiated Damage (SID)
Abstract: In the case of Surface Initiated Damage mechanisms (SID), such as a gray staining formation, there are existing influence factors which are known and described. There is, for instance, known a high influence by the particular bearing steel and heat treatment, or the surface quality, like the roughness. From different tests, there was observed the electrical current and/or the water intrusion as further potential influence factors on SID which are not described precisely yet. Are there known particular thresholds which are already defined in the view of their SID – risk?

Host: Kenred Stadler
Host Company: SKF
Title: How big is the (tribo-)mechanical versus chemical influence on bearing steels (in the sub-surface) with respect to overall performance?
Abstract: Several hypotheses have been formulated on the role of the lubricant and tribochemistry under mixed lubrication and high slip conditions, based on tests of 81212 bearings on FE-8 rigs.
Some authors suggest that certain oils will lead to hydrogen ingress and subsequent weakening of the bearing steel – real chemical influence due to certain additives. Others suggest that specific additives and/or reaction layer could induce high surface shear stresses promoting surface micro-cracks – (tribo-)mechanics, e.g. due to difference in friction as function of lubricant.

Host: Kenneth K. Cao
Host Company: John Deer
Title: How to eliminate the root cause of wear as well as the Boundary Lubrication regime
Abstract: Wear can be generated by different tribo-mechanisms. Is debris particulate contamination in liquid lubricant always bad?

Host: Manfred Jungk
Host Company: MJ-Tribology
Title: Fluid characterization beyond viscosity measurement in EHD
Abstract: The pressure viscosity coefficient of a fluid in the EHD contact is either determined by film thickness measurements and subsequent calculation or by measuring viscosity pressure curves semi-statically. Several approaches were made to predict the viscosity based on its molecular structure. Monomeric friction, radius of gyration and free volume are some of the parameters that were looked at. Participants can brainstorm on other model parameters or experimental ways to determine the state of the fluid in the EHD contact.

Host: Sven Wirsching and Sebastian Schwarz
Host Company: University Erlangen
Title: How can we make tribology attractive and of high quality in terms of content, especially in teaching?
Abstract: What are concrete measures to increase the attractivity of engineering studies, especially tribology, for young people and university students?
The statistics published by the German Federal Statistical Office in 2018 show a decline in the number of first-year students. This trend will become even more pronounced in the upcoming years and is particularly noticeable in the technical field. This can be explained, among other things, by demographic change and contributes to the fight for talents.
In order to maintain innovative strength, it is becoming increasingly important to generate highly qualified workers and inspire them to participate in STEM education. For instance, this can be achieved through interesting and motivating teaching.

5A Legends D

Rolling Element Bearings I

Session Chair: TBD
Session Vice Chair: TBD

8:30 - 9:00 am
Roughness Effect in Rolling Contact Fatigue of Silicon Nitride
Mohsen Mosleh, Keron Bradshaw, Sonya Smith, Howard University, Washington, DC, Khosro Shirvani, Rowan University, Glassboro, NJ, John Belk, ZeroTechnology, Saint Louis, MO

An experimental analysis of the role of surface roughness parameters on the rolling contact fatigue (RCF) life of silicon nitride against AISI 52100 steel under lubricated conditions was performed. Various roughness parameters of silicon nitride were varied while the roughness of the steel surface was unchanged. The correlation between the fatigue life and each roughness parameter for silicon nitride was obtained. The peak-to-valley roughness R_z was the only roughness parameter that exhibited positive correlation with the RCF life of silicon nitride. Fatigued surfaces exhibited crack propagation near the deepest scratch marks created by the polishing process.

9:00 - 9:30 am
Experimental and Numerical Studies into the Mechanisms of Surface Crack Propagation under Rolling Contact
Amir Kadiric, Pawel Rycerz, Björn Kunzelmann, Imperial College London, London, United Kingdom

This paper studies the mechanisms of crack growth of surface breaking rolling contact fatigue cracks in lubricated rolling-sliding contacts of hard steels. The work combines experimental measurements of crack propagation, performed on a triple-disc rig, with numerical simulations of stress fields experienced by such cracks during over-rolling. In particular, an attempt is made to use the calculated stress intensity factors to explain the previously reported crack propagation behaviour where two distinct phases of propagation were seen for short and 'long' cracks, with the latter obeying the Paris-type crack growth law. The effects of contact friction, crack face friction, surface roughness and contact pressure are also considered. On a higher level, the work attempts to establish the importance of crack propagation phase to the overall rolling contact fatigue life, and to draw parallels between crack behaviour known to exist in structural fatigue to that observed under rolling contact.

9:30 - 10:00 am
A Model for Hybrid Bearing Life with Surface and Subsurface Survival
Antonio Gabelli, SKF , Nieuwegein, Netherlands, Guillermo Morales-Espejel, SKF Reseach and Technology Development, Nieuwegein, UT, Netherlands

This paper addresses the issue of hybrid bearing life by applying a novel approach to rolling contact fatigue. Central to the new method is the survival probability of the raceway surface which is explicitly formulated into the basic life equations of the rolling contact. This allows to tailor the contribution of the stress system on, or near, the rolling surface to better represent the ceramic-steel interaction which has been proven to be substantially favorable in case of a hybrid contact. Comparison between experimentally obtained hybrid bearing fatigue lives and lives predicted using the new calculation model indicates good agreement. It is found that an increase of the fatigue strength of the raceway surface can, in most cases, compensate for the additional stress present in the subsurface region of the contact.

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

10:30 - 11:00 am
An Analysis of Rolling Element Bearings Fatigue Life Reduction Caused by Debris Denting
Alexis Bonetto, Daniel Nélias, Thibaut Chaise, Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, Villeurbanne, France, Laurent Zamponi, Airbus, Marignane, France

The objective of this study is to investigate the effects of debris denting on the fatigue life of heavily loaded rolling element bearings, specifically those used in the aeronautic field. Thanks to a previously developed coupled Eulerian-Lagrangian (CEL) model, realistic dent geometry and residual stresses field are generated and can be used for further investigations. Using semi-analytical methods, an analysis of the contact over the damaged surface is led to determine on what extent dents alter the contact conditions. A comparative study of fatigue criteria is conducted to identify the most relevant ones and quantify the fatigue life reduction due to the presence of dents.

11:00 - 11:30 am
Innovation in Testing and Calculation Methods against Surface Initiated Damage Mechanisms (SID) in Rolling Bearings
Daniel Merk, Bernd Vierneusel, Jörg Franke, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

Rolling bearings in some specific applications are running in a variety of harsh mixed friction conditions. Leading factors, like lubricant and material properties, surface roughness or sliding speeds provoke premature failure mechanism, called Surface Initiated Damage (SID). To provide robust bearing solutions, a detailed knowledge of the tribological system behavior in combination with optimization tools is needed. To gain this knowledge, a taylor-made experimental approach was developed, which is able to provoke SID repeatedly. This method was used to derive suitable countermeasures against SID and to investigate their effects on bearing performance. To maximize the benefits for future applications, this precision experimental data were used to refine a recently developed calculation method, which can predict the risk of SID in rolling bearings. This prediction allows a rapid assessment of counteractions and is thus able to solve design challenges for bearings at harsh conditions.

11:30 am - 12:00 pm
Investigation of the Dent Resistance of Instrument Bearings with NiTi-Hf Rolling Elements.
Samuel Howard, NASA Glenn Research Center, Cleveland, OH, Christopher DellaCorte, NASA, Cleveland, OH

Nickel Titanium Hafnium (NiTi-Hf) is an emerging alloy for rolling element bearings requiring superior corrosion resistance or high load capacity. Space instruments often fall into one or both categories. Small, precision space mechanism bearings must operate with very low torque due to limited power in drive motors. In addition, mechanism bearings must survive launch conditions without suffering raceway dents, (Brinell dents), that increase operating torque and reduce overall smoothness. NiTi-Hf can mitigate the concern of Brinell denting under extreme load conditions due to unusually high elastic strain. In the present work, a sample of small, precision bearings with three different ball materials (steel, ceramic, and NiTi-Hf) were subjected to a range of loads sufficient to dent the races. Dent depth as a function of load is compared and demonstrates that NiTi-Hf has the potential to increase bearing load capacity from the perspective of resistance to denting under severe load.

5B Music Row 1

Wear III

Session Chair: J. Bomidi, Baker Hugues
Session Vice Chair: B. Chavdar, Eaton

8:00 - 8:30 am
Developing Improved Anti-Wear Additives by Leveraging from Industry Trends
Christelle Chretien, Solvay, Bristol, PA

New additives and toolboxes are required to meet the upcoming transformation of the lubricant industry. These follow new regulatory standards on fuel efficiency and emissions, as well as the future shift of the lubricant industry to new transportation solutions. Environmental concerns, global warming, depletion of natural resources create an urgent need for new high performance and sustainable solutions. As a consequence, regulations on lubricant compositions (limitation of heavy metals, sulfur, phosphorus and waste management) make the availability of the chemical toolbox continuously more narrow. In this context, Solvay has been actively working on developing sustainable additives for lubricants with enhanced performances and milder classifications. This relies both on a renewed focus on existing technologies and development of innovative additives. The objective of this talk is to present an update on the development of anti-wear technologies to meet these new challenges.

8:30 - 9:00 am
A Study on Wear Effects From Methyl-Ester in Oil Mixtures
Gustavo Molina, Emeka Onyejizu, John Morrison, Valentin Soloiu, Georgia Southern University, Statesboro, GA

The authors conducted previous research in oil dilution by biodiesels because unburned biofuels, with their lower volatility and early aging, can enhance degradation of oil lubricity. Research is presented here on the dilution effects on wear for the most typical methyl-esters in biodiesels. Known percentages of these methyl esters are added to SAE 15W40 mineral oil in binary- and ternary-mixtures. Tribometer test wear studies are carried out for such mixtures to explain some of the observed differences between different feed-stock biodiesels when they are mixed in oil.

9:00 - 9:30 am
Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration Part I
Daulton Isaac, Mathew Kirsch, Patrick Hellman, Andrew Foye, Air Force Research Lab, Wright Patterson AFB, OH, Hitesh Trivedi, UES Inc., Dayton, OH

In this work, the adhesive wear performance of two heat treatments of the case hardened martensitic bearing steel Pyrowear 675 was investigated using a ball on disc apparatus in an all metal and hybrid configuration with a silicon nitride ball. Adhesive wear results obtained with AISI M50 disc was used as a baseline for comparison. Tests were conducted at a temperature of 200 ^{0}C and maximum Hertzian stress of 1.95 GPa. A MIL-PRF-23699G military specification oil with a nominal viscosity of 5 cSt at 100 ^{0}C was used as the lubricant. In the test protocol, different lubrication regimes were explored by varying the entraining velocity from 10.8 m/s down to 1.3 m/s at constant values of percent slip (15%, 30%, 50%, and 70%). Traction curves and optical microscope images were used to determine the occurrence of adhesive wear. To compare the performance of various materials, a modified ranking system which clearly differentiates between various material combinations is proposed.

9:30 - 10:00 am
Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration Part II
Mathew Kirsch, Daulton Isaac, Andrew Foye, Patrick Hellman, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH, Hitesh Trivedi, UES, Inc., Beavercreek, OH

In this work, the adhesive wear performance of two heat treatments of the case hardened martensitic bearing steel Pyrowear 675 was investigated using a ball on disc apparatus in an all metal and hybrid configuration with a silicon nitride ball. Tests were conducted at a temperature of 200 ^{0}C and maximum Hertzian stress of 1.95 GPa. A MIL-PRF-23699G military specification oil with a nominal viscosity of 5 cSt at 100 ^{0}C was used as the lubricant. In the test protocol, different lubrication regimes were explored by varying the entraining velocity from 10.8 m/s down to 1.3 m/s at constant values of percent slip (15%, 30%, 50%, and 70%). Scanning Electron Microscopy of the disc test tracks and ball specimens was performed to analyze the extent of adhesive wear and material transfer for each material pair.

Additionally, Energy Dispersive Spectroscopy was performed to investigate the surface chemistry after adhesive wear events.

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

10:30 - 11:00 am
Understanding How Scanning Strategy Affects the Wear Behavior of 3D-Printed Stainless Steel
Mohanad Bahshwan, Tom Reddyhoff, Connor Myant, Imperial College London, London, United Kingdom

Selective Laser Melting (SLM) is a 3D printing process employed in the manufacture of metallic objects. SLM presents an opportunity to manufacture novel, optimized, and complex engineering components. However, it is important we understand the tribological performance of 3D printed components compared to traditional ones. In this study we discuss the effects of SLM build parameters on the tribological performance of AISI 316L Stainless Steel. Results from three different SLM laser scanning strategies are presented and compared to traditionally-manufactured AISI 316L. Small differences in friction coefficient were observed, however, contrasting behavior was seen for wear. This strong dependence of wear performance on SLM laser parameters was linked to the distinct grain structure for each specimen type, caused by the different thermal history of each scanning strategy. The results suggest that the tribological properties can be locally controlled using SLM.

11:00 - 11:30 am
High Temperature Friction and Wear Behavior of Nimonic C263
Deepak Halenahally Veeregowda, Fabio Alemanno, Ducom Instruments Europe B.V, Groningen, Groningen, Netherlands, Ahmad Afiq Bin Pauzi, TNB research, Kualalumpur, Malaysia

Ducom high temperature tribometer with a pin and disk materials made of C 263 was sheared in fretting mode at RT, 300°C, 500°C, 700°C and 900°C. At each test temperature the total number of sliding cycles and load were fixed at 25,000 and 100 N, respectively. Friction coefficient decreased exponentially as the temperature increased to 900°C. Wear coefficient, as determined by using the volumetric weight loss and hardness of the C 263, decreased linearly over an increase in temperature. Lowest friction and wear were recorded at 900 ^{o}C. Elemental composition analysis of worn surfaces showed an exponential increase in concentration of oxygen as a function of temperature. It was only at 900°C that we observed a layer rich in chromium oxide, using the XRD. Interestingly, there were no traces of Ni or Cr in the wear debris generated at 900 ^{o}C. This wear mechanism is comparable to our field wear study of combustor parts and transient piece in gas turbines.

11:30 am - 12:00 pm
Investigation of the Effect of Coatings on Wear of Gas Turbine Components at Elevated Temperature
Akshat Sharma, Purdue University, West Lafayette, IN

Gas turbines undergo material loss due to wear at the interface of transition inlet ring and spring clip seal assembly. The objective of this study was to improve the wear resistance of these components by investigating the behavior of different coatings (Chromium Carbide, T800 and PS400) on them at elevated (500°C) temperature. In order to achieve the objective, an experimental test apparatus was designed and developed to simulate the test environment existing in a gas turbine. An in-situ wear depth measurement technique was used to continuously monitor and compare wear scar depths of differently coated specimen. It was found that HVOF-chromium carbide, T800 and PS400 coatings wear less than APS-chromium carbide coating in both running-in and steady state regime. There was a more profound impact of HVOF-chromium carbide, T800 and PS400 coatings on wear depth reduction with increasing load.

5C Music Row 5

Commercial Marketing Forum V

8:00 - 8:30 am - **ChemGroup, Inc.**

8:30 - 9:00 am - **Lockhart Chemical Co.**

9:00 - 9:30 am - **Pilot Chemical**

9:30 - 10:00 am
Huntsman Petrochemicals: JEFFADD® MW Specialty Amines: Multi-functional Products Developed for Metalworking
Ronald Maus, Huntsman Petrochemical LLC, Everberg, Belgium

Huntsman Petrochemical LLC is a producer of a wide range of chemistries that can satisfy customer's need for longer-lasting and high performing metalworking fluids.Stricter regulations and higher safety concerns have limited the number of additives available to the industry and have encouraged for the innovation and use of multi-functional components in metalworking fluids.To meet this need, Huntsman has developed multi-functional JEFFADD®MW specialty amines that go beyond pH buffering and introduce a range of benefits to meet customer requirements. JEFFADD®MW-703 amine aids in tramp oil rejection, shows low cobalt and copper leaching and imparts some lubricity.JEFFADD®MW-740 amine shows low cobalt leaching and ferrous corrosion inhibition.JEFFADD®MW-750 amine offers ferrous corrosion protection and whose salts show low staining on some aluminum alloys.JEFFADD®MW-781 amine and its salts show low staining on aluminum, low foaming and good performance in fully synthetic formulations.

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

10:30 - 11:00 am - **The Lubrizol Corporation**

11:00 - 11:30 am
Zschimmer & Schwarz: What's new at Zschimmer & Schwarz
Tyler Housel, Zschimmer & Schwarz, Lansdale, PA

In 2019, Zschimmer & Schwarz opened its state-of-the-art esterification plant in Ivey, Georgia. It has been a year of significant change at Zschimmer & Schwarz so this presentation will be an opportunity to discuss the highlights and look to the future with 20/20 vision.
Portfolio review- Synthetic Esters and beyond
Advances in product quality, efficiency, and consistency
New product developement - Fire resistant hydraulic fluids (private label)
Early stage research - Water based emulsion lubricants for high temperature applications including food processing.

11:30 am - 12:00 pm - **The Lubrizol Corporation**

5D Music Row 4

Joint STLE/CTI Symposium on Frontiers of Tribology Research I: Design

Session Chair: Q. Wang, Mechanical Engineerig, Northwestern University, Evanston, ILY. Meng, Tsinghua University, Beijing, China

8:00 - 8:30 am - **Session Starts at 8:30 am**

8:30 - 9:00 am
New Advance in Superlubricity
Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

Superlubricity has developed very fast in recent years as a new and an important area in tribology. Many new phenomena, new materials, and new mechanism both in liquid and solid superlubricity have been obtained. In the liquid area, a new system of superlubricity liquids with new mechanism has been found, which exhibits very good properties of superlubricity under the higher pressure. In solid area, more materials in superlubricity have been observed both by experiment and the molecular dynamics simulation (MDS), such as grapheme to grapheme surfaces, highly oriented pyrolytic graphite (HOPG) to grapheme etc. Mechanism for different tribo-systems has been discussed.

9:00 - 9:30 am - **Ali Erdemir - Advances in Surface and Interface Engineering for Ultra-low Wear and Friction**

9:30 - 10:00 am - **Zhongrong Zhou - Dental Biotribology and Bionic Design**

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

10:30 - 11:00 am - **Hong Liang - Co CMP**

11:00 - 11:30 am
Surface Texture Recognition from Fingertip Skin Frictional Sensing
Shirong Ge, China University of Mining and Technology, Beijing, Beijing, China

Tactile perception of surface texture is a complex process that relies on surface topography and frictional sensing from touching skin. In order to establish the relationship between tactile perception and surface texture properties, an experiment platform was developed to measure synchronous friction, vibration and electroencephalograph (EEG). Three fabrics with different friction coefficient were chosen as samples. Several parameters were extracted from friction and vibration to characterize surface texture. Evoked potentials by friction were calculated from EEG obtained under Go-Nogo mode. Rectified area of early components of evoked potentials was used to represent frictional stimulus. The results showed that early components of evoked potentials were strongly affected by different surface texture. This work is helpful for understanding the frictional effect on tactile perception of finger tip skin.

11:30 am - 12:00 pm
Application of Fluid Rheological Measurements to Improve the Accuracy of Rolling Element Bearing Torque Calculations
Ryan Evans, William Hannon, Praveen Pauskar, The Timken Company, North Canton, OH

Rolling element bearing torque and power losses arise because of rolling and sliding friction. Sliding losses occur at the bearing roller end-flange interface, or due to pivoting or skewing of the rollers, as well as conformal microslip. In most applications these losses constitute half of the total bearing power losses. In a properly designed bearing, these losses are brought about by lubricant shear. A detailed understanding of contacts within bearings thus require adequate lubricant rheological models. This work applies the Yasutomi and the Carreau-Yasuda models to the prediction of shear losses in a rolling element bearing. Lubricant property measurements are obtained using a falling body low shear viscometer, a Couette high shear viscometer, and friction results are presented using a ball on disk arrangement. Results demonstrate the effects of viscosity models from the perspective of bearing torque.

Tribotesting III

Session Chair: J. Xiao, RTEC Instruments
Session Vice Chair: O. Ogunsola, Shell Oil Company

8:00 - 8:30 am
Why All Test Rigs Do Not Give the Same Friction and Wear Response
Carlos Sanchez, Peter Lee, Michael Moneer, Southwest Research Institute, San Antonio, TX

Researchers are often presented with the option of running a tribotest on a number of test rigs. A reciprocating test, for example, can be run on a number of commercially available rigs. Likewise, one may be presented with data that was collected from a particular rig and left with the task of evaluating materials solely based on the results. However, the analysis may not be straightforward since friction and wear response from test rigs depend upon many factors beyond the test sample materials and contact geometry. The rigidity of the rig, loading method, and friction measurement method all play a part in the final outcome. The type of motion and method by which the motion is employed can also have an effect. This presentation will compare one specific test type undertaken across a range of different test rigs and explore why the outcome for friction and wear was varied. The distinctions in friction measurement and data recording methods for each rig will also be discussed.

8:30 - 9:00 am
A Holistic Approach to Characterize the Tribological Performance of Lubricants Applied to New EALs in Plain Bearings
Henry Brunskill, Peak to Peak Measurement Solutions / University of Sheffield, Sheffield , United Kingdom, Scott Beamish, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

There are a wide range of tools that can be used to characterise and qualify lubricating fluids ranging from COTS tribometers to new and novel research contraptions that require a PhD to operate. Environmentally acceptable lubricants EALs are an exciting innovation that aim to minimise the negative impact of lubricants on our fragile ecosystem. According to standard testing methods these EALs perform as well as their mineral oil counterparts. When they are used in field applications such as a marine propellor plain bearings, these new lubricants repeatedly underperform, displaying increased wear and failure due to the high pressures and shear rates. There are no lab tools that exist to perfectly replicate these conditions. To really understand what is happening to these EALs, a range of tests have been performed including using a heavily instrumented miniaturised plain bearing test platform, low, medium, and high shear viscometers, high-pressure viscometers and some new novel techniques.

9:00 - 9:30 am
A Study on Viscosity and Lubricity Effects of N-Butanol and its Mixtures in Oil
Gustavo Molina, John Morrison, Cesar Carapia, Valentin Soloiu, Georgia Southern University, Statesboro, GA

Mixing of N-Butanol with USLD diesel fuel seems to have an anomalous change in viscosity: the viscosity of the mixture is lower than the viscosity of the N-Butanol alone but the viscosity vs temperature curve has a flatter slope when heated causing it to eventually reach a higher viscosity than N-Butanol at same temperature. This change in viscosity and lubricity of the mixture could have effects on the wear if they are used in internal combustion engines. Research is presented here on the viscosity and tribometer-tested wear and lubricity of N-Butanol and of its mixtures in USLD diesel. Temperature-change viscosity and tribometer test wear studies for N-Butanol and for such mixtures are discussed, and future research plans are outlined.

9:30 - 10:00 am
Erosion-Corrosion of Heat-Exchanger Materials by Water/Ethylene-Glycol/Alumina Nanofluids
Gustavo Molina, Fnu Aktaruzzaman, Valentin Soloiu, Mosfequr Rahman, Georgia Southern University, Statesboro, GA

The tribological effects of nanofluids, the suspensions of nanoparticles in ordinary coolants, on heat-exchanger materials are largely unknown. Previous research explored wear on heat-exchanger materials from distilled-water-base nanofluids only, while most engine-coolants are alcohol solutions in water. In this research work the authors tested of aluminum and copper by jet impingement of 50%-ethylene-glycol in water solution and of its 2%-alumina nanofluid. The observed modifications showed that such nanofluid led to wear patterns that were different than those obtained with the base-fluid. Same tests also were performed with distilled water and its nanofluid as references. The results suggests that nanopowders can substantially enhance wear by decreasing the anticorrosion action of ethylene glycol by a synergetic mechanism of erosion-corrosion.

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

10:30 - 11:00 am
Pump Failures: A Laboratory Method to Distinguish between Lack of Lubricity and Presence of Abrasive Nanoparticles
Philip De Vaal, University of Pretoria, Pretoria, South Africa

Premature failure of fuel oil distribution pumps supplying fuel oil to support coal burners on coal-fired power plants in South Africa, raised concerns due to their high cost of replacement in addition to unacceptable downtime on power generating capacity. The objective of this research was to use a simple laboratory-based lubricity test to identify the cause of wear-based failures due to either: - Presence of abrasive particles in the fuel oil - possibly of a submicron size; - Lack of lubricity of the fuel oil. The origin of wear due to abrasive particles could be identified when all particles were removed using centrifugation and re-running the particle-free sample for lubricity. In the case of non-abrasive particles, there was no indication of abrasive wear inside the wear scar. Particle Size Analysis showed that sub-micron particles can cause wear. An analytical technique (ICP) could identify and quantify the nature of abrasive components.

11:00 - 11:30 am
The Tribolgolical Performance of Fuel Efficient Gear Oils in a Limited Slip Differential
Gregory Hansen, Southwest Research Institute, San Antonio, TX

UNCLASSIFIED
In developing a new axle efficiency test for the US Army, it was made known that a combat vehicle (the General Dynamics Land Systems Stryker) utilizes limited slip differentials. Additional compatibility work was needed to ensure that fuel efficient gear oil formulations would not compromise performance of this vehicle. Limited slip clutch performance testing was carried out on both an SAE No. 2 test machine, and a Bruker TriboLab. Comparisons were made between the different test parts, rigs, and oil formulations in order to assess frictional performance and chatter.
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11:30 am - 12:00 pm
Infrared Microscope Analysis – A Tool for Understanding Failure Analysis and Improving Equipment Reliability
Keith Schomburg, PerkinElmer, Magnolia, TX

Fourier Transform Infrared (FTIR) Spectroscopy is used routinely in the analysis of new and in-service lubricants to determine such chemical attributes as oxidation, nitration, sulfation, water and soot. A valuable accessory to the FTIR instrument that can be used for analysis of micro environments is the FTIR microscope. The main advantage of the FTIR microscope is the ability to focus the IR beam with optical apertures on sample sizes ranging from 5 to 500 µm in size. Once the sample position is

identified, the FTIR microscope may be operated in transmission, reflectance or ATR modes allowing for the analysis of liquids, solids and viscous samples. For this presentation the basic principles and techniques of FTIR micro analysis will be discussed and selected example spectra from the in-situ analysis of various lubricant thin films will be shown with emphasis on using these techniques for failure analysis in the lubricants industry.

5F Music Row 2

Synthetics & Hydraulics Lubricants I

Session Chair: R. Davidson, Afton Chemical
Session Vice Chair: P. Cusatis, BASF Corporation, Tarrytown, NY

8:00 - 8:30 am
Sensitivity Analysis of the FMVP Test Method to Evaluate Hydraulic Fluids for Vane Pumps.
Emmanuel Georgiou, Dirk Drees, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium, Michael Anderson, Falex Corporation, Sugar Grove, IL

The functional evaluation and ranking of commercial hydraulic fluids is mostly done by Conestoga Vickers vane pump testing (*ASTM D7043 - DIN 51389 - ISO 20763)*. However, this technique does not provide any information on the frictional behavior of the tribo-system, requires a large amount of hydraulic fluids and is time consuming. For these reason the pre-screening method, based on the Falex Multispecimen lab-tester, was developed in 2017. This method correlates well with Conestoga rankings of hydraulic fluids, additionally we can record the friction of these fluids. In this work, we evaluate the sensitivity limits of the method. To do this, we compare formulated hydraulic fluids with different concentations of additives. This is considered a important step towards standardization of this method.

8:30 - 9:00 am
Polymer-Enhanced Fluid Effects on Mechanical Efficiency of Hydraulic Pumps
Paul Michael, Milwaukee School of Engineering, Milwaukee, WI, Ashlie Martini, Michelle Len, University of California, Merced, Merced, CA

The mechanical efficiency of hydraulic pumps is affected by the properties of the hydraulic fluids, and particularly by polymeric viscosity modifiers used as additives. However, the mechanisms by which polymers affect efficiency are still poorly understood. Here, a well-characterized isobutylene polymer was blended with (poly)alphaolefin base stocks to produce simple, high-purity hydraulic fluids for analysis using molecular dynamics simulation, rheological testing, and dynamometer evaluations. The simulations were used to understand the polymer's response shear and the effect on viscosity. The dynamometer incorporated a variable displacement axial piston pump with torque, speed, pressure and flow sensors to measure mechanical and volumetric efficiency under various pressures and speeds. The fluids were also characterized by their permanent and temporary shear thinning. The results provide insight into the relationship between non-Newtonian fluid viscosity and hydraulic efficiency.

9:00 - 9:30 am
Improving Hydraulic Efficiency by Controlling Fluid Flow Characteristics
Timothy Smith, Lubrizol , Hazelwood, Derbyshire, United Kingdom

Improvements in hydraulic efficiency can be achieved by using a hydraulic fluid that has been specifically designed for this purpose. However the design and formulation of such a fluid is not trivial. Careful analysis of the rheological behaviour of a fluid is crucial for understanding how it might improve energy efficiency. Optimization of the bulk viscosity is well understood to be a key parameter. Surprisingly, the retention of this optimal bulk viscosity by formulating high viscosity index fluids does not appear to contribute to energy efficiency in our studies. Herein we demonstrate that the complex fluid flow

characteristics must be considered in order to formulate an effective energy efficient hydraulic fluid. A geometry change in the flow channel, such as an elbow or valve, induces secondary flows that result in a loss of fluid momentum. With appropriate formulating components, these secondary flows can be reduced to provide a striking improvement in hydraulic efficiency.

9:30 - 10:00 am
Tribological Performance of Composite Basefluid for Hydraulic Systems
M. Cinta Lorenzo Martin, Oyelayo Ajayi, Julie Nguyen, George Fenske, Argonne National Laboratory, Lemont, IL

The efficiency of fluid power systems depend on several properties of the hydraulic fluid. The main ones are viscosity (including VI), traction coefficient, bulk modulus, and the boundary friction with appropriate pump and motor materials. Optimization of these properties can provide opportunity for development of efficient hydraulic fluid. Composite fluids consisting of a mixture of PAO and bio-derived esters were formulated to have properties similar to commercially available hydraulic fluids. Measurement of the pertinent properties and evaluation of tribological performance, indicated the composite fluid has superior or equivalent performance as the current state-of-the-art hydraulic fluids. There are opportunities for further performance enhancement of the composite fluids though formulation.

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

10:30 - 11:00 am
Harvesting Benefits from the Next Generation of Agriculture Lubricant Specifications
Ricardo Gomes, Brian Hess, Joan Souchik, Evonik Oil Additives, Horsham, PA

Agriculture lubricants are multi-functional fluids uniquely defined by specific OEM standards. Today's demanding standards have a proven track record, ensuring fluids that provide long equipment life and high operational performance. Although the agriculture equipment industry is very conservative, there is a trend toward OEMs enhancing their agriculture lubricant specifications to meet the challenges of new equipment designs and demands for increased efficiency and field uptime. This presentation will compare and contrast obsolete, current and future fluid rheological requirements and their impact on fluid component choices. In particular, the benefits achieved by formulating a fluid to the proposed future rheological specifications will be presented and discussed.

11:00 - 11:30 am
Fluid Effects on Low Temperature Power Consumption and Cavitation Noise in Hydraulic Systems
Zheng Dai, Petro-Canada Lubricants, Mississauga, Ontario, Canada, Kimberly Rodriguez, University of California, Merced, CA, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI

In northern United States and Canada, hydraulic systems exposed to the external environment are vulnerable to the extreme low temperature conditions during winter. Low temperatures can stall hydraulic system actuation, increase power consumption, and cause cavitation damage. In this study, hydraulic fluids were evaluated in a commercial safety device at extreme low temperatures to determine how fluid properties affect machine performance and energy consumption. Operating temperatures, actuation times, noise emissions, and power consumption were measured. Multigrade hydraulic fluids containing VI improvers and select base oils provided a wider operating temperature window, actuate the system more quickly, produce less cavitation noise, and reduce power consumption. A model for relating fluid properties to low temperature power consumption was also developed. These results provide a rational basis for the formulation of hydraulic fluids for use in extreme low temperature operations.

11:30 am - 12:00 pm
Study on Water Separation of Evaluation for Hydraulic Oil
Zhongguo Liu, dalian Lubrication R&D Institute, Dalian, Liaoning, China

Hydraulic oils are one of most important groups of industrial lubricants. With the rapid development of hydraulic systems, the excellent demulsibility of hydraulic oil is another key requirement in the process of

practical work. Herein, a method of demulsibility based on ASTM 1401 was established to improve the practical demulsibility of fresh hydraulic oil. 12 kinds of demulsifiers were evaluated for the formulation of hydraulic oil using a more effective improved test method and confirmed the appropriate dosage. Improvement of hydraulic oil exhibited the excellent demulsibility after a field trial and correlated well with the result of improved test method. The results of this study will be providing a referential method for the design of lubricants.

5G Cumberland 1/2

Engine & Drive Train III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Effects of SAE 0W-20 Engine Oil Formulations in Taxi Cab Severe Field Service
JoRuetta Ellington, Andre Dawson, Evonik Oil Additives, Horsham, PA, Boris Eisenberg, Evonik Resource Efficiency GmbH, Darmstadt, Germany, Brian Hess, Evonik Oil Additives, Horsham, PA

There are many inherent challenges in taxi cab applications operating in the extreme desert heat, including stop-and-go driving, 24-hour operation, and continuous idling. These conditions place severe demands on the lubricant. A series of API SN 0W-20 engine oils was evaluated in a Las Vegas taxi cab fleet to study the durability of two different classes of VI Improvers in engine oils. These fluids were examined in turbocharged engines operating under severe service conditions. The 100,000 mile field trial, utilizing vehicles equipped with 2.0L Eco-boost engines, was performed to demonstrate that novel VII technology will do no harm to the vehicle while protecting the engine from sludge, varnish, and oxidation. This paper will present the fluid performance results from the end of test along with engine teardown analysis.

8:30 - 9:00 am
Automatic Transmission Fluid VII Effects in Taxi Cab Field Service
JoRuetta Ellington, Andre Dawson, Evonik Oil Additives, Horsham, PA, Jennifer Holtzinger, Evonik Resource Efficiency GmbH, Darmstadt, Germany, Brian Hess, Evonik Oil Additives, Horsham, PA

A series of automatic transmission fluids meeting MERCON® LV specifications was evaluated in a Las Vegas taxi cab fleet to study the durability of comb polymers compared to market general PAMA technology. Vehicles equipped with six-speed automatic transmissions ran for 100,000 miles to demonstrate no harm performance by maintaining viscosity and low temperature requirements. This paper will present the fluid performance results from the end of test along with transmission teardown analysis including sludge ratings. This paper will also examine the correlation between bench test shear results and the field test results.

9:00 - 9:30 am
Motor Oil, Fuel Economy and Real Driving Emissions in the Era of E-Mobility
Boris Zhmud, Applied Nano Surfaces, BIZOL Lubricants, Uppsala, Sweden

E-Mobility is viewed by many as the future as transportation. Electric powertrain technologies are rapidly evolving, raising concerns among lubricant manufacturers as to the future of motor oil. In the present communication, current market trends are reviewed and conclusive evidence presented that the internal combustion engine (ICE) is not going to disappear any soon. Hybrid powertrains are expected to dominate new car sales by 2040, while diesel engines will most likely remain the preferred option for commercial fleets. This justifies continuing investments into the development of low-friction ICE powertrains and resorce-conserving motor oils. New ICEs use a lot of innovative engineering solutions for

improving efficiency: a lightweight design, downsized boosting, nearly adiabatic operation, new materials and friction-reducing technologies, and set stricter requirements for the crankcase lubricant performance.

9:30 - 10:00 am
PPD Selection for Next Generation Engine Oil Formulations
Justin Mills, Joan Souchik, John Maxwell, Evonik Oil Additives, Horsham, PA

More stringent regulations coupled with an expanding global market create the need for next generation lubricants to ensure engines remain protected as new hardware technologies are introduced. Fresh, as well as aged engine oils, must meet new standards to ensure performance and longevity. To safeguard engines during low-temperature startup, the inclusion of aged oil low-temperature requirements remains in GF-6. The ASTM D7528 ROBO test allows formulators to readily determine a PPD's effectiveness in controlling the low temperature behavior of aged engine oils. Selecting the right PPD to meet these requirements may present a unique challenge to formulators. This presentation will demonstrate the ways that ROBO can be used to identify an optimized PPD for GF-6 formulations and to fine-tune the PPD treat rate. The impact of formulation options and the benefits of using a bench test over an engine test to optimize low temperature performance will be explored.

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

10:30 - 11:00 am
Low-viscosity Passenger Car Motor Oils and Automatic Transmission Fluids: A Comparative Evaluation of Group III, Group III+, Renewable Group III+, and PAO-based formulations
Lynn Rice, David Matucha, Steve Haffner, Paula Vettel, Novvi LLC, Emeryville, CA

Use of high-performance lubricants is required to meet the stringent requirements for low viscosity, 0WXX motor oils, which include low Noack volatility and good low-temperature properties as measured by Cold Crank Simulator (CCS) and Mini Rotary Viscometer (MRV) methods. Addition of renewable Group III+ base oils as trim stocks in low-viscosity engine oils is an effective approach to achieve the required performance in 0WXX motor oils. In this presentation, results of performance tests on 0W8, 0W12, 0W16 and 0W20 motor oils formulated with Group III, Group III+, Renewable Group III+, and PAO base stocks will be compared and discussed. Renewable group III+ base oils also offer performance advantages in low-viscosity automatic transmission fluids (ATFs). Test results on ATFs formulated with Renewable Group III+ base stocks will also be presented. We will demonstrate that key properties of base stocks can impact formulators' ability to meet tomorrow's lubricant requirements.

11:00 - 11:30 am
Hydroynamic Friction Reduction Due to Laser Texturing of IC Engine Journal Bearing Shells
Tom Reddyhoff, Sorin Vladescu, Imperial College, South Kensington, United Kingdom, Mark Fowell, Volvo Trucks, Göteborg, Sweden, Daniele Dini, Imperial College, South Kensington, United Kingdom

The effects of surface texture on friction has received considerable attention, however few studies have looked at journal bearing contacts. This presentation describes a new experimental and modelling study into the impact of laser surface texturing on crank shaft bearing friction. Laser etched patterns were applied to the surface of shell components and results compared with those from a non-texture reference. Tests were performed under a range of lubrication regimes to simulate the conditions encountered in a real IC engine. Reductions in measured friction of ~20% were observed in the hydrocyanic regime, in agreement with predictions from the finite different, mass-conserving, thermal model. This contrasts much of the research on reciprocating piston-liner type contacts, which show texture induced friction reductions only under mixed and boundary conditions. Analysis of the results are used to explain the mechanisms responsible for this texture induced friction reduction.

11:30 am - 12:00 pm
Fuel Economy Modeling: Engine to Engine Operating Regime Differences
Brendan Miller, Shelby Skelton, Chevron Oronite Co. LLC, Richmond, CA

Fuel efficiency has been, and will continue to be, a key topic for OEMs and lubricant suppliers. Overall fuel economy performance is dependent on the balance of boundary and hydrodynamic friction within an engine. Determination of this balance with respect to engine hardware, operating parameters, and formulation levers is discussed within each subsystem of the engine through examples generated by a first principles fuel economy model. Engines modeled will include passenger car, heavy duty, and 2-stroke marine engine.

5H Cumberland 3

Nanotribology V

Session Chair: P. Nalam, Civil and Environmental Engineering, University of Illinois Urbana Champaign, Champaign, IL
Session Vice Chair: N. Garabedian, Mechanical Engineering, University of Delaware, Newark, DE

8:00 - 8:30 am
Exploring the Limits of Contact Mechanics Models for Nanoscale Metal Contacts Using In-Situ and in Silico Techniques
Sai Bharadwaj Vishnubhotla, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, University of California-Merced, Merced, CA, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Ashlie Martini, University of California-Merced, Merced, CA, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Metallic nanocontacts are relevant in advanced technologies like conductive atomic force microscopy, scanning nano-thermometry, probe-based lithography, and micro-and nanoelectromechanical systems. In all cases, functional properties such as adhesion, friction, electrical and thermal transport depend on the size and nature of contact. Contact mechanics models are routinely applied to these contacts, despite evidence of breakdown of their underlying assumptions at the nanoscale. Here we directly investigate the limits of contact mechanics models using in situ transmission electron microscopy and matched molecular dynamics simulation. For contacts composed of platinum and titanium dioxide, we demonstrate how surface chemistry and sub-surface dislocation activity affect the behavior of the contact and therefore the applicability of continuum mechanics for nanoscale contacts.

8:30 - 9:00 am
Atomic-Scale Friction Behavior of Few-Layer Graphene under Ultra-High Vacuum Conditions
Philip Egberts, University of Calgary, Calgary, Alberta, Canada, Peng Gong, Univeristy of Calgary, Calgary, Alberta, Canada

Analysis of the atomic-scale friction behaviour of few-layer graphene using ultra-high vacuum atomic force microscopy (UHV-AFM) allows for the measurement of the intrinsic mechanisms of lubrication in the absence of environmental contaminants. Specifically, 0-4 atomic graphene layers supported on Si/SiO_2 substrates were produced through mechanical exfoliation. Load dependent friction measurements were acquired under UHV conditions and interpreted through a modified analytical Prandel-Tomlinson model. Experimental results showed a difference between the unloading and the loading processes under UHV conditions with a negative friction coefficient observed during the unloading process. This unloading behavior has been proposed to be a result of the pucker effect. Analysis of the stick-slip friction data showed that the corrugation potential and lateral stiffness increased with load, indicating that both increased energy corrugation and contact area contribute to increased friction.

9:00 - 9:30 am
The Chemistry of Friction, Wear and Tribo Film Growth on 2D materials
Shivaranjan Raghuraman, Jonathan Felts, Texas A&M University, College Station, TX

The phenomenon of friction has been studied for a few centuries, yet, its physical and chemical origin is as elusive as ever. Friction force can depend on the chemical composition of surfaces in contact,

temperature, direction of sliding and the contact stress between the surfaces. We explore the chemical origins of sliding friction between a Silicon AFM tip pushing and sliding on Graphene Oxide surface. Our results reveal that mechanochemical wear distinctly depends on both the normal and lateral force applied by the AFM tip. Our theory of velocity dependent wear based on transition state theory quantitatively relates the friction evolution to the bonded states of oxygen groups between the Silicon tip and Graphene. This knowledge can be extended to quantitatively predict the friction force between two surfaces of known composition and thereby efficiently design surfaces to mitigate wear.

9:30 - 10:00 am
Tribological Behavior Comparison of MoS_2 and Graphene Influenced by Humidity and Counter Surface Oxides
Taib Arif, University of Toronto, Mississauga, Ontario, Canada, Guillaume Colas, FEMTO-ST institute , Besançon, Bourgogne Franche-Comté, France, Tobin Filleter, University of Toronto, Mississauga, Ontario, Canada

This work highlights the tribological behavior of MoS_2 and Graphenenano-sheets at varying environmental humidity against SiO_2 and 440C steel single-asperity contact using customized AFM cantilevers. Experiments done using SiO_2 tips reveal MoS_2 to be more sensitive to water with adhesion and friction force increasing at much lower humidity (RH20%) as compared to graphene (RH50%). Water adsorption on the top surfaces of Graphene and MoS_2 was observed from AFM thickness measurements, confirming surface water adsorption as the primary mechanism. However, with the 440C steel tip, additional tribochemical mechanism plays a role due to the presence of oxides. The strong interaction between the Cr-oxides and sulfur atoms reflect on the higher adhesion and friction between the steel/MoS_2 interface. Furthermore, water adsorption between RH7-44% lubricated the Steel/MoS_2 interface likely by forming a protective water film, whilst having no significant effect for the Steel/graphene interface.

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

10:30 - 11:30 am
Pushing Tiny Sliders, or: What We Can Learn from the Controlled Translation of Really Small Objects on Well-Defined Surfaces
Udo Schwarz, Yale University, New Haven, CT

Nanotribology attempts to shed light on how atomic interactions relate to frictional effects. Experimental approaches usually include the sliding of very small contacts, but when the goal is to truly recognize the effect of individual atoms, challenges remain. In this talk, we review approaches to produce small but well-defined slider-substrate contacts that allow to isolate the contribution of individual atoms to the observed friction. We focus in particular on a strategy where tiny sliders are laterally translated by external “pushing”. This approach led to the characterization of the scaling laws of structural lubricity when the area was continuously enlarged. Following the opposite route, we developed techniques that allow to measure the lateral forces needed to push individual molecules on single-crystalline surfaces, which offers insight into the fundamental parameters that affect the lateral translation of atomic-scale objects such as energy barriers and chemical environment.

11:30 am - 12:00 pm
Atomic-Scale Insights into Contacts between Nanoscale Bodies: In-Situ Experiments and Matched Atomistic Simulations
Tevis Jacobs, Sai Bharadwaj Vishnubhotla, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, Xiaoli Hu, Ashlie Martini, University of California, Merced, Merced, CA

In probe-based microscopy, nanomanufacturing, and small-scale devices, performance often depends on contacts between nanoscale bodies. Adhesion, deformation, and thermal or electrical transport across the contact can be load-dependent and difficult to predict. Traditional continuum-based contact models rely on assumptions that may not hold at the nanoscale. Here we used experiments and simulations to quantitatively investigate nanoscale asperities during formation, loading, and separation of contact.

Experimentally, controlled-load tests were performed inside of a transmission electron microscope, enabling high-resolution measurement of contact properties with simultaneous characterization of materials structure and geometry. Molecular dynamics simulations were performed on matched nanocontacts with the same materials, geometry, and loading conditions. The results demonstrate deviations from traditional models because of atomic-scale interactions.

5I Cumberland 4

Surface Engineering I

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Tribology of Micro-textured ATSP Polymers in Synthetic Seawater
Reza Gheisari, Texas A&M University, College Station, TX

A novel texturing technique was developed to generate precise micro dimples on advanced bearing polymer materials through hot sintering method. Applying this technique, perpendicular arrays of semi cylindrical micro dimples with pitch of approximately 185 µm average diameter of 78 µm and a height of 65 µm were produced. Polymeric pins were tested against copper alloy disks in water lubricated conditions. Effect of sliding velocity on the friction coefficient of the contact was studied by orchestrating a Stribeck curve analysis with sliding velocities from 2.0 to 0.05 m/s. Effect of normal load on the tribological performance of the textured pins were investigated as well. Identical tests were carried out on a flat ATSP pin to provide a reference frame to assess the performance of the micro-textured pin. Results reveal that micro-texturing could be used as an effective technique to enhance the tribological performance of polymeric bearing materials used in marine applications.

8:30 - 9:00 am
Low Cost Fabrication Method for Surface Textures on Engine Components
Stephen Hsu, Govindaiah Patakamuri, George Washington University, Washington DC, DC

Micro-surface textures, to be effective in friction reduction, need to be designed based on the dominant lubrication mechanism of the two interacting surfaces. For engine components, the kinematics of the movement, stresses, temperature, real area of contact of the two surfaces are important parameters in designing the specific surface texture features: shape, orientation, areal density, depth, and pattern. At the same time, location specific conditions will also require dimple variations. To accommodate all these requirements, micro-lithographic coupled with electrochemical etching is the preferred method. However, this technique requires two UV exposures, flat surface, and no significant roughness. We have developed a once through soft mask direct write technique to produce soft polymeric mask for easy etching of complex engine component surfaces. This results in an order of magnitude cost reduction, making surface texturing a viable technology for wide spread use.

9:00 - 9:30 am
Characterization and Tribological Application of High Porosity Coatings
Hamed Ghaednia, Arup Gangopadhyay, Brian Almeria, Ford Motor Company, Dearborn, MI

Engineering surfaces are often decorated with scratches, grooves and textures which act as oil retention features. However, the common practice to reduce friction, is to reduce the surface roughness. These two concepts need to be balanced to achieve the optimized state of a surface. Recently, the application of high porosity coatings has offered a novel method to optimize oil retention while keeping the top surface smooth. These surfaces are constructed of a super smooth top plateau and isolated micron-scale pockets also known as surface porosity. The current work describes the background and tribological benefits of high porosity coatings deposited on an engine bore. The friction has been assessed using a ring on liner

rig and tested against various other coatings such as PVD and DLC. Characterization techniques have been developed to define the surfaces. This includes 2D profile analysis, 3D surface analysis and cluster analysis to characterize pore depth, size and distribution.

9:30 - 10:00 am
Improved Wear and Fatigue Resistance of a Boron-Doped DLC Coating Deposited on UNSM Pre-Treated 52100 Steel Substrate
Zhencheng Ren, Haifeng Qin, Gary Doll, Yalin Dong, Chang Ye, University of Akron, Cuyahoga Falls, OH

In this work, a boron-doped diamond-like carbon (BC/a-C:H) coating was developed and deposited on 52100 steel by magnetron sputtering process, which combines the high hardness of B_4C and low friction of DLC. The coating structure and composition were characterized by Raman Spectrum and X-ray photoelectron spectroscopy (XPS) respectively. All specimens were tested in sliding, rolling and mixed mode contact conditions, and the result proved that the highest wear and fatigue resistance of coating was obtained when B/C ratio is around 1%. Ultrasonic Nanocrystalline Surface Modification (UNSM) was applied prior to the coating on 52100 steel substrate to induce a grain refinement layer. Benefited from the increased hardness and compressive residual stress resulted from the grain refinement layer, UNSM increased the adhesion between coating and substrate and improved both wear and fatigue performance of coating regardless of the coating composition.

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

10:30 - 11:00 am
Elastic and Elastic-Plastic Analysis of an Axisymmetric Sinusoidal Surface Asperity Contact
Swarna Saha, Robert Jackson, Auburn University, Auburn, AL

This work has analyzed and quantified the behavior of an elastic and elastic perfectly plastic axisymmetric sinusoidal surface in contact with a rigid flat for a wide range of material properties and different values of the amplitude to wavelength ratios. The model considers interaction with adjacent asperities. Numerical complexities have also been reduced to a great extent because of its geometry. The results agreed well with the Hertz model and the Jackson-Green spherical contact model at low pressures where the sinusoidal peak is similar to a sphere. Empirical equations for elastic and also elastic-plastic cases are formulated for the contact pressure, contact area and surface separation. The critical value of the amplitude of the sinusoidal asperity below which it will deform completely elastically and the evolution of average pressure i.e. hardness and its relation with yield strength has also been examined from the initial to complete contact.

11:00 - 11:30 am
A New Approach to Model Effect of Surface Roughness on Fatigue of Tensile Specimen
Kushagra Singh, Farshid Sadeghi, Purdue University, West Lafayette, IN

A finite element approach to model effect of surface roughness on fatigue of tensile specimen is presented, along with experimental validation on 4130 steel specimen. To model progressive material degradation during fatigue process, continuum damage mechanics with jump-in cycles approach was used. Voronoi tessellation was used to represent material microstructure as well as surface roughness. The parameters of tessellation were obtained from actual grain size distribution and grain directionality as observed in the specimen during SEM imaging. Surface roughness was modeled based on R_a obtained from experimental measurements of surface profile. Three levels of roughness were chosen for this study, including one smooth surface finish as per ASTM standard. Fatigue lives distribution resulting from simulation was in good agreement with experimental results.

11:30 am - 12:00 pm
Multi-Resolution Characterization of Surface Topography for Improved Properties Prediction
Tevis Jacobs, Abhijeet Gujrati, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Lars Pastewka, University of Freiburg, Freiburg, Germany

Surface roughness affects surface function. However, experimental investigations to quantify these links are often inconclusive because surfaces are fractal-like, and the values of measured roughness parameters depend on measurement size. Here we use nanocrystalline diamond films of varying grain size as model systems to investigate the quantitative connection between topography and properties. We show the characterization of topography across length scales by using electron microscopy in combination with conventional techniques. Many measurements, taken at various length scales, are combined using spectral analysis to yield scale-independent roughness parameters. These scale-independent parameters can be used with continuum mechanics models to describe surface properties. By comparing with experimental measurements of adhesion, we show that this multi-resolution approach is far more effective at predicting properties than conventional (single-scale) roughness measurement.

5J Cumberland 5

Lubrication Fundamentals V

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Molecular Science and Engineering Application of High Performance Lubricants
Weimin Liu, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, Gansu, China

Nowadays, various organic molecular were designed, synthesized and formulated to develop high performance lubricant in order to meet the ever-increasing demand of fuel-efficiency, reliability, as well as extended service life of modern machines. In this report, we first made a brief review of the origin and functionality of lubricants. Then we illustrate several examples about the molecular design and engineering application of synthetic ester based lubricants. After that, a brief introduction of our work about how to design and functional modification of silicone oil and multi-alkyl cyclopentanes (MACs) based oil and their application in aerospace machines was introduced. Last, recent developments of room temperature ionic liquids (ILs) as high performance lubricants were also discussed.

8:30 - 9:00 am
The Autoxidation of Polyisobutylene Succinimide Dispersant Mimics: Products, Mechanisms and Performance Implications
Jonny Ruffell, Moray Stark, Thomas Farmer, Duncan Macquarrie, University of York, York, United Kingdom

Chemically equivalent mimics for polyisobutylene succinimides have been synthesised and their liquid phase autoxidation has been investigated, to further understand the autoxidative stability of dispersants used in engine oil lubricants. Autoxidation of the mimics at ring-pack temperatures in a model base oil, squalane, showed them to degrade at significantly higher rates compared to squalane itself. From liquid phase autoxidation studies of the neat mimic, thirteen major products were fully characterised and quantified by GC-MS and GC-FID. The products from the rapid and site selective degradation of the chemical mimic were shown to form *via* three major autoxidation mechanisms. These degradation products can have serious negative implications on lubricant viscosity, fuel economy and engine cleanliness.

9:00 - 9:30 am
Relationship between Structures and Anti-Oxidation Performance of Hindered Phenolic Antioxidants
Tom Tang, Smith Scott, Glenn Kenreck, Amaron Barr-Cook, Gertrude Jacobs, SI Group, Orangeburg, SC

Hindered phenolic antioxidants as radical scavengers are widely used in lubricant applications to prevent the lubricant breakdown, extending its service life. 2,6-Di-tert-butylphenol (DTBP) and 2,6-di-tert-butyl-4-methylphenol (BHT) are two hindered phenolic antioxidants used in this study. The antioxidation performance was evaluated by RPVOT, PDSC, and TOST. DTBP outperforms BHT in all three tests, despite the different test conditions. Factors affecting the anti-oxidation performance may include 1) O-H bond dissociation energy of hindered phenolic antioxidants, 2) the stability of the corresponding hindered phenoxy radicals, and 3) the number of free radicals that a single antioxidant can scavenge. The study of the relationship between structures and anti-oxidation performance of DTBP and BHT sheds light on designing new lubricant antioxidants and helping formulators select the right antioxidants for specific applications.

9:30 - 10:00 am
The Use of Microcapsulated Additives Fuel Economy Eenhancement
Stephen Hsu, Govindaiah Patakamuri, George Washington University , Washington DC, DC, Timothy Cushing, GMC, Warren, MI
Microcapsules provide timed-release of additives to replenish depleted or degraded additive during service. As such, it has tremendous potential for long lasting lubrication effectiveness. In view of the movement towards autonomous systems throughout our society in the future, this technology will enable long drain intervals, smart lubricants, self-healing and deliver the right additive to the right location on demand. We have demonstrated that such capsules can be made, scaled up, and their effectiveness demonstrated in the bench tests. How they will fare in actual engine environment? This presentation will report such an attempt.

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

10:30 - 11:00 am
Is Oxidation Terminated? Latest Technologies for Low Varnishing and Long-Life Turbine Oils Highlight the Need for Revised Oxidative Stability Testing
Alex Mannion, Eugene Scanlon, Ryan Fenton, Jeff Schoonmaker, Michael Hoey, Thomas Rühle, BASF, Florham Park, NJ

Modern turbine oils face challenges like longer lifetimes, sludge and varnishing. Hydrotreated base stocks have gained attraction as they provide better thermal stability compared to Gr. I base stocks; however, they show a poorer solvency for polar aging products, leading to increased sludge and varnish formation. With hydrotreated base stocks, it is already difficult to meet the severe requirements from OEMs like Siemens, GE, and MAN. The Mitsubishi MHPS MS04-MA-CL005 specification for turbine fluids, though, goes one step further by significantly increasing oxidative stability standards:
● RPVOT: minimum 1,200 minutes
● Dry TOST / RPVOT Retention Test: new method not required in other turbine specifications
● High Temp Oxidation Test (D4636)
In the process of meeting this challenge, modern technologies have significantly exceeded the current limits of oxidation tests. So, either oxidation is terminated, or the industry must revise these methods as the old standards are obsolete.

11:00 - 11:30 am
Fuel Economy Low Viscosity Engine Oil Compatible with Low Speed Pre-Ignition
Jiayang Zhao, Sinopec Lubricant Co., Ltd, Beijing, China

Compare with traditional formulation with Ca-Mg type compound detergent to reduce the LSPI frequency, this paper introduce an engine oil compatible with LSPI performance by new technology just adapting high content of Ca-type detergent. The performance of LSPI prevention meet the requirement of OEM's. As is well-known that MoDTC benefits for friction reduction performance. Therefore it is widely used as friction modifier by many OEMs. This paper compared the different performances of molybdenum friction modifiers formulation and organic friction modifiers formulation on worldwide harmonized light vehicles test cycle (WLTC). Through the test the different fuel economy improvement (FEI) performance of different type VIIs formulation also could be found. This paper introduce a fuel economy low viscosity

engine oil just with organic friction modifier. WLTC and NEDC are both to evaluate the oil FE performance. The performance of fuel economy meets the requirement of OEM's.

11:30 am - 12:00 pm
Evolution of ZDDP Crystallinity and Its Effect on Film Durability
Mao Ueda, Amir Kadiric, Hugh Spikes, Imperial College London, London, United Kingdom

In recent years the role of zinc dialkyldithiophosphate (ZDDP) as an antiwear additive in engine oils has become increasingly important because of the use of low viscosity oils to improve fuel economy. Such low viscosities mean that engine components operate for longer periods in thin film mixed lubrication conditions where wear may occur. Although a great deal of research has been carried out on ZDDP, one area of very limited current understanding concerns the durability of ZDDP tribofilms. It has recently been shown that ZDDP films can have either a nanocrystalline or amorphous structure and that this may influence their film strength. This presentation describes the use of focussed ion beam-transmission electron microscopy (FIB-TEM) to explore in detail the factors influencing ZDDP crystallinity and investigates the impact of such structure on ZDDP film properties and durability.

5K Cumberland 6

Tribology of Biomaterials - Biotribology & Materials Joint Session

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Session Chair: TBD
Session Vice Chair: TBD

8:00 - 9:00 am - **Invited Talk**

9:00 - 9:30 am
Bio-Tribocorrosion of CoCrMo During Reciprocating Sliding Against Bovine Articular Cartilage
Manel Rodriguez Ripoll, Bojana Stojanovic, AC2T research GmbH, Wiener Neustadt, Austria, Christoph Stotter, Christoph Bauer, Thomas Klestil, Stefan Nehrer, Danube University Krems , Krems, Austria, Friedrich Franek, AC2T research GmbH, Wiener Neustadt, Austria

This work addresses the role of bio-tribocorrision in partial replacements sliding against cartilage tissue. The synergistic effect of biocorrosion and mechanical wear, i.e. bio-tribocorrosion, is a common failure mechanism in metallic implants, but the electrochemical conditions are rarely controlled in biotribological tests. Bovine cartilage response was investigated under reciprocating sliding motion against a CoCrMo cylinder. The experiments were performed under controlled electrochemical conditions using a floating cell with a three electrode set up coupled to a microtribometer. A drop of the open circuit potential was systematically detected at the onset of sliding. This drop is attributed to changes in passive layer on the metal surface which lead to Co ion release. Low quantities of Co were found in the electrolyte after the experiments. The critical apoptotic Co concentrations were subsequently studied using cell cultures exposed to artificial Co containing saline solutions.

9:30 - 10:00 am
Biomechanics of Hierarchically-Structured Enamel in Grinding Dentitions
Tomas Grejtak, Tomas Babuska, Xiu Jia, Brandon Krick, Lehigh University, Bethlehem, PA, Siddhartha Pathak, University of Nevada, Reno, Reno, NV, Stephen Hendricks, Gregory Erickson, Florida State University, Tallahassee, FL

Dental tissues of grazing animals are designed to be subjected to high surface stresses over millions of loading cycles. The enamel tissue is a ceramic-like bio-composite showing remarkable wear resistance, strength, toughness, and controlled crack propagation. The secret to the exceptional biomechanics of this tissue lies in the hierarchically-structured enamel prism. In this work, for the first time, the mechanical and

wear properties of the enamel tissues of various animals, across nano- to whole-tooth scale are evaluated. Hardness, fracture and wear-relevant material attributes relationship to the underlying structure are evaluated by using a combination of structural, morphological and chemical microscopy tools with multi-scale mechanical testing. The tribological properties are used to develop 3D wear models to determine how the tissue arrangement and topology of the composite grinding surfaces self-wear to optimal topography for long-term functionality.

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

10:30 - 11:00 am
Fabrication of Cartilage-Inspired Surface Textures Using Photolithography for Orthopedic Implants
Dipankar Choudhury, Gabriel Dharwadker, Evelyn Smith, Josh Goss, Min Zou, University of Arkansas, Fayetteville, AR

Inspired by the porous cartilage topography, several studies have been carried out to fabricate micro dimples for reducing friction and wear of orthopedic implants. However, most reported dimple sizes are big and of circular shape. Herein we used photolithography and wet etching processes to fabricate smooth micro dimples on Ti-6Al-4V ELI substrates with smaller size and various shapes to study the effects of different dimple size and shapes. Star-, square-, triangular-, and circular-shaped micro dimple arrays were fabricated. The dimples were consistent and without any unexpected protrusion. The fabricated textured surfaces were more hydrophilic than that of the non-dimpled Ti-6Al-4V ELI substrates. Currently, in-vitro biotribological experiments are being conducted on the fabricated samples against ultra-high molecular weight polyethylene (UHMWPE) and polyether ether ketone (PEEK) pins to determine their impact on friction and wear rate for orthopedic implants.

11:00 - 11:30 am
Friction Across Soft Matter Interfaces
Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

Tear film stability and ocular epithelial health are closely coupled and both are essential for comfort. During contact lens wear frictional forces at the ocular interfaces are difficult to measure in vivo. This work aimed to measure the effects of shear stresses on human corneal epithelial (hTCEpi) cells in vitro by sliding a soft probe against cell layers. Tribological experiments were performed in cell culture conditions: 37±0.2°C, 5% CO_2, and >80% RH. Over 10,000 cycles, the normal force was F_n = 218.6±20.3 µN, the friction force was F_f = 12.8±3.2 µN, friction coefficient was µ = 0.058 ±0.008, and shear stresses were ~ 60 Pa. Molecular biology assays revealed increased expression of pro-apoptotic (DDIT3, FAS) and pro-inflammatory genes (IL-1b, IL-6, MMP9) in cells subjected to high shear stresses (~65 Pa), yet low shear stresses (~30 Pa) did not elicit significant changes in gene expression compared to controls. This work may assist in the informed design of medical implants.

11:30 am - 12:00 pm
Understanding the Interaction Between Contact Lens and Eye Using In-Vivo and In-Silico Techniques
Rachel Morecroft, Yunok Craze-Romero, University of Sheffield, Sheffield, United Kingdom, William Kay, Stephen Connell, Pete Toomey, Royal Hallamshire Hospital, Sheffield, United Kingdom, Raman Maiti, University of Sheffield, Sheffield, United Kingdom

74% of the UK population would prefer wearing corrective eyewear to help them see clearer. And, more than half of these people have reported irritation due to contact lens. The aim of the project was to understand the damage on the eye surfaces due to the usage of the contact lens. Twelve volunteers were invited for the in-vivo study. The eye surfaces were imaged using Heidelberg Spectralis (Heidelberg Engineering, UK) for three adjacent sessions: before wearing the contact lens, after wearing the contact lens for a period of 6-7 hours and recovery the next day. A solid model replicating the contact lens and the eye interaction was developed in multi-body modelling simulation (MSc ADAMS, CA). The input data for the modelling was obtained from fluoroscopy and literature. The paper provides information on the

contact mechanics of the interaction and changes in the morphological properties. The information will be useful to design new comfortable and patient specific contact lens.

6A Legends D

Rolling Element Bearings II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Microstructural Improvements of Advanced Ball Bearing Materials through Alloying Elements, Powder Metallurgy and Deformation Processes
Christopher DellaCorte, NASA, Cleveland, OH

Aerospace mechanical components like ball bearings face severe challenges that demand construction materials with unique capabilities. Extremely high static load capacity, for instance, is often a prerequisite to survive rocket launch. Immunity to corrosion and compatibility with space lubricants are key attributes that many conventional bearing alloys cannot provide. In these cases, new alloys and new processing methods applied to conventional alloys may be required to meet the demands of space applications. Recent efforts have been undertaken to develop ceramic-free, fine grained high-carbide tool steel via powder metallurgy and resilient cast NiTi alloys suitable for long-life, highly reliable precision bearings. The processes involve ceramic-free processing methods coupled with hot deformation to produce materials capable of meeting extreme bearing material needs today and well into the future.

2:00 - 2:30 pm
The Lubricant Formulation: Driver for Premature Bearing Failures and White Etching Cracks?
Kenred Stadler, SKF GmbH, Schweinfurt, Germany, Arnaud Ruellan, SKF B.V., Nieuwegein, Netherlands

Premature bearing failures associated to White Etching Cracks (WECs) have been extensively studied in the past decade. Several hypotheses have been formulated on the role of the lubricant and tribochemistry under mixed lubrication and high slip conditions, based on tests of 81212 bearings on FE-8 rigs. It has been suggested that WECs may develop in points of high frictional energy accumulation, but evidence suggests that it is very dependent on the presence of specific additives. Some authors suggest that certain oils will lead to hydrogen ingress and subsequent weakening of the bearing steel. Others suggest that specific additives and/or reaction layer could induce high surface shear stresses promoting surface micro-cracks. The aim of this study is to verify or falsify the assumption that certain additive and/or reaction layers can accelerate bearing failures using different test set-ups and to discuss the relevance of the findings with respect to the field.

2:30 - 3:00 pm
Surface Driven Formation of White Etching Cracks in Bearings Used in Wind Turbines
Mohanchand Paladugu, The TIMKEN company, North Canton, OH

Bearings used in wind turbine gear boxes experience dynamic loads, torque and speed changes, boundary lubrication conditions and non-RCF (rolling contact fatigue) loads from shafts. Because of these demanding application conditions, some fraction of bearings used in this application is known to get damaged prematurely. The prematurely damaged bearings showed cracks and spalls on the rolling contact surfaces. Metallographic investigations on the damaged bearings showed cracks in the subsurface regions and white etching matter along the cracks (called white etching cracks). To answer how and why these white etching cracks are formed, in this presentation, the insights obtained from laboratory testing of bearings are shown. The results suggest that, although the cracks form in subsurface, their formation is driven by the contacting surface. In addition, role of bearing steels' microstructure and heat treat processes will be explained.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
The Evolution of Dark Etching Regions and White Etching Bands in Bearing Steel due to Rolling Contact Fatigue
Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom, Bernd Vierneusel, Martin Correns, Toni Blass, Schaeffler Technologies GmbH & Co. KG, Schweinfurt, Germany

Subsurface microstructural alterations such as Dark Etching Regions (DERs) and White Etching Bands (WEBs) can form in bearing components due to Rolling Contact Fatigue (RCF) under medium to high over-rolling cycles. These alterations are found to initiate as DERs followed by WEBs firstly at a low angle of 30° then at a high angle of 80° over hundreds of million cycles. Such transformations have been widely reported in literature however their formation mechanisms and the influence of bearing operating conditions are not well understood. This paper presents a study of DERs and WEBs formed in the bearing inner ring at two grades of AISI 52100 steel cleanliness under two different contact pressures over a range of load cycles. The results show while DERs and WEBs appear to be uniformly distributed when fully developed, the 30 & 80° WEBs are found to form in conglomerates at their early stages.

4:00 - 4:30 pm
The Major Acceleration Factor of White Etching Crack(WEC)
Yujiro Toda, NSK Ltd., Fujisawa, Kanagawa, Japan

White etching crack (WEC) occasionally occurs in ball bearings used for electrical accessories, such as alternators and pulleys and it occurs less than one–tenth of the calculated bearing life. Therefore, a lot of replication tests have been done to find out the mechanism of WEC formation. Although various acceleration factors have been proposed in the previous studies, the major factor has not been clarified. In this study, our investigation showed that potential difference between inner ring and outer ring resulting from static electrical charge is the major acceleration factor of WEC formation. It is spontaneously generated by friction between the drive belt and pulley, and is accumulated by insulation of oil film. Besides, the effect of grease component has been investigated.

4:30 - 5:00 pm
Formation of White Etching Areas/Cracks on a Four Disk Rig– Influence of Electrical Current and Slip
Florian Steinweg, Institute for Materials Applications in Mechanical Engineering, RWTH Aachen University, Aachen, Germany, Adrian Mikitisin, Central Facility for Electron Microscopy, RWTH Aachen University, Aachen, Germany

White Etching Cracks (WEC) are currently discussed as a common cause for premature failure of roller bearings in various applications. The formation mechanism of WEC is still under debate in published literature however it is emphasised that varying additional loadings, like electrical current or hydrogen, have an amplifying effect on the formation of WEC. In this work, the formation of WEC under the influence of electrical current was investigated. The testing was conducted on a four-wheel test rig using rollers made from the steel SAE 52100. These rollers were tested utilizing different electrical polarities, current intensities and slide roll ratios with the objective to obtain thresholds for WEC formation for the varied testing parameters. Detailed microstructure analysis using SEM, EBSD and TEM have been conducted, to investigate the effect of electrical current, polarization and slide roll ratio on the WEC damage pattern.

5:00 - 5:30 pm
The Influence of Material Properties and Steel Cleanliness on the Formation of Subsurface Cracking Failures Associated with Microstructural Alterations.
Benjamin Gould, Aaron Greco, Nicholaos Demas, Argonne National Laboratory, Argonne, IL

White etching cracks (WECs) have been identified as a dominant mode of premature failure within wind turbine gearbox bearings. Though WECs have been reported in the field for over a decade, the conditions leading to this failure, and the process by which this failure culminates, are both highly debated. Because of this, the development of benchtop tests capable of accurately recreating these failures at an accelerated rate are difficult to come by. Recent work has identified inclusions containing both an aluminum oxide component as well as a manganese sulfide component as preferential initiators of these failures. These inclusions are prevalent in larger bearings but sparse in standard benchtop test samples. The present work investigates the formation of WECs using special samples manufactured from a WT bearing, and shows the cleanliness of the test specimen plays a drastic role in the formation of these failures.

5:30 - 6:00 pm
Structure Change of Cementite just below the Sliding Surface on Ball Bearings
Kenji Matsumoto, Honda R & D Co.,Ltd , Haga-gun, Tochigi, Japan, Naoaki Yoshida, Kyushu University, Kasuga, Fukuoka, Japan

Many ball bearings have widely been made with SUJ2 (high carbon chromium bearing steel). The material maintains its hardness by the precipitation of cementite. By the observation of the subsurface below rotating race using TEM (transmission electron microscope), we found the distortion and the fracture of cementite bands after the bearing operation under the half of the dynamic load capacity. The damaged cementite bands were cracked easily and consequently expected to promote wear. Because the phenomenon greatly affects bearing life, we would like to report and discuss these TEM images.

6:00 - 6:30 pm
Analysis of Material Defects in Relation to Different Damage Mechanisms
Joerg Binderszewsky, Toni Blass, Wolfram Kruhoeffer, Joerg Loos, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

The influence of material defects on rolling contact fatigue has been investigated in numerous experimental and analytical examinations. However, the impact of inclusions on different damage mechanisms is still a controversial issue. An analytical evaluation of defects can be executed by means of a finite element analysis (FEA) of idealized inclusions or with fracture mechanical methods. The multiaxial stress state, and depending on the desired accuracy, microstructural effects, plasticity, soften- or hardening, local residual stresses, and more can be considered. In a fracture mechanical analysis, the consideration of crack closure effects, as well as appropriate models for crack growth are challenging. Different analysis models are presented and results are compared with the rating life calculation according to ISO 281, that has been proven for many years. Finally, results are discussed in the context of different damage mechanisms.

6:30 - 7:00 pm - **REB Business Meeting**

6B Music Row 1

Biotribology I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Cartilage Lubrication: Why Everything I Thought I Knew is Wrong…
Itai Cohen, Cornell University, Ithaca, NY

We've all heard the story: articular cartilage provides some of the lowest friction coefficients in nature. This lubrication arises from a meshwork of lubricin, hyaluronic acid, and aggrecans that trap water

solvation layers that act as ball bearings and allow for slippage. This picture, while heavily promoted, is wrong. In this talk, I will show that when compressed, so that water in the tissue is squeezed out, cartilage friction coefficients are quite ordinary, comparable to an oiled block of wood. The amazing “lubrication” properties of cartilage only arise when the tissue extracellular matrix is hydrated and the interface is mostly water. This transition from the compressed boundary mode to hydrated lubrication mode can be understood via a modified Stribeck curve framework. I will use this framework to describe the biological consequences of these lubrication modalities on cartilage cells and some recent work indicating the potential to change cell fate after trauma.

2:00 - 2:30 pm
Cartilage Fluid Load Support in the Migrating Contact Area: How Much Migration Is Necessary?
Jamie Benson, David Burris, University of Delaware, Newark, DE

The accepted hypothesis for cartilage interstitial fluid load support under joint loading is that contact migration leaves insufficient time for fluid exudation. However, it’s also evident that the benefits of migration dissipate as range of motion approaches contact length. This study quantifies the coupled effects of migration length, probe radius, normal force, and contact stress on cartilage fluid load support. Testing was performed on cartilage plugs using varied probe sizes, loads and track lengths. Fluid load support depended primarily on migration length per unit contact length (S*) and maintained a maximal magnitude (F*=100%) at S*>10. At S*<10, it varied as a sigmoidal function falling to F*=50% by S*»0.1. This transition migration length (F*=50%), was independent of probe and increased slightly with load. Given the relatively short tracks (S*~1) and high stresses in the joint (sigma~0.5-5MPa), this suggests that migration contributes less to fluid load support than expected.

2:30 - 3:00 pm
Rate-Dependent Cartilage Adhesion Derived from Poroviscoelastic Relaxations
Guebum Han, Corinne Henak, Melih Eriten, University of Wisconsin Madison, Madison, WI

This study aims to examine mechanisms underlying rate-dependent adhesion in cartilage. Adhesion tests were conducted on cartilage at different unloading rates. Pull-off forces and work of adhesion increased with increasing loading rate. Rate-dependent pull-off forces correlated with poroviscoelastic (PVE) relaxation response of cartilage. Viscoelastic, poroelastic, and PVE finite element (FE) models were developed to understand mechanisms of rate-dependent adhesion. FE-predicted adhesive response had a similar trend to the experiments for PVE models only. The correlation between rate-dependent pull-off forces and load relaxation response indicated that PVE relaxations had a pronounced effect on cartilage adhesion. FE-predicted results suggested that PVE was essential in the fluid pressure build-up within the contact area, which lead to rate-dependent pull-off forces. These findings provide new insight into stick-induced damage and frictional response of cartilage.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Quantifying Adhesion in Articular Cartilage
Jamie Benson, David Burris, University of Delaware, Newark, DE

The primary function of cartilage is to support varying loads while sustaining joint lubrication. Its unique ability to balance low friction under heavy loads has been studied extensively over the past decade. Yet, there remains a lack of research into the adhesive properties of cartilage. This study directly quantifies the relationship between works of adhesion and indentation depth, and probe size. Micro-indentation testing was performed on N=5, 19mm diameter osteochondral plugs under varied indentation depths (5, 50, 500mm) and probe sizes (diameter: 6.4, 3.9, 2.4mm) and we found that works of adhesion increased with increasing indentation depths and increasing probe sizes. We measured an effective work of adhesion to be 4600 mJ/m^2—two orders of magnitude larger than rubber against glass (70 mJ/m^2). These findings fill a significant gap in our understanding of cartilage and the functional implications adhesion has in contact mechanics.

4:00 - 4:30 pm
Elegant Shadow Making Tiny Force Visible and Measurable
Hongyu Lu, Tsinghua University, Beijing, China, Yelong Zheng, Tianjin University, Tianjin, China, Wei Yin, Yonggang Meng, Yu Tian, Tsinghua University, Beijing, China

Forces acted on legs of water-walking arthropods with weights in dynes are of great interest for entomologist, physicists, and engineers. While their floating mechanism has been recognized, the in vivo leg forces stationary have not yet been simultaneously achieved. In this study, their elegant bright-edged leg shadows are used to make the tiny forces visible and measurable based on the updated Archimedes' principle. This study also demonstrated the feasibility of a simple method to visually measure the force applied on the top surface of this circular plate by using its shadow image. With an ordinary camera to monitor the shadow, a simple circular plate device could realize a force resolution of up to 10 nN. The force measuring range and sensitivity can be easily extended by changing the radius of the circular plate. The shadow method could be conveniently developed into a novel tiny force measurement apparatus.

4:30 - 5:00 pm - **Biotribology Business Meeting**

6C Music Row 5

Commercial Marketing Forum VI

1:30 - 2:00 pm - **SEQENS**

2:00 - 2:30 pm - **Biosynthetic Technologies**

2:30 - 3:00 pm - **Bruker**

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
AMRRI: IIoT Meets Tribology: LubeCoach Pro 5.0
Mike Johnson, Advanced Machine Reliability Resources, Inc., Franklin, TN

Building accurate, thorough & effective machine lubrication work plans has previously required the time & attention of skilled lubrication engineers. With the erosion of this skill set the lubricant supply community finds itself needing to satisfy customer needs with low-experience personnel (which creates liability posibilities), or asking customers to wait, neither of which is appealing. LubeCoach Pro is a solution to this problem. LubeCoach Pro provides the entry level and the experienced technical specialist with the means to accurately, thoroughly, rapidly, and succinctly create detailed machine lubricaiton work plans that will deliver superior results. The plan is customized to the production environment and the supplier product array to deliver a comprehensive and functional solution. Suppliers will be able to deliver engineering work in half the previously required time, and with uniform consistency between service personnel, and customized to vendor product preferences.

4:00 - 4:30 pm - **Clariant**

4:30 - 5:00 pm - **Sasol Performance Chemicals**

6D Music Row 4

Joint STLE/CTI Symposium on Frontiers of Tribology Research II: Lubricant and Chemistry

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Session Chair: Y. Meng, Tsinghua University, Beijing, ChinaQ. Wang, Mechanical Engineerig, Northwestern University, Evanston, IL

1:30 - 2:00 pm - **Weimin Lu - Molecular Science and Engineering Application of High Performance Lubricants**

2:00 - 2:30 pm - **Seong Han Kim - Tribochemistry - Myths and Facts**

2:30 - 3:00 pm
Boundary Lubrication of Polar Molecule in Aqueous Solutions under Electric Field
Yonggang Meng, Jun Zhang, Tsinghua University, Beijing, China

Aqueous lubrication is basic in biosystems and also widely used in industry. When some kinds of lubricious polar molecule, such as surfactants, are solved in water, the polar constituents can be adsorbed into an adsorption boundary film on sliding contact surfaces, the structure of which depends on the properties and the electrical potential of the solid surfaces. Previous studies have shown that the boundary lubrication performance of the adsorption film can be reversibly modulated by an externally applied electric field. In this study, atomic force microscopy (AFM) was used to characterize the changes in film structure, adhesion and friction of the adsorption film under different external electric fields. Moreover, a continuous multiscale model was developed to analyze the surface redox reactions and microscopic double layer structure at the aqueous solution/metal interface.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Tribological and Electric Properties of C/Cu Pairs under Dynamic Contact during Current-Carrying Sliding
Yongzhen Zhang, Feng Ni, Chenfei Song, Yanyan Zhang, Zhenghai Yang, Bao Shangguan, Henan University of Science and Technology, Luoyang, Henan, China

Contact force between C pantograph and Cu contact wire presents periodic variation, which can be described by $70+B \sin(2\pi ft)$. The amplitude B and frequency f of the dynamic contact force increased during speeding up, and the inflection of friction coefficient and wear rate was observed. The arcing rate increased with f and B, which led to the decrease of current-carrying quality. When the arcing rate was lower than 2%, the pure carbon strip was able to maintain its excellent current-carrying capability, if not, the current-carrying quality deteriorated abruptly. Meanwhile, the wear mechanism transferred from mechanical wear to arc erosion with the increase of the arcing rate. These results show a deeper understanding of the damage to a pantograph/catenary system subjected to dynamic contact force, and will be beneficial for the safe operation of high-speed railway.

4:00 - 4:30 pm - **Ashlie Martini - Tribochemical Reaction Pathways Explored with Reactive Atomistic Simulations**

4:30 - 5:00 pm
Integrated Biomechanics and Biotribology of Artificial Joints
Zhongmin Jin, Southwest Jiaotong University, Chengdu, China

Tribological considerations have improved the materials selection and design of the bearing surfaces of artificial joints and consequently extended the clinical life-time of the prostheses. However it has become increasingly recognised that tribological considerations alone may be limited to further improve the clinical performance of artificial joints and biomechanical considerations may also be necessary. Biomechanical considerations not only provide the load and motion inputs required for the tribological studies, but also tribological considerations may affect the biomechanical predictions. Such an integrated approach is able to consider the implants as well as the patients and the surgeons. The purpose of this presentation is to review the current literature and to highlight the integrated biomechanical and biotribological studies of

artificial hip and knee joints.

5:00 - 5:30 pm - **Robert Carpick - Fundatmental Insights into Adhesion, Friction and Wear Through Nanoscale Contact Experiments**

5:30 - 6:00 pm - **Zhendong Da - Bio-inspired Adhesive Technology: From Biology to Engineering**

6E Music Row 3

Tribochemistry - Materials Tribology and Nanotribology Joint Session I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
The Effect of TiO_2 Nanoparticle Addition to the Tribological Performance of MoDTC-Containing Lubricants
Fabrice Dassenoy, Pushkar Deshpande, Clotilde Minfray, Ecole Centrale de Lyon, Ecully, France, Istvan Jenei, University of Stockholm, Stockholm, Sweden, Thierry Le Mogne, Ecole Centrale de Lyon, Ecully, France, Benoit Thiebaut, TOTAL, Solaize, France

Nanoparticles as lubricant additives have been widely investigated in recent years. Lamellar structured nanoparticles like MoS_2 or WS_2 show the most remarkable friction modifier properties. Ceramic oxides nanoparticles like TiO_2, ZrO_2, Al_2O_3, have also been studied for their tribological properties and were found to be good in friction or wear reduction. However, interactions between the nanoparticles and other lubricant additives can lead to either exacerbated properties or lower lubricant performance. The aim of this work was to study the consequences of the addition of TiO_2 nanoparticles on the tribological properties of a lubricant containing MoDTC. Significant reduction in friction coefficient and wear was observed when TiO_2 nanoparticles were blended with MoDTC compared to MoDTC alone. A thorough characterization of the tribofilms was carried out in order to understand the mechanisms of friction reduction.

2:00 - 2:30 pm
One-Pot Synthesis of Serpentine@Polymer Nanoparticles with Outstanding Anti-Wear Property
Qiuying Chang, Hao Zhang, Beijing jiaotong University, Beijing, China, Pavlo Rudenko, Tribotex, Colfax, WA
Core-shell nanoparticles (NP) of Serpentine@polymer were synthesized hydrothermally. The synthetic conditions of duration, temperature and gelatin concentration were examined to screen the optimized NP in term of tribological property. The characterization of the NPs was conducted with Scanning Electronic Microscopy (SEM), High Resolution Transmission Electronic Microscopy (HRTEM), X-Ray Diffractometer (XRD), Fourier Transform Infra Red spectrometer (FTIR) and X-Ray photoelectron spectroscopy (XPS). The anti-wear property of the resultant NPs as Extreme Pressure (EP) lubricant additive was carried out with a four-ball tribometer. The results showed novel EP additive exhibited remarkable anti-wear performance under extreme pressure conditions with formation of distinct boundary tribofilm. This materials offer possibility of formulating industrial lubricants without Sulphur and Phosphorus where restrictive limits are often imposed.

2:30 - 3:00 pm
A Stress-Activated Model for Tribofilm Growth Based on a Nanoparticle Sintering Mechanism
Allen Comfort, Steven Thrush, US Army TARDEC, Warren, MI

A model for the macroscale growth of zirconium oxide tribofilms formed by a mechanism of nanoparticle capture and sintering in the contact region was developed. The model combines a stress-activated

Arrhenius growth equation and a simple Archard wear equation to predict the evolution and steady-state thickness of the tribofilm. In particular, the proposed model successfully predicts the self-limiting behavior observable in the experimental data. The model was parameterized using experimental data obtained from a ball-on-disc tribometer where the tribofilm thickness was tracked in-situ at set intervals. The fluid tested was a colloidal solution of spherical, 10 nanometer diameter, zirconium oxide nanoparticles dispersed in a polyalphaolefin synthetic base oil. If the proposed mechanism and model are correct, it represents another example of the application of transition state theory to lubrication.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Tribochemistry of Ultralow Wear PTFE-Based Composites: Assessing the Role of the Sliding Environment
Kasey Campbell, Cooper Atkinson, Lehigh University , Bethlehem, PA, Tomas Babuska, Lehigh University, Bethlehem, PA, Brantley Balsamo, Lehigh University , Bethlehem, PA, Mark Sidebottom, Miami University, Oxford, OH, Christopher Junk, Brandon Krick, Lehigh University , Bethlehem, PA

The friction and wear properties of polytetrafluoroethylene (PTFE) (K~ 5 x 10^{-4} mm^3/Nm) have been studied well over a decade. It has been shown that adding fillers such as α- alumina and polyether ether ketone (PEEK) can greatly improve the wear rate of the unfilled PTFE up to four orders of magnitude (K~1-5x10-^{8}mm^3/Nm). This observation is attributed to the formation of a robust transfer film created by bonds formed by carboxylate end groups that bond to the counter sample and fillers. This behavior has been observed in ambient (humidity controlled), dry nitrogen and high vacuum conditions and has further supported the need for water to be present. Yet, when these composites are submerged in water, the wear rate is drastically increased, and the composite wears comparably to the unfilled material. To further assess the wear mechanism of the composite, it will be submerged in oil. SEM, XPS, and FTIR was used to understand and probe any chemical alterations during oil submersion.

4:00 - 4:30 pm
Nanomechanics of Ultralow Wear PTFE-Based Composites: Microstructure and Mechanics of Filler Particles

Cooper Atkinson, Lehigh University, Allentown, PA, Mark Sidebottom, Miami University, Oxford, OH, Tomas Babuska, Tomas Grejtak, Brantley Balsamo, Kasey Campbell, Brandon Krick, Christopher Junk, Lehigh University, Bethlehem, PA, Heidi Burch, Du Pont Company, Wilmington, DE

Fluoropolymers including polytetrafluoroethylene (PTFE) and perfluoroalkoxy polymer (PFA) are often used due to their thermal and chemical resistance, as well as their low friction coefficient. The high wear rate of fluoropolymers has been reduced by ~10,000 times through the addition of porous, micron-sized alumina particles. The success of alumina as a filler material motivated the experimentation of other micron-sized oxide, ceramic and metal fillers in low concentrations (1-10 wt %). The role of the mechanical properties of the particles was evaluated through nanomechanical testing, wear testing and microstructural characterization. It was determined that, in addition to tribochemistry, the wear performance relies on the mechanical properties and structure of the filler particles. Additionally, the polymers were tested over a broadened pressure and velocity range, contributing to a more complete understanding of the wear reduction mechanisms in ultralow wear fluoropolymer systems.

4:30 - 5:00 pm
Promotion of Ultralow-Wear Fluoropolymer-Metal-Oxide Composites through Tribochemistry
Mark Sidebottom, Miami University, Oxford, OH, Christopher Junk, Lehigh University, Bethlehem, PA, Holly Salerno, Heidi Burch, Gregory Blackman, DuPont Company, Wilmington, DE, Tomas Babuska, Kasey Campbell, Cooper Atkinson, Brandon Krick, Lehigh University, Bethlehem, PA

Composites of nanostructured-metal oxide particles (e.g. alumina) and polytetrafluoroethylene (PTFE) have exhibited wear rates 10,000x lower than unfilled PTFE. This reduction in wear is attributed to the tribochemical reinforcement of the composite surface and the development of a thin, robust transfer film

on the countersurface. Recently, the tribochemical framework of the ultralow PTFE alumina composites has been extended to Perfluoroalkoxy Polymer (PFA), a melt processible fluoropolymer. The increased ease of manufacturing of PFA-alumina composites may lead to easier incorporation into current bearing and seal applications. Through designed experimentation and materials characterization techniques, a number of factors were identified that can affect wear of these composites by two or more orders of magnitude. These influencing factors include testing environment and hardness of metal-oxide filler particles, which can inhibit the ultralow wear mechanism of these composites.

5:00 - 5:30 pm
Clarifying Transfer Film Effects by Removing Them
Istiaque Alam, David Burris, University of Delaware, Newark, DE

The fact that tribological performance correlates strongly to transfer film morphology is interpreted either as evidence that high quality transfer films cause low friction and wear or evidence that low friction and low wear sliding causes high quality transfer films. This work aimed to elucidate this causal relationship for a particularly well-studied material family by eliminating its transfer film. Alumina-PTFE composites were subjected to indexed reciprocation to eliminate the transfer film; standard reciprocation was used as a control. Three distinct alumina fillers known to produce low wear, moderate wear, and high wear when added to PTFE were used to gain insight into how each affects debris creation, debris size, counterface abrasion, transfer film morphology, tribochemistry, and other attributes of interest. Given the orders of magnitude differences in the wear rates reported for these materials, we observed surprising similarities.

5:30 - 6:00 pm
Ultra-Low Wear of PEALD Nitride Thin Films
Tomas Babuska, Lehigh University, Bethlehem, PA, Nicholas Strandwitz, Lehigh University , Bethlehem, PA, Mark Sowa, Veeco CNT, Boston, MA, Alexander Kozen, Navy Research Lab, Washington DC, MD, Guosong Zeng, lawrence berkeley national laboratory, Berkeley, CA, Brandon Krick, Lehigh University, Bethlehem, PA

Typical commercial nitride films such as TiN are deposited using PVD techniques such as magnetron sputtering. Recently, plasma enhanced atomic layer deposited TiN, VNand TiVN thin films have shown interesting tribological behavior and superb performance over their traditional PVD counterparts; in one instance, low friction (μ~0.16) and ultralow wear rates (K ~ 2x10-9 mm3/Nm and less) were measured in TixV1-xN thin films that are electrically conductive. These materials exhibit wear rates approaching those of diamond but are deposited in a low deposition temperature, conformal plasma-ALD process, and are thus highly promising for a wide array of industrial applications that require low thermal budget in microelectronics, MEMS/NEMS, biomedical implants, aerospace components and consumer products. The highly controlled thickness and conformality of the ALD process is useful for systems that require tight dimensional tolerances and complex surfaces (MEMS/NEMS, implants).

6:00 - 6:30 pm
Friction and Oxidation of MoS2 In Low Earth Orbit: Results from the Space Tribometers
Brandon Krick, Lehigh University, Bethlehem, PA, John Curry, Sandia National Laboratory, Albuquerque, NM, Tomas Babuska, Lehigh University, Bethlehem, PA, Christopher Muratore, University of Dayton, Dayton, OH, Michael Dugger, Sandia National Laboratories, Albuquerque, NM, Nicolas Argibay, Somuri Prasad, Sandia National Laboratory, Albuquerque, NM, Andrey Voevodin, University of North Texas, Denton, TX, John Jones, Air Force Research Laboratory, Dayton, OH, WG Sawyer, University of Florida, Gainesville, FL

Nearly 8 years ago, eight tribometers returned from their journey in low earth orbit. Of the eight samples, half were MoS2-based coatings. On orbit friction data suggests significant impacts of atomic oxygen on their tribological performance. Postflight characterization and tribology experiments confirms the detrimental effects of atomic oxygen. Detailed studies of microstructure and surface chemistry of various MoS2 coatings provides a promising outlook in ways to address oxidation of MoS2 composites.

Synthetics & Hydraulics Lubricants II

Session Chair: L. Huffman, Dow Chemica,
Session Vice Chair: R. Davidson, Afton Chemical

1:30 - 2:00 pm
Synthesis of Dibenzyl Toluene as Heat Transfer Fluid
Peng Li, Zhongguo Liu, Daxin Sun, Chaoliang Wei, Chao Yang, Xianzhen Gao, Yanbo Zheng, Dalian Lubricating Oil Research and Development Institute, Dalian, Liaoning, China

Dibenzyl toluene is a synthetic heat transfer fluid and safety for the people and environment because of its chemical composition. SO_4^{2-}/TiO_2solid super acid was using as a catalyst for the synthesis of dibenzyl toluene, which is an environmentally benign process when solid acid catalyst was used. The conversion of benzyl chloride is 99.0%. The final product was further separated by molecular distillation and further characterized using GC, IR, TG and NMR compared with market product. The results show that the dibenzyl toluene exhibit much better thermal stability, which would be applied to the operations requiring high temperature heating.

2:00 - 2:30 pm
A New Group V Base Oil for Low Viscosity Engine Oil
Yaokun Han, Dow Chemical, Shanghai, China

A continued move to lower viscosity lubricants is becoming a trend in the development of modern automotive lubricants. Lower viscosity lubricants are known to contribute to improved fuel economy benefits. However, it is well known that lower viscosity base oils of the same chemical family are normally more volatile with lower viscosity index. Low viscosity base oils which have both a high viscosity index and a low NOACK volatility are highly desired but also a great technical challenge. A new series oil soluble polyalkylene glycols were designed and developed to combat this challenge. These new group V base oils exhibited performance benefits of high VI, good lubricity, low temperature viscosity and Noack volatilities at low viscosity.

2:30 - 3:00 pm
Naphthenic Base Oils for High Performance, High Viscosity Index Hydraulic Fluids Applications
Thomas Norrby, Jinxia Li, Nynas AB, Nynashamn, Sweden

In this follow-up of last year's STLE paper, we show how Naphthenic speciality wax-free base oils bring value to Hydraulic fluid formulations for low temperature application in aviation and mobile applications. Wax-free NSP are a good starting point, as the low viscosity naphthenic base oils have pour point and kinematic viscosity rivalled only by PAO, but brings much higher solvency, supporting high VI Improver additive treat rate, and are available at a small fraction of the cost of other base fluids. Typical aviation hydraulic fluid formulations would have a low starting base oil viscosity, e.g. a KV @ -54 °C of 400 cSt, combined with high treat rates of VII yielding final fluid VI in the range of 250 to 400, and with a KV @ -54 °C of less than 3000 cSt, meeting e.g. Defence Standard 91-48/2. Other outdoor and mobile hydraulic applications utilize VG 15, 22 and 32, which in a similar fashion can be made from low viscosity base oils and appropriate VI Improvers.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Performance and Implemenation of Perfluoropolyether (PFPE) Lubricants

Joanna Dawczyk, Janet Wong, Imperial College London, London, United Kingdom

Perfluororpolyethers (PFPEs) are a group of fluorinated synthetic fluids which find use as high-performance lubricants owing to their exceptional thermo-oxidative stability. Their high viscosity index (VI), low vapour pressure together with high oxidative stability has facilitated the application of PFPE as a lubricant in aerospace, vacuum pumps and gas turbines. Despite their outstanding properties, PFPEs failed to provide adequate protection of plain roller bearings, which are used in widely used high vacuum pumps. The current research aims to better understand the cause of this failure by making fundamental studies of PFPE performance in both EHD and mixed lubrication conditions. Potential methods of delaying bearing failure are investigated, including the incorporation of additives.

4:00 - 4:30 pm
Thermodynamic Characterization of Base Oil Viscosity and Vapor Pressure
Tom Karis, TEK Data Systems, Aromas, CA, Raj Shah, Koehler Instrument Company, Inc., Holtsville, NY

The goal of this work is to investigate the molecular parameters governing the vapor pressure and viscosity of base oils. Kinetic rate theory is employed to extract the activation free energy from the vapor pressure and viscosity vs. temperature data for synthetic hydrocarbon base oils with a range of molecular weight, polarity, and isomerism. Thermodynamic properties are derived from the slope and intercept of the Arrhenius plot for vapor pressure and viscosity. The slope provides the activation energy, and the intercept provides the activation entropy. Decreasing the viscosity without increasing the vapor pressure should be possible by increasing the flow activation entropy without increasing the vaporization activation entropy. However, it is still not clear exactly how molecular structure and composition changes can accomplish this optimization. We discuss the feasibility of applying non-equilibrium molecular dynamics to calculate the flow activation entropy.

4:30 - 5:00 pm - **Synthetics and Hydraulics Business Meeting**

6G Cumberland 1/2

Engine & Drive Train IV: Advanced fuel-efficiency engine and drivetrain hardware technologies

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Session Chair: TBD
Session Vice Chair: TBD

1:30 - 1:30 pm - **Session Description**

1:30 - 2:00 pm - **Arun Solomon - Combustion Technologies for High-Efficiency Light-Duty Automotive Engines**

2:00 - 2:30 pm
Next Generation Wet Friction Technologies for Improving Drivetrain Efficiency
Feng Dong, BorgWarner, Inc., Auburn Hills, MI

Recent automotive transmission designs have been more focused on improving efficiency, shift quality and NVH characteristics due to the stringent emissions and fuel economy regulations. Various transmission types include 8, 9 even 10 speed automatic transmissions, DCT and hybrid drivetrain have been developed to meet customer and government requirements. Wet friction clutch has been identified as one of the key areas affecting automotive drivetrain efficiency. In this presentation we will discuss different approaches to improve wet friction clutch efficiency including new friction material technology, friction plate and clutch pack design, and modeling.

2:30 - 3:00 pm
Tribological Challenges of Advanced Engine Technologies

Peter Lee, Southwest Research Institute, San Antonio, TX

As vehicle manufacturers work towards meeting ever stringent environmental controls and improved fuel economy, advanced engine technologies become increasingly important. Such technologies include combustion strategies, variable compression and valve timing, lighter materials, increased fuel line pressures, increasingly complex air handling, stop-start and hybridization. All these have effects on the lubrication, friction and wear of these advanced engines. This presentation will explore the tribological challenges and benefits of using various advanced engine technologies.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Modifications of Ferrous Based Thermal Spray Coatings for Improved Tribological System Performance
Paulo Rosa, Comau, Southfield, MI

In the development of increasingly higher efficiencies in powertrain, development engineers have had to make decisions balancing structural weight and tribological requirements. Adaptation of coatings in these systems has enabled the designs to become lighter and better tribologically. As such, new trend in powertrain is replacement of cast iron liners with thermal spray coatings on parent bores. Significantly this has created an alternative to the traditional wear insert approach with its inherent thermal and weight inefficiencies, now a PTWA coating reduces surface temperatures and its morphology changes the tribology system. Comau has been developing and working with partners in expanding this, by leveraging the finish coating process and feedstock modifying the coatings composition and both structural and metallurgical morphology. We will demonstrate such modifications and how they enhance the friction and wear performance beyond known values for typical ferrous based feedstock.

4:00 - 4:30 pm - **Open Discussion**

4:30 - 5:30 pm - **Engine and Drive Train Business Meeting**

6H Cumberland 3

Nanotribology VI

Session Chair: K. Mutyala, Center for Nanoscale Materials, Argonne National Laboratory, Lemont, IL
Session Vice Chair: Z. Chen, Penn State University, State College, PA

1:30 - 2:00 pm
In-Situ Tribofilm Growth Study of a Mechanical Sintering Nanoparticle Antiwear Additive
Steven Thrush, Allen Comfort, US Army, Warren, MI

A research effort was conducted to investigate tribofilm formation mechanisms of a novel nanoparticle antiwear additive. Spherical 10 nanometer diameter zirconium oxide nanoparticles were dispersed in polyalphaolefin synthetic base oil and tested between AISI 52100 steel counterfaces in a ball on flat tribometer with a slide to roll ratio of 50%. The apparatus allowed tribofilm thickness data to be tracked in-situ at set intervals. Tribofilms reaching a maximum film thickness of ~150 nanometers were measured. A previous study investigated nanoparticle concentration, which was expanded to include temperature and load to further understand parameters affecting tribofilm generation. Contrary to the chemical tribofilm formation processes of traditional antiwear additives like zinc dialkyldithiophosphate, testing suggests the primary mechanism of tribofilm growth for zirconium oxide is nanoparticle adsorption followed by particle accumulation and sintering.

2:00 - 2:30 pm
Tribological Behavior of Plasma Functionalized ZnO Nano-Additives
Kimaya Vyavhare, Pranesh Aswath, UTA-Materials Science and Engineering, Arlington, TX, Ali Erdemir, Argonne National Lab, Lemont, IL

An innovative approach of coating ZnO nanoparticles through plasma polymerization was employed to ensure dispersion and delivery of beneficiary chemical species to tribological contacts. A rotary plasma reactor was used to encapsulate ZnO nanoparticles with methacrylate and boron rich plasma coatings. Tribological behavior of these nano-additives with and without ZDDP was examined using cylinder on flat reciprocating test setup. In situ electrical contact resistance measurements were recorded to understand dynamics of tribofilm formation with these functionalized ZnO nano-additives. Additionally, surface analysis techniques like XPS and XANES were used to elucidate chemical makeup of the tribofilms formed at rubbing surfaces. Experimental results suggests that coated ZnO nanoparticles contribute to enhance antifriction and antiwear performance compare to uncoated ones, when used by themselves or in a mixture with ZDDP.

2:30 - 3:00 pm
In-Situ SEM Nanomechanical Characterization of Tribofilms Derived from Inorganic Nanoparticles
Kora Farokhzadeh, Praveena Manimunda, Joseph Lefebvre, Syed-Asif Syed-Amanulla, Steven Shaffer, Bruker Nano Surfaces, San Jose, CA

Nanoparticles are introduced in lubricants due to their ability to augment load bearing capacity and maintain low friction in boundary lubrication regime. To implement model lubricants on larger scales, it is essential to gain detailed understanding of the mechanisms of lubrication and tribofilm formation in mixed or boundary lubrication regimes. In this study, base oil with suspended MoS_2, ZrO_2 and CeO_2 nanoparticles were used to lubricate steel-steel interfaces. The tribofilms generated during pin-on-disk experiments were characterized using in-situ SEM nanomechanical testing instrument. In-situ SEM nanoScratch tests revealed the adhesion strength as well as shear characteristics of tribofilms. Further, the nanoparticles were tested in combination with fully formulated engine oil, to understand the effect of conventional additives on tribofilm characteristics. Combination of in-situ SEM and macro-scale tribological tests revealed the interfacial phenomena at different length scales.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Dislocations Associated with Stick-Slip Friction of Lubricants in Boundary Lubrication
Rong-Guang Xu, Yongsheng Leng, George Washington University, Washington, DC

Improved understanding of squeezing and friction behaviors of lubricant films under extreme confinement at nanometer scales can lead to strategies for preventing surface failure and efficient energy usage. Shearing of a solidified simple nonpolar film under nanoconfinement is studied by using a liquid-vapor molecular dynamics simulation method. We find that, in contrast with the shear melting and recrystallization behavior of the solidlike phase during the stick-slip motion, interlayer slips within the film and wall slips at the wall-film interface are often observed. The ordered solidified film is well maintained during the slip. However, repeated film dilation and collapse of the lubricant film during the stick-slip friction are observed, which is associated with the nucleation, propagation and annihilation of dislocations found in the solidlike film. These novel observations may provide new insights into the mechanical behaviors of lubricant films and thus improved lubricant design.

4:00 - 4:30 pm
PEI-RGO Nanosheets as a Nanoadditive for Enhancing the Tribological Properties of Water-Based Lubricants
Chengcheng Liu, Deguo Wang, Yanbao Guo, China University of Petroleum-Beijing, Beijing, China

In order to enhance dispersion of graphene in water and obtain high effective water-based lubrication

nanoadditives, polyethylenimine-reduced graphene oxide (PEI-RGO) nanosheets were synthesized via an improved Hummer's method and water bath method. The physical and chemical properties of the product were characterized using FTIR, Raman spectroscopy, SEM and TEM. PEI-RGO nanosheets had an excellent dispersibility and stability as a nanoadditive for water-based lubricants. The steel-steel ball-plate tribotest results revealed that the lubrication properties of water-based lubricant significantly improved by adding PEI-RGO nanosheets. Compared with pure deionized water, the friction coefficient and wear rate had 52.3% and 43.4% reduction respectively when the content of PEI-RGO in water was 0.05 wt%. The graphene adsorption occurred on the wear surfaces of steel plate suggested PEI-RGO nanosheets formed a lubricating layer, thus leading to the superior tribological properties.

4:30 - 5:00 pm
Study on the Quantitative Evaluation of the Surface Force Using a Scanning Probe Microscope
Wataru Yagi, Tomomi Honda, University of Fukui, Fukui, Japan, Kazushi Tamura, Idemitsu Kosan Co., Ltd., Ichihara, Japan

There are two types of friction modifiers (FMs) used as lubricant additives: Reaction film FMs (RF-FMs) and adsorption film FMs (AF-FMs). While RF-FMs provide good performance in severe condition, AF-FMs excels in mild condition. These empirical evidences lead us to combining these two FMs to cover broader condition. However, the effects of their combination are highly complicated due to the interaction between these FMs. If the interaction force of AF-FMs with various materials can be evaluated, it would help us to improve tribological performances of lubricants. Although a scanning probe microscope (SPM) seems suitable for this application, we found some obstacles to achieve proper measurements of pull-off force due to static electricity, laser position, sample deformation and so on. In this study, we thoroughly investigated those effects on pull-off force quantitatively. We will propose a calibration method of an SPM and present some important aspects of the forces acting on AF-FMs.

5:00 – 5:30 pm
The Molecular Arrangement and Frictional Response of Sams of a Planar Phthalocyanine Molecule
Yijun Qiao, Yuhong Liu, Tsinghua University, Beijing, China

The researches on molecular arrangement of Self-assembled monolayers(SAMs) are the demand of novel lubricants in micro world, such as in Micro-Electro-Mechanical System. It also promotes the understanding of mechanism of friction energy dissipation. A phthalocyanine derivative, which has a planar structure, formed SAMs with four kinds of molecular arrangement. A growth model of the SAMs was established. The edge-on arrangements with different orientation angles and face-on arrangement of SAMs were revealed by analyzing the thickness, adhesion and surface potential measured by AFM and KPFM. Friction experiments by Lateral Force Microscopy indicates that the molecular arrangement and deformation of SAMs are closely related to its frictional response. The edge-on SAMs reduce friction by 72%, more efficiently than the face-on ones, comparing with bare substrate. This work helps the understanding of the microscopic friction mechanism based on molecular arrangement and deformation.

5:30 - 6:00 pm - **Nanotribology Business Meeting**

6I Cumberland 4

Surface Engineering II: Additive Manufacturing

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Tribological Behavior of 17-4 PH Stainless Steel Fabricated by Traditional Subtractive and Laser-Based Additive Manufacturing Methods

Sanjeev KC, Auburn University, Auburn, AL

This study investigates if additive manufacturing processes meet the desired mechanical and wear properties of conventionally fabricated wrought counterparts. The wear rate of 17-4 PH SS disks fabricated by both laser powder bed fusion (L-PBF) manufacturing method and conventional processes was compared under dry and lubricated conditions. The results showed difference between lubricated and dry condition for friction and wear for both L-PBF and wrought samples. The conventionally wrought samples tend to have a higher wear rate for dry, but its opposite for the lubricated condition because the lubrication changed the dominant wear mechanism from adhesion to surface fatigue and abrasion. The wear rate for the dry condition showed that the wear rate is dependent on load, where a 30 N load had higher wear rate than 10 N, for both samples. The results showed that additively manufactured parts had good potential to be an alternative to wrought parts in terms of friction and wear behavior.

2:00 - 2:30 pm

Laser Additive Manufacturing of Ni-Al-Cr-C Alloys: A High Temperature Sliding Wear Study

Tyler Torgerson, Srinivas Mantri, Rajarshi Banerjee, Thomas Scharf, The University of North Texas, Denton, TX

Laser Engineered Net Shaping (LENS™) permits the processing of novel, tailored hybrid composites with unique microstructures that are not possible to achieve via conventional melt or solid-state powder techniques. Such novel microstructures include solid solution/precipitation strengthened metallic matrices with a distribution of reinforcing in situ formed hard ceramic and solid lubricant phases. In this study, three such novel composites composed of Ni-18Al-11Cr-9C, Ni-14Al-8Cr-29C, and Ni-12Al-2Cr-45C (in at.%) were processed by LENS™. The dry sliding friction and wear behavior of the composites were studied at room temperature and 500°C to determine the chemical and microstructural evolution during wear. Due to the variation in graphite content in the composites, different microstructures and morphologies of nickel aluminide (γ' phase), chromium carbide and graphite phases were formed during solidification that were determined to affect the mechanical and tribological properties.

2:30 - 3:00 pm

The Effects of Laser Shock Peening on the Fatigue Performance of the 3D-Printed AlSi10Mg Alloy

Hao Zhang, Zhencheng Ren, Ruixia Zhang, Chang Ye, Yalin Dong, University of Akron, Akron, OH

Although rapid solidification during additive manufacturing could introduce refined and homogeneously distributed eutectic silicon phase, which enhances the mechanical properties of AlSi10Mg alloy, it also leads to high tensile residual stress that deteriorates the fatigue properties of the alloy. In this work, laser shock peening (LSP) is applied to process DMLM-processed AlSi10Mg alloy. After LSP process, the surface hardness of the AlSi10Mg alloy increased from 132.8 HV to 144.8 HV. Besides, the tensile residual stress induced by rapid cooling was converted to the compressive residual stress on the top surface. As the result of the hardness increase and residual stress conversion, the rotation bending fatigue life increased to 1.8 times and 2.8 times under the test loads of 100 MPa and 60 MPa, respectively. This study indicates that the fatigue resistance of 3D-printed AlSi10Mg alloy can be tailored by LSP process efficiently.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm

Improving Surface Finish and Wear Resistance of Additive Manufactured Nickel-Titanium by Ultrasonic Nano-Crystal Surface Modification

Chi Ma, The University of Akron, Akron, OH, Mohsen Andani, University of Toledo, Toledo, OH, Haifeng Qin, The University of Akron, Akron, OH, Narges Moghaddam, Hamdy Ibrahim, University of Toledo, Toledo, OH, Zhencheng Ren, Hao Zhang, Gary Doll, Yalin Dong, The University of Akron, Akron, OH, Mohammad Elahinia, University of Toledo, Toledo, OH, Chang Ye, The University of Akron, Akron, OH

Additive manufactured nickel-titanium (NiTi) alloys possess poor surface finish and sub-surface porosity, which leads to disappointing mechanical performance and potential release of toxic element Ni. This

study utilizes ultrasonic nano-crystal surface modification (UNSM) to improve surface finish and harden the surface. With a tungsten carbide tip, UNSM simultaneously impacted and burnished the surface at an ultrasonic frequency (20 kHz). After treatment, the surface roughness was reduced from 12.1 to 9.0 µm and surface porosity was significantly decreased by 10 times. Surface hardness was found to increase from 304 to 408 Hv, corresponding to a 34.2% increase. UNSM swept and burnished the metal surface, pushing roughness peaks towards valleys. Meanwhile, ultrasonic strikes induced compressive residual stress and extensive dislocations. Therefore, improved surface finish, lower porosity and hardened surface layer were achieved, which leads to higher wear and corrosion resistance.

4:00 - 4:30 pm
Increase in Mechanical Properties and Wear Resistance of Selective Laser Melted Stainless Steel 316L by Surface Modification
Auezhan Amanov, Jun-Seok Roh, Young-Sik Pyun, Sun Moon University, Asan, Korea (the Republic of)

This paper presents the microstructure, mechanical properties and wear resistance of stainless steel 316L manufactured by selective laser melting (SLM) method. Stainless steel 316L was treated by ultrasonic nanocrystal surface modification (UNSM) technology. It was found that UNSM technology was able to increase the mechanical properties and to reduce the surface roughness of the as-printed stainless steel 316L that may be attributed to the grain size refinement and elimination of pores from the surface, respectively. Moreover, the friction coefficient of the as-printed stainless steel 316L was reduced and the wear resistance was increased after UNSM treatment. The friction behavior and wear mechanisms were also discussed based on the obtained SEM images of the wear tracks. Results provide an insight on how to improve the mechanical properties, friction and wear behavior of stainless steel 316L manufactured by SLM method by tailoring the microstructure and surface conditions.

4:30 - 5:00 pm
Patterning and Fusion of Alumina Particles on S7 Tool Steel by Pulsed Laser Remelting
Shixuan Chen, Melih Eriten, University of Wisconsin-Madison, Madison, WI

Microscale pulsed laser alters microstructure and finish of thin surface layer through rapid melting and solidification. This study explores its potential to create a composite layer by adding nano/microparticles. In particular, surface of S7 tool steel dip-coated with alumina particles is treated by pulsed laser. Electron microscopy, chemical characterization and scanning wear tests are conducted on the processed surface. Rapid laser pulses are found to redistribute the alumina into patterns aligned with pulse geometry. Super-heating and cooling cycles during each pulse, and heat treatment due to consecutive pulses neighboring a surface patch result in microstructural changes as well as diffuse interface between patterned alumina and steel substrate. Diffuse interface of alumina patterns exhibits more wear-resistance compared to the dip-coated alumina coating. Thus, pulsed laser remelting simultaneously achieves patterning and enhanced-fusion of alumina particles on steel substrates.

5:00 - 5:30 pm - **Surface Engineering Business Meeting**

6J Cumberland 5

Lubrication Fundamentals VI

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Proposals to Improve the Viscosity Index Method, ASTM D2270
Jack Zakarian, JAZTech Consulting, LLC, Orinda, CA

In previous papers the author has shown that the Viscosity Index rating scale (ASTM D2270) suffers from

the following problems: (1) Low viscosity oils are assigned significantly lower VIs than deserved; (2) The 0 VI & 100 VI reference oil series are formed from a patchwork of inconsistent data; (3) The calculation method changes for VI>100 in order to prevent erratic behavior. In this paper, the author proposes new rating methods designed to fix the above problems while retaining those features of the VI scale that are familiar to and desired by users.

2:00 - 2:30 pm
Effects of Oiliness Additives on Lubrication Conditions in Rolling Bearings
Taisuke Maruyama, Masayuki Maeda, NSK Ltd., Fujisawa, Kanagawa, Japan, Ken Nakano, Yokohama National University, Yokohama, Japan

Various studies have been already reported on the effects of oiliness additives (e.g., stearic acid) on tribological performances. However, it has not been clarified the breakdown processes of their boundary films in EHD contacts of practical bearings. In the previous studies, the authors have developed the electrical impedance method which simultaneously measures the thickness and breakdown ratio of oil films in EHD contacts. Besides, it has been confirmed that the method measures the oil film thickness with high accuracy comparable to the optical interferometry, which is applicable to practical bearings. In the present study, the effects of oiliness additives on lubrication condition in rolling bearings have been investigated by the electrical impedance method, especially to clarify the breakdown processes.

2:30 pm - 3:00 pm
Mechanism of ZDDP Boundary Film Formation
Hugh Spikes, Imperial College, London, United Kingdom

ZDDPs (zinc dialkyl- and diaryldithiophosphates) have been used in engine oils as anti-wear and ep additives for more than seventy years and it now seems probable that they will continue in this role for the foreseeable future. However a number of factors suggest that the selection of optimal ZDDP molecular structure is becoming increasingly important. One is the need to reduce phosphorus volatility to meet current engine oil specifications. It has been show that ZDDP molecular structure plays a significant role in determining boundary friction and thus fuel economy. The rate of tribofilm formation by ZDDP is also strongly structure-dependent and if too rapid can lead to micropitting wear. Unfortunately we still know relatively little about the influence of ZDDP molecular structure of ZDDP film formation. This presentation therefore describes new work to explore the impact of molecular structure on the rate and mechanisms of ZDDP tribofilm formation in thin film conditions.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
A Mixed Lubrication Model for Paralleled Plain Faces
Yuechang Wang, Gaolong Zhang, Ying Liu, Tsinghua University, Beijing, Beijing, China

The experimental work of the conformal contacts such as plain face have proved that the flat-on-flat surface can form a hydrodynamic effect under lubricated condition. Limited numerical model have proposed to simulate the lubrication phenomenon. In the present work, we extend some well-developed numerical techniques in the simulation of non-conformal contact surfaces to the conformal contact surfaces. The proposed method is verified by the experimental works of former researchers. Then the effect of the scale of the surface topography on the simulation of the tribologcial performance is studied. The results show that the scale has dramatically influence on the simulation results. Only with proper scale, the simulation can get the results which are matched with the experiments.

4:00 - 4:30 pm
The Investigation of Oil Replenishment in a Rolling Bearing
He Liang, Yu Zhang, Hongbai Chen, Wenzhong Wang, Beijing insititute of Technology, Beijing, China

The formation of EHL film formed between the ball and the ring in a rolling bearing is strongly affected by the oil replenishment into the rolling track following the passage of the preceding balls. This paper directly

observes and measures lubricant films in the rolling track using a custom-made, model ball bearing rig and uses a simulation model to investigate the mechanism of replenishment in a rolling bearing. The contact pressures and rotational speeds employed are commensurate with those present in a real rolling bearing. The results are presented to illustrate the influence of multiple factors including entrainment speed, oil fill level, interval time between passage of adjacent balls, and oil viscosity on oil films in and around the contact.

4:30 - 5:00 pm
Impact of ZDDP Degradation - Influence of Engine Oil Condition on Friction and Wear
Nicole Doerr, Serhiy Budnyk, Andjelka Ristic, Marcella Frauscher, Adam Agocs, AC2T research GmbH, Wiener Neustadt, Austria

Tribochemical behavior of zinc dialkyl dithiophosphate (ZDDP) antiwear additives is a key criterion for engine oil performance and strongly depends on operating and environmental conditions. In order to understand tribochemical mechanisms from the molecular level and their effect on micro/macroscopic tribocontact surface, engine oils collected from passenger cars at different stages of the oil change interval were compared with engine oils artificially altered in the laboratory. The (ZDDP) degradation products were identified by mass spectrometry (MS) to classify the engine oils according to the degree of degradation. Steel surfaces obtained by tribo-experiments with engine oils from the field and the laboratory were analysed by X-ray photoelectron spectroscopy (XPS). Correlations between operating conditions, engine oil conditions, tribolayers, friction and wear were established.

5:00 - 5:30 pm
Influence of Lubricant Additive Chemistry on the Viscosity of Model Base oil Formulations
Sendhil Poornachary, Xin Yi Tee, Jim Lee, Ann Chow, A*STAR Institute of Chemical and Engineering Sciences, Singapore, Singapore

This study aims to provide an improved understanding of the mechanisms underpinning the functional property of viscosity modifiers (VMs). Steady state rheology measurements were performed to investigate the effects of additive chemistry and concentration on the viscosity of model base oils. Polyalkyl methacrylates was chosen as model VM with different pendant functional groups attached to the polymer backbone. Either pure or a mixture of organic solvents were used as base oils. Trends between viscosity, additive chemistry and concentration could be established, with insights into polymer-polymer and polymer-solvent interactions. The viscosity modifying ability of a polymer additive was found to be dependent on the base oil composition. Ongoing work is focused on establishing the effect of temperature on viscosity modification, and microstructural characterization of the oil solutions using in-situ SAXS to further discern the effect of additive structure on lubricant oil performance.

5:30 - 6:00 pm - **Lubrication Fundamentals Business Meeting**

6K Cumberland 6

Condition Monitoring I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Contributing Factors That Influence Oil Analysis Data
Michael Holloway, ALS Tribology, Highland Village, TX

The tests that are used for oil analysis have been designed to provide repeatable and reproducable data yet there are various factors that will influence the data. Lubricant chemistry, enviromental considerations, and slight deviations in the test methods protocols can have dramatic effects on the results. This

presentation explores the various influences that can effect metal concentrations, particle analysis, contamination analysis, and oil condition analysis.

2:00 - 2:30 pm
Monitoring Engine Lubricating Oil Viscosity In-Situ in a Test Marine Diesel Engine Using a Novel Ultrasonic Technique
Xiangwei Li, Tomos Brenchley, Olivia Manfredi, Henry Brunskill, University of Sheffield, Sheffield, United Kingdom, Matthias Stark, Winterthur Gas & Diesel, Winterthur, Switzerland, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Lubrication between engine piston and liner is vital to prevent direct metal-metal contact and scuffing on the interior of liner and maintain the efficiency of a marine diesel engine. Lubricant injection time and rate is dependent on viscosity of the lubricant. Measurement of the lubricant viscosity in feeding channel in-situ is important in efficient injection control and it also provides a robust way to monitor the quality of the lubricant oil. A bespoke in-situ viscosity sensor is developed and implemented on the lubrication oil feeding channel of a test engine using a novel ultrasonic technique. The lubricant oil is oscillated ultrasonically by a shear polarised transducer. The sensitivity is improved using an acoustically soft material sandwiched between the oil and the transducer. Tests found the ultrasonic signal varied with the engine operating conditions, which suggest that the measurement of lubricant viscosity would enable real-time feedback into injection control system.

2:30 - 3:00 pm
Management of Lubricated Machinery Assets in an Industrial Setting
Bryan Johnson, Arizona Public Service, Tonopah, AZ

Optimal management of lubricated assets in an industrial environment has a high rate of return to the organization. Lubricated machinery are a primary concentration of maintenance efforts and are a significant cost center. The implementation of elements within a lubrication program that are endorsed by the organization's management are responsible for the effectiveness of the program. Asset management is garnering additional emphasis in industry and is being driven by standard such as the ISO 55000(x). This ISO series includes three documents that provide requirements and guidelines. The International Council for Machinery Lubrication (ICML) has generated standards that are based upon the ISO requirements with an emphasis on optimizing lubricated machinery assets to improve reliability and cost. Twelve primary elements asset management will be presented and discussed in the context of improving the quality of lubrication programs in industrial environments.
3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Study on the Condition Monitoring System for the Sliding Surface Using Machine Learning
Tomomi Honda, Yuka Hashimoto, Yusuke Mochida, University of Fukui, Fukui, Japan, Kazuhiko Sugiyama, Yumiko Nakamura, Chikako Takatoh, Ebara Corporation, Fujisawa, Kanagawa, Japan

This study aims to propose a cost- and time- effective system that detect the signs of breakdown during equipment operation by using machine learning to identify abnormalities. We conducted wear tests in contaminated oil and used multiple sensors to collect data regarding the friction force, the electrical contact resistance, the acoustic emission (AE) signal, and vibration. An appropriate learning sample was selected using k-fold cross-validation. The electrical contact resistance was found to contribute relatively little to the detection of abnormalities, whereas the friction coefficient contributed greatly. Furthermore, the AE signal and the vibration detected local changes on the sliding surface. Consequently, we found that machine learning can judge whether monitoring data are normal or abnormal.

4:00 - 4:30 pm
A New Approach to Onsite Oil Analysis for Industry 4.0
Lisa Williams, Spectro Scientific, Chelmsford, MA

In the dawn of Industry 4.0, new tools are available for standardizing oil analysis programs on a global

scale. Condition monitoring by lubricant analysis is one of the basic tools of predictive maintenance programs; however, thus far, industries have struggled managing programs on a global scale, standardizing knowledge world-wide and capturing global program success. Through the use of on-site oil analysis tools, we will explore the benefits of pairing fluid intelligence software with an on-site oil analysis laboratory at a steel mill and demonstrate the value of new technologies available in the Industry 4.0 Era.

4:30 - 5:00 pm
Bridging the Gap: Filter Debris Analysis
Henry Neicamp, POLARIS Laboratories, Indianapolis, IN

The purpose of oil filters is to prevent contamination and wear debris from circulating through oil systems. While that's good for your equipment, it hides problems during fluid analysis. Filter debris analysis helps you see the whole picture of what's happening in your oil system. By back-flushing the filter to release captured particles, samples can be collected and additional testing performed. Leveraging this in-depth analysis helps pinpoint the source of the wear and can even determine the cause of breakdowns. Additional value can be found in trend analysis over several filter tests on the same unit.

5:00 - 5:30 pm - **Condition Monitoring Business Meeting**

Rolling Element Bearings III

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Hoot Noise of Rolling Element Bearings – Are Non Linear Vibrations the Key Theory?
Hannes Grillenberger, Mark Nichols, Stefan Kopsch, Christoph Schroeder, Schaeffler Technologies AG & Co.KG, Herzogenaurach, Germany

Hoot Noise (HN) of rolling element bearings is a phenomenon known for decades. This noise phenomenon occurs in automotive applications almost exclusively at cold start conditions in winter. This is the usual regime, when lubrication conditions are below operating regime of the lubricant used close to the engine. Thus the current theory is HN to be excited by the lubrication. This is also based on tests which show in most cases that a change of lubricant is a counter measure – with drawbacks of normal grease properties at normal or high temperature operation. The presentation will show that hoot noise may be excited independent of a lubricant and at normal temperature by elementary test and simulation results. This generates the need for a wider view on HN. First theoretical approaches will be presented validated by test and simulation including mislubrication and non-linear oscillations.

8:30 - 9:00 am
“Reliving Pain” - Highest Performance at Toughest Conditions / The Development of a New Ball Bearing Type with Integrated Tilt Compensation
Thomas Kreis, Herbert Niedermeier, Gebr. Reinfurt GmbH & Co. KG, Rimpar, Bavaria, Germany

Deep-groove ball bearings, running under tilted conditions, are subjected to high constraining forces. The balls of the ball set move on elliptical orbits, with the consequence that they are driven with different circulation speeds depending on the ellipse position, which causes a permanent alternating stress to the cage. The consequences would be: rapidly progressing cage wear which will cause a premature bearing failure, reduced load carrying capacity in tilted position and noise abnormalities. The new GRW design ensures smooth rolling of each ball of the ball set even under tilted conditions in the harsh environment of a dental miniature bearing. The presentation shows: - requirements of "Dental Turbine" application; - kinematic basic function of the new design;- simulation results on the dynamic bearing behavior;- exemplary test results from lifetime and functional tests; - resulting performance improvements

9:00 - 9:30 am
Investigations on Cage Dynamics in Rolling Bearings by Test and Simulation
Sebastian Schwarz, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany, Hannes Grillenberger, Schaeffler Technologies AG & Co.KG, Herzogenaurach, Germany, Stephan Tremmel, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany

Rolling bearing cages perform a very high-frequency movement within their cage pocket clearance compared to the rotational speed under certain operating conditions. This is often accompanied by higher elastic deformation and noise. An unstable cage movement causes high contact forces and reduces the performance of the bearing used. The presentation gives an overview of the essential properties of the unstable cage movement derived by multi-body simulations. Relations between the cage movement and the boundary conditions in the simulation such as coefficient of friction and load are identified. Based on the simulation results, an index is defined that allows the calculated or measured cage movement to be classified into different types and objectively evaluates the cage dynamics. A comparison of the calculated and experimentally measured cage dynamics for different load cases is presented to validate

the simulation results.

9:30 - 10:00 am
Effect of Microgravity and High Temperature on the Dynamics of Ball Bearing
Yuanqing Liu, Wenzhong Wang, Beijing Institute of Technology, Beijing, China

In the space environment, the bearing system is subjected to negligible gravity force. What's more, the operating temperature fluctuation is much large, which greatly changes the lubricant traction coefficient and affects the motion of bearing. In this paper, a dynamic model is developed for angular contact ball bearings to investigate the effect of operating microgravity and temperature on motions of balls and stability of cage. The friction coefficient between ball and raceways is determined based on the experiments, while the traction coefficient is obtained under different operating temperatures and loads. The results show that the microgravity increases the slip ratio of cage and reduces the stability of bearing; Under the higher operating temperature, the stability of cage is lower and the slip ratio of balls and cage is higher.

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

10:30 - 11:00 am
Measured Lubricant Rheology Based Traction Model for Rolling Bearings
Pradeep Gupta, PKG Inc, Clifton Park, NY

A simple elastohydrodynamic traction model, based on measured lubricant rheology, is formulated for rolling bearing performance simulations. With the experimentally measured dependence of viscosity on pressure and temperature, the energy equation is integrated through the lubricant film to first compute average Newtonian traction with applicable thermal effects. Compressibility effects are modeled by implementing pressure and temperature dependence of thermal conductivity. Viscosity dependence on shear stress is then applied to model "shear-thinning" effects. At very high contact pressure and very low slide-to-roll ratios material creep effects, where the behavior of lubricated and dry contacts is similar, are implemented, while a shear stress limit is applied at very high slide-to-roll ratios. Traction predictions for a typical contact in a traction rig show good agreement with experimental traction data.

11:00 - 11:30 am
Experimental and Numerical Investigation of Hydraulic Losses in Rolling Bearings
Attila Gonda, Technical University of Kaiserslautern, Kaiserslautern, Germany, Daniel Großberndt, Technical University of Clausthal, Clausthal, Germany, Sauer Bernd, Technical University of Kaiserslautern, Kaiserslautern, Germany, Hubert Schwarze, Technical University of Clausthal, Clausthal, Germany

During the operation of an oil-lubricated rolling bearing losses are occurred, which can be divided into the contact losses resulting from mechanical friction and the hydraulic losses caused by the displacement of the lubricant. Different calculation approaches and methods can be used to calculate the contact losses, but the selection of available calculation approaches is limited to determine the hydraulic losses. Within the scope of the current research project, axially loaded rolling bearings in horizontal arrangement were investigated in order to better predict the influence of hydraulic losses on the total friction torque and to investigate the influence of the operating parameters (viscosity, rotational speed, oil quantity) on the hydraulic losses. At the STLE Annual Meeting & Exhibition the current results of the experimental and simulative investigations are presented.

11:30 am - 12:00 pm
The Effectiveness of Ball-On-Disc Tests at Simulating Friction in Greased Rolling Bearings – A Direct Comparison of Experimental Results
Nicola De Laurentis, Yuta Kanazawa, Amir Kadiric, Imperial College London, London, United Kingdom

The frictional behaviour of a series of model bearing greases was investigated by measuring the torque generated in greased thrust ball and cylindrical roller bearings. The findings were directly compared with

friction results obtained using the same set of greases in a ball-on-disc laboratory tribometer. The grease samples were strategically formulated with the aim of focussing the study on the individual effect of thickener type, base oil viscosity and presence of a friction modifier on bearing torque, by isolating each of these parameters of influence in the grease composition. A strong correspondence was found between the torque generated in the bearings and the friction values obtained in the ball-on-disc tests as a function of grease composition. It was verified that, with appropriate analysis of the results, ball-on-disc tests are representative of full bearings and can be effectively used to screen the impact of grease formulation on bearing torque.

7B Music Row 1

Biotribology II

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Lubricity of Synovial Fluid Constituents for Hydrogel Cartilage Model
Yoshinori Sawae, Mayo Kubota, Hironori Shinmori, Takehiro Morita, Tetsuo Yamaguchi, Kyushu University, Fukuoka, Japan

Soft, permeable and highly hydrated hydrogel was used as a model of articular cartilage tissue and lubricity of macromolecules contained in synovial fluid for the cartilage model was examined. The friction coefficient between cylindrical glass and the hydrogel cartilage model was evaluated in test lubricants which contain proteins, phospholipids and hyaluronic acid (HA) with different concentrations. Results indicated that phospholipids and HA had clear lubrication effect for the cartilage model and showed excellent lubricity if they mixed together. On the other hand, proteins increased the friction coefficient under the severe condition with high load and low sliding speed.

8:30 - 9:00 am
Size of Worn Region Predicts Fluid Pressures during Human Slips
Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA, Vani Sundaram, University of Colorado - Boulder, Boulder, CO, Sarah Hemler, University of Pittsburgh, Pittsburgh, PA

Shoe tread is intended to mitigate under-shoe fluid pressures. As tread becomes worn, its performance can be compromised. Previous modeling studies have suggested that under-shoe lubrication behavior is sensitive to the size of the worn region. The goal of this study was to determine whether the size of the worn region on shoes can predict under-shoe fluid pressures. Forty-one participants were exposed to a liquid contaminant (90% glycerol) in their own used shoes. Thirty fluid pressure sensors, embedded in the floor, recorded under-shoe fluid pressures to quantify the peak pressure. The size of the worn region was the product of the length and width of the worn heel region. Linear regression assessed the impact of worn tread size on peak pressure. The worn region predicted the peak pressure for both slip-resistant and non-slip-resistant shoes ($p=0.003$). Thus, using the dimensions of the worn region appears to be a reasonable method for determining when worn shoes should be replaced.

9:00 - 9:30 am
Role of Poroviscoelastic Relaxations in Rate-Dependent Cartilage Microfracture
Guebum Han, Melih Eriten, Corinne Henak, University of Wisconsin Madison, Madison, WI

The aim of this study is to investigate the potential role of poroviscoelastic relaxations in rate-dependent crack nucleation in cartilage. Crack nucleation was induced at different loading rates via displacement-controlled microindentation. A sudden drop in measured load signaled crack nucleation. Experimentally measured critical load, critical displacement, and mechanical work at crack nucleation decreased with increasing loading rate. The rate dependence of critical loads correlated well with the load relaxation

response. Critical total work at nucleation was relatively low at fast loading rates as poroviscoelastic relaxations could not disperse mechanical energy, and thus, more work was directed to rupture of collagen fibers. This correlation between critical loads and poroviscoelastic relaxation response suggests that poroviscoelastic relaxations play a governing role in the rate dependence of crack nucleation in cartilage.

9:30 - 10:00 am
Competitive Rates of Cartilage Rehydration
David Burris, University of Delaware, Newark, DE

Cartilage, a porous fluid-soaked tissue, maintains thickness and function via a balance between load-induced exudation and movement-induced fluid recovery; yet, the competitive rates involved remain virtually unstudied. This paper quantifies the relevant rates of cartilage fluid loss and recovery. Under physiologically relevant conditions, tribological rehydration rates exceeded 1,000 nm/s, which exceeded exudation rates by ~1,000x and passive (unloaded) swelling rates by 100x, and was comparable to free-swelling rates. The results suggest that: (1) tribological rehydration and free-swelling contribute synergistically to fluid and solute recovery in the joint; (2) that active recovery is far faster than passive recovery; (3) that fluid, thickness, and function are restored at least an order of magnitude faster than they are lost. The results clarify how relatively little activity is sufficient to maintain joint space and function while clarifying the relative contributions.

10:00 - 10:30 am - **break**

10:30 - 11:00 am
Tribocorrosion of Duplex Treatments on Ti-6Al-4V in Ringer's Solution
Brandon Strahin, Gary Doll, The University of Akron, Akron, OH

Tribocorrosion is a major problem in many industries. In tribocorrosion, the material experiences simultaneous wear and corrosion. The result is not the sum of wear and corrosion together but is typically increased. In this study, the affect electrochemical tribocorrosion on various treated and untreated Ti-6Al-4V surfaces was examined. The surfaces examined were untreated, nitrided, thermally oxidized, a supplementary duplex treatment, and a complimentary duplex treatment. Tribocorrosion testing was performed using a high-frequency reciprocating rig while simultaneously performing impedance testing in simulated body fluid (Ringer’s solution.) Measurements were taken using 25 m, 50 m, and 100 m distances and 2 N load. These data were then compared to tribological data collected in the dry condition.

11:00 - 11:30 am
Raman Spectroscopic Analysis of the Biochemical Reaction of Hyaluronic Acid in Joint Replacement
Risha Rufaqua, Martin Vrbka, Brno University of Technology, Brno, Czechia, Dipankar Choudhury, University of Arkansas, Fayetteville, AR, USA., Fayetteville, AR, Dušan Hemzal, Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic., Brno, Czechia, David Rebenda, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czechia

Hyaluronic acid is a nonprotein component of synovial fluid, which acts as a key reactant in the tribo-chemical mechanics of joint lubrication. In this study, the biochemical responses of hyaluronic acid were evaluated in an artificial hip joint. The experiments were conducted in the ball-on-cup configuration in a hip joint simulator, where the balls are made from respectively cobalt chromium molybdenum alloy and ceramics (biolox forte and biolox delta). The cups are of respectively polyethylene and ceramic. Raman spectroscopic method was used to analyze the biochemical responses. The results revealed that biolox delta ball could be involved in the chemical reaction with hyaluronic acid as it provides different spectra compare to others. Therefore, the results have significant information regarding hyaluronic acid reactivity within the joint replacement.

11:30 am - 12:00 pm
Agarose Hydrogel as a Carrier for Hyaluronic Acid with the Lubrication Efficiency of the Sustained Release
Mahshid Hafezi, Liquo Qin, Guangneng Dong, Qunfeng Zeng, Institute of Design Science and Basic Components, Xian, Shaanxi, China

Hyaluronic acid (HA) as a major constituent of bionic synovial fluid (BSF) has significant role in lubrication of human body joints. Those who mostly suffer from joint related disease prefer to try injection of synovia after total hip arthroplasty (THR). However affection of Metabolism process to the injected synovia is able to destroy prolonging the life time of the prostheses. In this study injectable, thermosensitive agarose hydrogel as a carrier for hyaluronic acid has been investigated to extend the life time of the artificial joints. Experimental evidences reveal bioactivity, superior viscoelasticity and naturally amorphous network structure of the HA in combination with the large molecules of agarose could be released slowly to separate the contact surfaces and improve the lubrication with more than 30% reduction rate in coefficient of the friction. Novelty of the present work provides a survey to the long-term lubrication of artificial joints.

7C Music Row 5

Power Generation I

Session Chair: J. Mehta, Chemical Engineering, City University of New York, Bayonne, NJ
Session Vice Chair: S. Rea, Lanxess Corp., Perkasie, PA

8:00 - 8:30 am
The Tribological Performance of Gas Turbine Lubricants
Jake Airey, The University of Birmingham, Derby, Derbyshire, United Kingdom, Matt Spencer, Rolls-Royce Plc, Derby, Derbyshire, United Kingdom, Mark Simmons, Richard Greenwood, The University of Birmingham, Derby, Derbyshire, United Kingdom

This study aims to evaluate the performance of several different lubricant formulations over the range of conditions seen within Rolls-Royce's future concept gas turbine design called the UltraFan®. The design features a Power Gearbox (PGB) that allows optimisation of the speed of the fan system and the intermediate pressure (IP) turbine. The PGB presents a new tribological challenge for the lubricant as well the need to continue protecting other oil system components such as various bearing chambers and other gearboxes. Oils have been evaluated using a Micro-Pitting Rig (MPR) to explore how different types and concentrations of anti-wear additives in the lubricants formulation influence micropitting. Also, an MTM (Mini Traction Machine) was used to understand how the molecular structure of group V basestocks influence friction. Evaluation of different components in these lubricants will aid better understanding of how lubricants behave in specific engine environments.

8:30 - 9:00 am
Oxidation Life and Sludge of Turbine Oil by Dry-TOST Test
Daxin Sun, Yu Jiang, Chao Yang, Yanbo Zheng, Dalian Lubricating Oil Research & Development Institute, PetroChina Lubicant Company, Dalian, Liaoning, China, Peng Li, Dalian Lubricating Oil Research and Development Institute, Dalian, Liaoning, China, Zhongguo Liu, Dalian Lubricating Oil Research & Development Institute, PetroChina Lubicant Company, Dalian, Liaoning, China

For power generation plants, long term stable is very important for turbine oils.Due to the increased gas temperatures at the inlet of the turbine, sludge and varnish problems arise in the turbine bearings, pipelines and the hydraulic control system. Oxidation life and sludge of different types basestocks and additives are investigated by dry-TOST test. The results indicate that the oxidation duration of Group IV base stocks is longer than Group I-III, meanwhile the sludge of Group I basestock is much more than Group II-IV.The effect of antioxidants,rust inhibitors,metal deactivators, and EP additives are also

investigated. Hindered phenolics and aromatic amines have a great impact on oxidation duration and sludge by Dry-TOST test. The sludge of amide derivatives is more than other additives with hindered phenolics.

9:00 - 9:30 am
There are No "Varnish-Free" Turbine Oils
Matthew Hobbs, Peter Dufresne, EPT, Calgary, Alberta, Canada

Varnish has recently received a great deal of attention due to its costly impact on critical equipment. End users are, therefore, more aware than ever of the risks associated with varnishing. As a consequence, oil suppliers have developed new products which are marketed as "low-varnish" or even "non-varnishing" alternatives to their conventional offerings. Some of these lubricants contain additives designed to increase their varnish-holding capacities while others feature more robust or polar base fluids. Regardless of the formulator's strategy, it is important for end users to understand that there are no "varnish-free" oils. Next generation products may be more resistant to varnishing but operators are still best-served to adopt multiple strategies to prevent varnish-related failures. Among these, ion exchange-based filtration provides a reliable means of removing varnish-causing breakdown products and, therefore, preventing varnish in a broad range of applications.

9:30 - 10:00 am
High Performance New Hybrid Turbine Oil Made by Mineral Oil and PAG
Hiroki Sekiguchi, Yuhei Shirakura, Junya Iwasaki, Idemitsu Kosan Co.,Ltd, Ichihara-shi,Chiba, Japan

For efficient electric power generation, long-term stable operation of turbine is required. As turbine operation temperature increases for efficient power generation, sludge and varnish have been generated easily. As the countermeasure of this issue, the highly refine mineral oil and the appropriate antioxidant have been used to reduce the generation of sludge and varnish. In the recent year, PAG has been used as base oil to dissolve them. By combining the both strengths, we developed high performance new hybrid turbine oils made by mineral oil and PAG.

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

7E Music Row 3

Tribochemistry - Materials Tribology and Nanotribology Joint Session II

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Formation and Nature of Lubricious Carbon Containing Tribofilms
Qian Wang, Arman Khan, Hongxing Wu, Yip-Wah Chung, Northwestern University, Evanston, IL

Minimizing friction and wear at a rubbing interface continues to be a challenge and has resulted in the recent surge toward the use of coatings such as diamond-like carbon on machine components. The problem with the coating approach is the limitation of coating wear life. Here, we report a robust lubrication approach in which lubricious, wear-protective carbon-containing tribofilms can be self-generated and replenishable, without any surface pretreatment. Such carbon-containing films were formed under modest sliding conditions in a lubricant consisting of cyclopropanecarboxylic acid (CPCa) as an additive dissolved in polyalphaolefin base oil. Systematic reactive molecular dynamics simulations were conducted to explore the nature of the carbon tribofilm, analyze the related tribochemistry and reveal the atomistic mechanisms involved that lead to the formation of such tribofilm.

8:30 - 9:00 am

Interactions between Tri-Cresyl Phosphate Lubricant Additive and Iron Oxide Explored Using Statistical Analysis of Reactive Molecular Dynamics Simulations

Arash Khajeh, Xiaoli Hu, University of California Merced, Merced, CA, Stephen Berkebile, Army Research Laboratory , Baltimore, MD, Ashlie Martini, University of California Merced, Merced, CA

Tri-cresyl phosphate (TCP) is widely used as an anti-wear additive in lubricants because it reacts with ferrous surfaces to form protective films through chemical reactions between the TCP molecules and surfaces with a native oxide. To understand the reaction pathways that lead to TCP film formation, we used reactive molecular dynamics simulations to model the reaction pathways for TCP molecules interacting with an amorphous iron oxide surface at different temperatures. Multiple replica simulations were run at each temperature so that statistical analysis of the reactions and reaction pathways could be performed. This approach enabled characterization of the initial steps of TCP film growth and forms the basis of a fundamental understanding of anti-wear films that may ultimately lead to design of additives to produce faster forming and more robust tribofilms.

9:00 - 9:30 am

Reactive Molecular Dynamics Simulations of Thermal and Tribochemical Film Growth from Di-tert-butyl Disulfide on an Fe(100) Surface

Karen Mohammadtabar, University of California Merced - Merced, CA, Merced, CA, Stefan Eder, Pedro Bedolla, Nicole Doerr, AC2T research GmbH, Wiener Neustadt, Lower Austria, Austria, Ashlie Martini, University of California Merced - Merced, CA, Merced, CA

Di-tert-butyl disulfide is an extreme pressure additive that forms protective films to increase the lifetime of moving components. As film evolution between two sliding surfaces cannot be observed directly by common experimental approaches, we used molecular dynamics simulation with a reactive potential to model chemical reactions between di-tert-butyl disulfide and Fe(100). Thermal and shear-induced (tribochemical) films were grown to observe individual species and their reactions in the early stages of film formation. In order to mimic additive replenishment in a sliding contact, di-tert-butyl disulfide molecules were added iteratively to the model system. The film formation mechanisms – involving S-S breakage, Fe-S bonding and C-S breakage resulting in tert-butyl release – were analyzed in the context of previously reported results. Finally, tribological behavior was modelled for a single asperity sliding on the resultant iron sulfide films.

9:30 - 10:00 am

Surface Absorption and Chemical Reaction of Additives Studied by Molecular Dynamics

Hitoshi Washizu, University of Hyogo, Kobe, Japan

Molecular dynamics studies are carried out for the study of surface absorption process of additives. Formation process of organic monolayer of organic acids in hydrocarbon base oil on the charged metal surface are studied using all-atom molecular dynamics. We found that the base oil molecules made highly oriented (laid) adsorbed layer on the surface at first. Then the additive molecules is prevented to physically adsorb on the surface. The absorbing time is due to the structure of base oil. For surface coating, the sliding friction between ZrO2 and diamond like carbon (DLC) film including small amount of water and ethanol molecules between them, are studied. We found the transfer film formation in the Friction Fade Out phenomena. As a model system of absorption process of anti-corrosion additives on the metal surface, MD simulations of benzotriazole (BTA) molecules with copper slabs are done. A selective absorption phenomena is found.

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

10:30 - 11:00 am

Impact of Nanodiamonds on ZDDP Tribo-Film Formation at Stainless-Steel Contacts.

Biplav Acharya, Jacqueline Krim, NC State University, Raleigh, NC

Nanodiamonds are known to improve tribological performance when added to lubricants and be beneficial and synergistic with TCP additives in oil-based lubricants. In particular they induce film formation on the

oxide surfaces that are otherwise highly resistant to film formation. ZDDP forms a tribofilm at temperatures lower than TCP, assisted by various mechanisms distinct from that of TCP, particularly stress promoted mechanisms. Here we report on a study of nanodiamonds' effect on the stress promoted activation of ZDDP tribofilm formation at stainless-steel contacts. The tribofilm formation rates were measured in-situ with a quartz crystal microbalance (QCM) immersed in oil at different temperatures and in contact with a spherical ball with a variable normal force on it. The surface morphology, roughness, and thickness of the tribo-films were measured by AFM. Their chemical compositions were studied with EDS.

11:00 - 11:30 am
In-Situ Raman Spectroscopic Characterization of ZDDP Tribofilms
Carlos Garcia, Imperial College London, London, United Kingdom, Hugh Spikes, Imperial College, London, United Kingdom, Janet Wong, Imperial College London, London, United Kingdom

Zinc dialkyldithiophosphates (ZDDPs) are lubricant additives that play a triple role as anti-wear agents, antioxidants and corrosion inhibitors. In their role as anti-wear agents, they help protect the rubbing surfaces by forming a mechanically protective film upon sliding contact. While the composition and properties of ZDDP tribofilms have been studied extensively through ex-situ measurements, the mechanism by which they form remains to be elucidated. It has been suggested that intermediate species could be identified by means of in-situ vibrational spectroscopy, however, the small volumes involved present a challenge to collect and measure the signal. In this presentation, we detail our attempt to overcome this challenge by a custom-built optical platform that allows the application of Raman spectroscopy on a lubricated contact. Preliminary results, correlated to friction and the process of tribofilm formation, will be presented. Remaining technical challenges are discussed.

11:30 am - 12:00 pm
Effect of ZDDP on Hydrogen Absorption in Two Synthetic Oils
Monica Ratoi, University of Southampton, Southampton, Hampshire, United Kingdom, Vlad Niste, Kyushu University, Fukuoka, Japan, Angelos Stavrinidis, University of Southampton, Southampton, Hampshire, United Kingdom, Hiroyoshi Tanaka, Kyushu University, Fukuoka, Japan, Brian Mellor, University of Southampton, Southampton, Hampshire, United Kingdom, Joichi Sugimura, Kyushu University, Fukuoka, Japan

Bearing steels suffer from a degradation in mechanical properties when hydrogen diffuses into the steel from the contact surface. Previous work has reported that during rolling contact fatigue tests, the fatigue lives of the specimens is reduced significantly with the increase in the amount of hydrogen diffused into the steel. To mitigate this aspect different synthetic oils have been studied and two types, polyol esters and poly−α−olefins found to generate tribofilms that reduce wear and hydrogen damage of bearing steels. The current study has investigated the effect of ZDDP addition to these oils on the RCF performance of bearings tested in air and hydrogen environments. The rolling contact fatigue life values were correlated with the amount of hydrogen species absorbed in the disc and ball specimens, the lubrication performance i.e. wear track volume loss, surface and subsurface defects, tribofilms characteristics and chemistry.

7F — Music Row 2

Synthetics & Hydraulics Lubricants III

Session Chair: P. Cusatis, BASF Corporation, Tarrytown, NY
Session Vice Chair: L. Huffman, Dow Chemical

8:00 - 8:30 am
Novel Functionalized Polyalkylene Glycols and Their Synergy with Primary Anti-oxidants
Martin Greaves, Dow Chemical, Horgen, Switzerland

Thermal stresses on lubricants are expected to increase in the future as equipment is designed to operate under more severe conditions. Primary anti-oxidants (free radical scavengers) are frequently used in lubricant compositions. The inclusion of novel polyalkylene glycols (PAGs) as additives in combination with primary anti-oxidants in lubricant compositions can significantly boost the activity of the anti-oxidant and may lead to longer life fluids. The novel PAG additives have been carefully designed to include sulphur within the polymer backbone. A mechanism on their mode of action will also be proposed.

8:30 - 9:00 am
From Jet Engine Oils to High Temperature Industrial Lubricants: High Performance Anti-oxidants for Synthetic Esters
Siegfried Lucazeau, NYCO, Paris Cedex 08, France

The formulation of latest generation jet engine lubricants has led to the development of specific anti-oxidant systems that, used in fully synthetic esters, deliver increased stability and longevity, as well as improved control over deposit formation and coking. It is only relatively recently that such a technology was extended to industrial applications. As in jet engines, the combination of carefully selected neopolyol esters and specifically synthesized anti-oxidant systems delivers outstanding performance when evaluated through tests such as Micro-Coking Test at various temperatures, thermo-gravimetric analyses and dish tests – in addition to the standard fire safety tests. This technology may be used in high temperature chain oils, or even in greases. In addition, specific synergistic blends of classical anti-oxidants and aviation derived anti-oxidant systems have been examined in trimellitate esters as a cost-effective way of boosting performance of high temperature chain oils.

9:00 - 9:30 am
Time-Resolved Oxidative Degradation of Ester-Based Lubricants Identified by Mass Spectrometry
Nicole Doerr, Marcella Frauscher, Andjelka Ristic, Charlotte Besser, AC2T research GmbH, Wiener Neustadt, Austria, Guenter Allmaier, Vienna University of Technology, Vienna, Austria

A commercial ester base oil used for hydraulic applications was blended with antioxidant and antiwear additives. In order to reveal the degradation products and processes caused by oxidation, a combined approach of artificial alteration, isotope labelling, and mass spectrometry (MS) was applied. Thereby, isotope labelling was performed with $^{16}O_2$ and $^{18}O_2$ to label the oxygen atoms, which were incorporated into the degradation products. Subsequently, the degradation products formed were unambiguously identified by MS. The time-dependent appearance/disappearance and abundance of both initial components and their degradation products allowed the description of oxidative degradation mechanisms. Emphasis was put on the correlation of oxygen consumption with the residual antioxidant contents. The role of antioxidant degradation products acting as indicators for critical lubricant conditions of lubricants is discussed.

9:30 - 10:00 am
Hydraulic Lubricant Performance, a Corrosion and Oxidative Perspective
Rajeev Kumar, Kathleen Cooper, ExxonMobil, Annandale, NJ

Performance considerations for hydraulic lubricants include how they interact with the metallurgy used within the equipment. Tests used to assess a lubricants suitability in hydraulic equipment for stationary & mobile applications, typically include assessments for wear and corrosion. Others however, are targeted towards an understanding of how the metallurgy contributes to catalytic oxidation of the lubricant. Both are at the core of the lubricant performance features for hydraulics that when robustly managed ensure a good service lubricant. This presentation will discuss standard hydraulic lubricant test methods importance to assessing corrosion and lubricant thermo-oxidation and their significance for hydraulic lubricants.

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

10:30 - 11:00 am
Hybrid Antifoam Technology for Lubricating Oils
Ernest Galgoci, Justin Mykietyn, Munzing, Bloomfield, NJ

An antifoam is a critical part of a lubricating oil formulation. Although the criteria for choosing an antifoam may vary, the antifoam should generally exhibit strong surface foam control, persistence, air release, and compatibility with the lubricant. Because lubricant formulations can vary substantially, this produces a complexity that makes the choice of antifoam difficult to predict, the optimal choice of the antifoam is often best determined empirically. Fortunately, experiential knowledge and first principles can be used as guidelines to narrow the search. This paper will describe the theoretical framework of foam generation and stabilization, the thermodynamic and physical considerations of the action of antifoams, and the general formulation of antifoams used in lubricants. The discussion will focus on the performance of a hybrid chemistry approach, which delivers an excellent combination of foam control and air release relative to conventional chemistries alone.

11:00 - 11:30 am
Ionic Liquid Additized Environmentally-Friendly Hydraulic Fluids
Xin He, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Environmentally-friendly ionic liquids (ILs) are being developed as ashless additives for hydraulic fluids. Candidate ILs, at a treat rate of 0.5 wt.%, were blended into a non-polar mineral base oil, a hydrophilic polyalkylene glycol (PAG), and an oil-soluble PAG (OSP). Boundary lubrication tribological tests were conducted on the IL-containing oils using a ball-on-flat reciprocating sliding configuration at 82 ^{o}C. Compared with a commercial primary zinc dithiophosphate (ZDDP), the ILs showed lower friction coefficient and wear volume. This attributes to the formation of a protective layer on the contact surface as revealed by characterization of wear scar morphology and composition. In addition to the superior lubricating performance, these ILs have advantages of higher thermal stability and lower toxicity than commecial hydraulic fluid additives.

11:30 am - 12:00 pm
Hydrocarbon-Mimicking Ionic Liquids as Low Vapor Pressure Triboimprovers
Erik Nyberg, Didac Llopart, Ichiro Minami, Luleå university of technology, Luleå, Sweden

Tribochemically active lubricants are essential to high performance machine elements, such as gears and bearings. The past century has seen the development of a wide range of triboimproving lubricant additives (anti-wear and friction modifiers) to provide hydrocarbon base fluids with high performance capacity. However, for unconventional applications, such as mechanical devices in space missions, there is a lack of high performance triboimprovers. Near future space missions are projected to expand from scientific to engineering objectives, and consequently requests for radically increased tribological performances can be foreseen. In this work, we evaluate novel hydrocarbon mimicking ionic liquids as tribochemically active synthetic lubricants for use in mechanical devices that operate in space environments. Model scale tribotesting is combined with lubricant evaluation in actuator gearboxes typically employed in space robotics.

7G Cumberland 1

Grease I

Session Chair: C. Liu, Kluber
Session Vice Chair: V. Parker, Sasol

8:00 - 8:30 am
Back to the Basics: Fundamental Building Blocks of Grease Formulation
Joseph Kaperick, Afton Chemical Corporation, Richmond, VA

This presentation explores the main performance areas for which grease additives are primarily used and some common questions and misunderstandings surrounding them. Data was generated using a variety of additives and testing from these different performance areas and includes discussion of (and some answers to) questions such as: Is there a difference between primary and secondary ZDDPs? Does the grease thickener help prevent rust? Are all rust tests equal? Is there really such a thing as synergistic combinations of antioxidants? Is EP performance in a grease really “all about the sulfur”? Is all sulfur created equal? Are all additive packages created equal? Does “one size fit all”? Does the grease thickener really interact with performance additives?

8:30 - 9:00 am
A New Preformed Polyurea Thickener for Grease
Zhe Jia, John Cuthbert, Nathan Wilmot, Bruce Hook, Dow Chemical, Freeport, TX

Polyurea grease consists of a three-dimensional physical network incorporating a lubricating base oil, a thickener formed *in situ* between isocyanates and amines, and a variety of additives. The featuring urea functional groups will generate sufficient hydrogen bonding to hold base stock within the network for lubricating purpose.
In this work, we proposed to develop a pre-formed polyurea thickener, with carefully designed chemical structure that allows the thickening agent to be compatible with the base oil at elevated temperatures and shearing conditions. The resulted product exhibits minimized handling complexity of toxic raw materials and inherent polyurea grease properties, including unique high temperature capabilities, enhanced shear stability and anti-oxidative characteristics. This preformed thickener, offering improved lubrication properties and EH&S and handling benefits for grease manufacturers, would be a promising alternative for conventional polyurea grease.

9:00 - 9:30 am
Film Thickness in a Grease Lubricated Ball Bearing
Piet Lugt, SKF Research and Technology Development, Nieuwegein, Utrecht, Netherlands, Hui Cen, Xuchang University, Xuchang, Henan Province, China

The film thickness for grease lubricated bearings is normally calculated using the base oil viscosity, where it is assumed that the bearing is running under fully flooded conditions. It is well known that this is not accurate since grease lubricated bearings are usually running under starved lubricated conditions leading to thinner films. Single contact measurements have shown that, in the case of starvation, the film thickness decreases significantly with increasing speed. It is shown in this paper that that effect is clearly different in full rolling bearings. This is shown for three types of thickener material and base oil. To quantify this starvation effect, the film thickness can be expressed as the ratio between the real film thickness and the calculated film thickness using the base oil viscosity, h_b/h_{ff}. The measurements in this paper show that $h_b/h_{ff} > 1$ for very low speeds but decreases with speed to values $h_b/h_{ff} <1$. This decrease reduces with increasing speed.

9:30 - 10:00 am
Effect of the Alkyl Chain Length of ZDDP Combined with Amine Phosphate on Wear Rates as Studied by Profilometry
Nicole St Pierre, Nye Lubricant Inc, Fairhaven, MA

The effect of the alkyl chain length on ZDDP was studied in combination with amine phosphate to potentially identify synergistic effects between the additives that lead to lower wear rates in various base oil chemistries. The fortified base oils looked at varying both the additive treat rate as well as the ratio of the additives which were analyzed using tribological tests such as 4 ball wear, SRV, and MTM. This wear study will utilize optical profilometry to look at the wear scars in the 3rd dimension to see if there are noticeable differences in total wear volume that would differentiate the additive combinations best suited

for mixed lubrication leading to better formulated products. The study will also allow us to analyze the data to identify two-way interactions between variables.

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

10:30 - 11:00 am
How Reliable and Sensitive Is the New Indentation/Retraction Method in Measuring Tackiness of Industrial Greases?
Emmanuel Georgiou, Dirk Drees, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium, Michael Anderson, Falex Corporation, Sugar Grove, IL

The tackiness of lubricating greases, used in various industrial applications is an important property to ensure good adherence and distribution to components, and maintain consistency of the lubrication layer. The new test method developed by Falex, to measure the adhesion and tackiness of greases, is based on indentation/retraction measurements. This method takes into account the effect of temperature, retraction speed and applied load. Until now, the sensitivity and repeatability were less studied. This presentation focuses on getting a better insight on sensitivity to additive levels, by testing formulated greases with a known concentration of tackifiers. The reliability of the method is evaluated by statistical analysis of multiple tests. We believe that this information is of vital importance towards standardization of the method.

11:00 - 11:30 am
Simulation of Grease Flow in Speed Reducer of Robot.
Akihiro Shishikura, Hideki Nakata, Kei Sakakura, IDEMITSU KOSAN CO., LTD., Chiba, Chiba, Japan

The grease flow in speed reducer (cyclo gear type) was observed by using an acrylic model. Only grease near the rotating part moved and the flow speed decreased with the grease hardness. We have already been reported that the particle method simulation (DEM-MPS) of grease flow is effective for flow analysis of grease and we applied this calculation method for this case. The observation result of the grease flow in the speed reducer well agreed with calculation result. In the case feeding iron powder as a tracer, the moving speed of the iron powder is remarkably slow, and it hardly moves in the reducer. This phenomenon also agreed well with the simulation result of grease flow. The bypass phenomenon of grease in speed reducer at grease-up operation can also be predicted by the calculation. Therefore, this flow analysis using DEM-MPS is effective for grease lubrication management of complex gear system.

11:30 am - 12:00 pm
Effect of Rheological Properties of Grease on Rotational Torque of Ball Bearings Caused by Stirring Resistance
Yurie Yamashita, Takeshi Tsuda, Kouji Yoshizaki, JTEKT Corporation, Kashiwara, Osaka, Japan

In recent years, developing grease-lubricated ball bearings with low torque performance is required to improve energy efficiency, especially for industrial electric motors. Although many research reports have been published about the effect of grease on low torque performance of ball bearings, hardly any reports have studied about quantifying the grease factors affecting stirring resistance on bearing rotational torque. In this study, a new concept of “energy for viscous reduction property” measured with rotational-type rheometer was introduced, to consider rheological properties of grease during bearing rotation. Our results, obtained on urea grease with thickener made from single or multiple amine in several kinds of synthetic oils, suggested that the higher the energy for viscous reduction property, the lower the bearing rotational torque. Moreover, greases with thickeners composition containing a short carbon chain amine displayed improved low torque characteristic.

Materials Tribology IV

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 9:00 am
Mechanisms of Abrasive Wear in WC/Co Hardmetals
Mark Gee, National Physical Laboratory, Teddington, United Kingdom

Because of their combination of high strength and toughness, WC/Co hardmetals have remarkable wear resistance and are therefore used in applications where this property enables good performance. This presentation will focus on the understanding that has been achieved about the mechanisms of abrasive wear for WC/Co hardmetals. This understanding has been achieved through laboratory experiments that have been conducted including macroscopic wear tests such as the ASTM B611 and ASTMG65 tests, single and multipass scratch tests which aim to simulate the mechanisms that occur in abrasion, and experiments carried out in situ in the SEM which provide in operando information on how the mechanisms of damage relate to the microstructure of the WC/Co materials. The interpretation of the experimental results is aided by the microstructural characterisation of worn surfaces by techniques including high resolution SEM, EBSD and ECCI analysis, and FIB tomography.

9:00 - 9:30 am
Nickel MAX-Phase Composites for High Temperature and High Sliding Applications
Nikhil Murthy, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, Maharshi Dey, Matt Fuka, Surojit Gupta, University of North Dakota, Grand Forks, ND, Stephen Berkebile, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD

MAX-phase materials are a promising group of materials for tribological application due to their high thermal stability and potential for adding lubricity to structural material. We used hot press sintering to synthesize MAX-phase metal composites attempting to improve the properties for high speed and high temperature conditions such as in turbomachinery applications. The friction and wear rates of pure nickel and Ni-MAX (90 wt.% Ni + 10 wt.% Ti_3SiC_2) specimens were measured with a ball-on-disk tribometer at low (1 m/s) and high (10 m/s) sliding speeds. The specimen were also tested using a reciprocating tribometer at temperatures ranging from 20 to 900 °C. The wear tracks of the specimen were inspected using scanning electron microscopy, electron dispersive spectroscopy, and laser scanning confocal microscopy to determine the morphology and presence of tribofilms. The coefficient of friction was generally lower and wear rate higher for the Ni-MAX composite than pure Ni specimen.

9:30 - 10:00 am
Effect of MoS_2 on the Tribological Performance of AA7075/Si_3N_4 Composite
Mir Irfan Ul Haq, Ankush Anand, Shri Mata Vaishno Devi University, Jammu, India

In this work we examine the effect of MoS_2 on the friction and wear behaviour of AA7075/Si_3N_4 Composites. The percentage of Silicon Nitride was decided based on our previous work . Molybdenum Disulphide (MoS_2) was added in concentrations of 2 wt.%, 4 wt.% and 6 wt.%. The samples were fabricated via stir casting route as per the details in our recent work. The physical and microstructural evaluation of the composites was carried out prior to microhardness testing. The friction and wear behaviour of the cast composites was studied using a pin on disc machine with EN31 steel disc as the counter face material. The effect of applied load, MoS_2 content, sliding speed was studied on the friction and wear of the cast composites. The wear mechanisms in the worn out surfaces was studied using Scanning Electron Microscope. It was observed that MoS_2 plays a vital role in lowering the Coefficient of Friction at the contact due to its film formation capability.

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

10:30 - 11:00 am
Influence of Operational and Surface Conditions on the Tribological Performance of Self-Lubricating Polymer Composite Bearing Materials Used in Hydropower Applications
Kim Berglund, Maria Rodiouchkina, Roland Larsson, Luleå University of Technology, Lulea, Sweden

In hydropower applications, self-lubricating polymer composite bearings has proven to be a good and environmentally friendly replacement for the traditionally used grease lubricated bronze bearings. However, in recent years, end users have experienced several bearing failures due to more demanding operating conditions due to integration of fluctuating renewable energy sources, e.g. wind and solar power, into the electric power systems. The aim of this work is to summarize and highlight important findings regarding the influence of various parameters on the tribological behaviour of these bearing materials using a linear reciprocating pin-on-disc configuration. Results indicates that low sliding speed and high nominal pressure offer the best performance for these bearing materials, with a reduction in frictional loses with up to 45% and almost three times lower wear. Furthermore, friction and wear can be reduced even more by optimizing the surface topography and hardness of the shaft.

11:00 - 11:30 am
Tribological Behavior of Self-Lubricating Polymer Composite Bearing Materials during Long-Time Dry Sliding
Maria Rodiouchkina, Leonardo Pelcastre, Luleå University of Technology, Lulea, Sweden, Jonna Lind, Uppsala University, Uppsala, Sweden, Kim Berglund, Luleå University of Technology, Lulea, Sweden, Åsa Kassman Rudolphi, Uppsala University, Uppsala, Sweden, Roland Larsson, Luleå University of Technology, Lulea, Sweden

Thermosets and thermoplastics containing PTFE are used in marine and hydropower applications due to their long service life and self-lubricity in dry and water-lubricated contacts. Their tribological performance is usually extrapolated from short, accelerated tests, which induces risks of inaccurate or incorrect interpretation. The aim of this study is to investigate the tribological behaviour and development of transfer layers during long sliding tests (160 hours), corresponding to years of operation. To mimic operational shutdowns, the tests were stopped every 20 hours to study the evolution of the surface topography and transfer layers. The wear rates of both materials decreased significantly with time. For the thermoplastic, COF decreased due to accelerated material transfer after 80 hours, highlighting the importance of long duration tests. The thermoset showed the highest transfer amount after 20 h and cause severe abrasive wear on the counter surface accompanied by a COF increase.

11:30 am - 12:00 pm
Fabrication of Porous Alumina-IF-MoS2 Self-Lubricant Composite and its Tribological Behavior
Abdul Salam, Tsinghua University, Beijing, Beijing, China

The solid lubricant MoS2 immersed into pores of Alumina matrix can improve self- lubrication efficiency in the composite and maintain the exceptional mechanical properties of the matrix. Alumina ceramics are good candidates for the composite because they have high hardness, high compressive strength, and high resistance to chemical corrosion. In this study, Porous Alumina-IF-MoS2 matrix was fabricated as self-lubricant composite. Porous Alumina ceramics was produced using Graphite Powder as a pore forming agent while fullerene-like molybdenum disulfide was synthesized by thermal decomposition of Ammonium thiomolybdate ((NH4)2MoS4) in choice of solvents followed by Annealing in tubular furnace.The MoS2 characterized by Field emission scanning electron microscope (FESEM) and Transmission electron microscope (TEM) shows that fullerene-like structures formed into pores of the composite.The friction and wear test results reveal that the composite displayed excellent tribological properties.

Contact Mechanics I

Session Chair: K. Schulze, University of Florida, Gainesville, FL

8:00 - 8:30 am
Indenting Soft Swollen Elastomers with a Microparticle
Jonathan Pham, Justin Glover, University of Kentucky, Lexington, KY, Michael Kappl, Hans-Jürgen Butt, Max Planck Institute for Polymer Research, Mainz, Germany

Indentation of small particles into soft materials is important for many applications, from repellent surfaces to bioinspired adhesives. The mechanics of soft contact is typically defined by a balance of adhesion and elastic deformation, and often described by the Johnson-Kendall-Roberts (JKR) theory. For super soft materials on small length scales, JKR theory breaks down because liquid-like behavior emerges. Experimentally, this discrepancy has been shown mostly using crosslinked silicones. However, the majority of these materials possess a non-negligible amount of free molecules, leading to a self-swollen polymer network after preparation. We investigate indentation of soft silicones using a combination of confocal microscopy, atomic force microscopy, and fluorescent dyes. We confirm that JKR theory does not quantitatively agree with our experimental measurements, and explore the potential effects of free molecules in describing how a microparticle interacts with a soft surface.

8:30 - 9:00 am
Transparent Hydrogel Indentation and Slip Mechanics Through In-Situ Particle Inclusion and Exclusion
Alison Dunn, Christopher Johnson, Jiho Kim, Shabnam Bonyadi, University of Illinois, Urbana, IL

Many hypotheses exist to explain the coupled deformation and slip mechanics of interfaces where at least one surface is a transparent, high-water-content hydrogel. In this work we show versatile techniques of particle inclusion and exclusion microscopy in-situ with microindentation and sliding experiments of polyacrylamide hydrogels with > 90% water by mass. The particles are green fluorescent polystyrene spheres of 0.5 or 1 µm diameter. We identify time-dependent contact mechanics in migrating, stationary, and self-mated Gemini contact; our data suggests that for long times, Gemini contact approaches a constant-pressure contact model. Finally, we present for the first time asymmetric contact areas developed under slip as visualized by in situ particle exclusion which manifests as a flow field around the probe. The results of this work confirm the importance of in-situ microtribometry and begin to support mechanistic connections between hydrogel slip and deformation.

9:00 - 9:30 am
Small Forces, Large Noise: Scaling Nano-Indentation to the Micro Scale
Christopher O'Bryan, Kyle Schulze, Thomas Angelini, University of Florida, Gainesville, FL

Micro-indentation is a powerful tool for measuring moduli of soft materials; however, forces within the Hertz contact regime for thin samples are often below the detection threshold, requiring more sensitive techniques (e.g. colloidal-probe AFM). Alternatively, the Winkler model can be used with large-radius probes when sample thickness is known. However, uncertainty in sample thickness can lead to large errors in measured moduli. A method that enables micro-indentation for soft materials without knowledge of sample thickness would aid researchers lacking instruments like colloidal-probe AFM. Here, we present a micro-indentation method designed to measure the moduli of soft samples using a combination of roughened probes and data correlation analysis. This approach enables us to extract the moduli from indentation curves in which the measured load is larger than the noise. We demonstrate this method through indentation experiments of hydrogel samples of varying thickness and stiffness.

9:30 - 10:00 am
Eliminating the Challenges Associated with Physically Oscillating Contact Instruments
Daniel Garcia, Thomas Angelini, University of Florida, Gainesville, FL

The material properties of soft matter systems are measured with rheometers and tensile testing instruments whenever there exist few limitations on sample volume and fixturing where samples can be prepared specifically to work with the hardware of a given instrument. By contrast, indentation methods are advantageous for measuring material properties when sample preparation and geometry are highly constrained, which is often the case with tissue samples, hydrogel coatings, or soft objects with defined shapes like contact lenses. However, many soft matter materials exhibit frequency-dependent moduli, which are challenging to account for using the simple models of Hertz and Winkler. In this talk I will review our recent work to developed a Fourier-analysis method that leverages the Kramers-Kronig relations to extract frequency dependent elastic and viscous moduli from Force-indentation curves, eliminating the challenges associated with physically oscillating contact instruments.

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

10:30 - 11:00 am
Shape Memory: The Contact Mechanics of Photonic Crystal Structure
Kyle Schulze, Yongliang Ni, WG Sawyer, University of Florida, Gainesville, FL

The combination of stimuli-responsive polymer networks and photonic crystal structures has allowed for generation of functional material that have shape memory. These shape memory polymers exist in three states dependent upon their mechanical properties and applied stimuli: original,deformed, and recovered. Here, we examine the shape memory of several PEG based PSMPC systems due to direct applied pressure and how it allows the system to transisition between these three states. Through in situ indentation measurements we observe the pressures that change the surface and bulk charactersistics that allow for an optical memory of the indent (much like a fingerprint scanner). We are also able to observe the links between the physical and chemical properties of the polymer used in conjunction with the mechanical properties of the overall structure and the overall response of the PSMPC.

11:00 - 11:30 am
The Tribomechadynamics of Jointed Interfaces: New Observations and Their Ramifications
Matthew Brake, Rice University, Houston, TX

Despite the prevalence of jointed structures, models of these assemblies are unable to predict the nonlinear dynamic properties (in terms of the amplitude dependent frequency and damping, and the evolution of damage within the interface). Recent research has demonstrated that several commonly held assumptions for modeling jointed structures are fundamentally incorrect. For instance, the dissipative mechanisms internal to an interface do not support the Masing hypothesis (i.e. that the hysteretic behavior of a jointed structure can be deduced from looking at only a quarter cycle of loading the joint). A series of experiments using novel electronic pressure film systems and high speed digital image correlation are used to compliment numerical insights into the physics of jointed systems. The ramifications of the findings are discussed in terms of a new generation of joint models.

11:30 am - 12:00 pm
Method for Calculating the Contact Between Roller End Face and Ring Flange in Multi-Body Simulations
Sven Wirsching, Design Engineering, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany, Christof Bohnert, Schaeffler Technologies AG & Co.KG, Herzogenaurach, Germany, Stephan Tremmel, Sandro Wartzack, Design Engineering, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

The contacts in rolling bearings like roller/flange contact under axial or combined loads are not extensively researched as them under pure radial loads, such as roller/raceway contact. To correctly compute friction in multi-body simulations for these contacts, one needs to calculate the pressure

distribution in the contact, which is also vital for lifetime and load capacity. Afterwards the friction is computed. Current contact calculation methods normally work with the theory of Hertz, which leads to inaccuracies with higher-order geometries, like tori. The presented method discretizes a small area around the contact point. The analytically described geometries of both contacting bodies build a substitutive geometry via co-projection. A calculation with 2D bedding according to Winkler yields the pressure distribution. These results of the new method are compared with them, obtained by common simulation methods, such as the finite element method to assess accuracy and efficiency.

7J Cumberland 4

Surface Engineering III :Surface Texturing

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
The Effect of Graphene as Additive on the Anti-Corrosion of Polyurethane Coating
Hai Tan, Deguo Wang, Yanbao Guo, China University of Petroleum-Beijing, Beijing, China

Ocean is of the extraordinary riches where people are looking forward to. However, sea-water could enhance the corrosion of marine equipment . Various coatings -for example polyurethane (PU) coatings- are spraying on the steel surfaces to enhance the anti-corrosion performance. In this paper, the corrosion behaviors of 4130 steel with or without PU coatings were discussed by electrochemical mean in the sea-water. And the graphene as the additive in different concentrations were also studied. A series of characterized methods were introduced to identify the corrosion behaviors and anti-corrosion performances of 4130 steel with or without coatings (in different concentrations of graphene), respectively. The results showed that the corrosion property of 4130 can enhanced obviously when sprayed the PU coatings. The graphene additive can further improve the anti-corrosion of PU coatings and in the graphene concentration of 0.6 % the PU/Graphene coatings worked best.

8:30 - 9:00 am
Friction Properties of Milling Micro-Textured Surface on Al-Si Alloy under Sliding Boundary Conditions
Chao Guo, Qinghua Song, Zhanqiang Liu, Bing Wang, Key Laboratory of High Efficiency and Clean Mechanical Manufacture, Ministry of Education, School of Mechanical Engineering, Shandong University, Jinan, China, Long Chen, National Demonstration Center for Experimental Mechanical Engineering Education, Shandong University, Jinan, China

Texturing surfaces with different shapes to improve friction performance are generally investigated by using experimental approaches rather than theoretical analysis due to the complex boundary conditions. A comprehensive method is proposed to optimize textures and enhance lubrication in this paper. Considering the slip boundary of micro-gap flow, Reynolds equation is employed to solve slip velocity, and then the hydrodynamic lubrication effects are presented based on the Stokes equation using Galerkin finite element method. The influences of texturing geometry parameters on groove surface are investigated and discussed in detail. The results show that taper texture is more favorable to increase bearing capacity, and slip boundary makes the trend smooth. Finally, micro-milling cutters are used to machining different sizes of cylindrical, taper and hemispherical textures on Al-Si alloy 6061 surfaces, and friction experiments are performed to confirm the method presented in this paper.

9:00 - 9:30 am
Numerical and Experimental Studies on Friction Reduction by Surface Modification in TEHL Contacts
Max Marian, Tim Weikert, Stephan Tremmel, Engineering Design, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

With the aim of improved energy efficiency of engine components, it is crucial to understand the underlying mechanisms of surface modification approaches, such as applying tribological coatings or microtextures. Within this contribution, TEHL simulations of the cam/tappet contact with modified surfaces are performed. Input data, like material and fluid parameters, geometries and load cases, are chosen according to the setup of a component test-rig, on which experimental tests are carried out to support the numerical findings. In particular, variants of amorphous carbon coatings and microtextures fabricated by laser ablation are investigated. Obtained insights indicate that coatings can reduce solid and fluid friction in all lubrication regimes. This corresponds to a shift of the Stribeck curve to the lower left. Conversely, microtexturing may reduce the fraction of solid friction while increasing fluid friction. This in turn resembles to a counterclockwise tilt of the Stribeck curve.

9:30 - 10:00 am
The Effect of Texture Shape on the Frictional Resistance under Unidirectional Sliding
Pawel Pawlus, Slawomir Wos, Waldemar Koszela, Rzeszow University of Technology, Rzeszow, Poland

Tribological tests were carried out using a pin-on-disc tester under starved lubrication conditions. In order to achieve a conformal contact between sliding elements a special construction was used with self-aligning counter sample. During tests friction force were measured as a function of time. Disc surface texturing was performed with abrasive jet machining. Textured disc surfaces with two dimple patterns (spiral and radial) and four shapes (circle, oval, triangle and chevron) were tested. The contact area was lubricated by 0.08 ml of L-AN-46 oil. All tests were performed at ambient temperature, the normal force was 20 N, the sliding speed was 0.4 m/s, the number of revolutions was 10000. Tests revealed that in starved lubrication conditions both dimple shape and pattern affected the frictional resistance. In all cases surface texturing resulted in a decrease of the friction force. Chevron like oil pockets were the most universal shape independently of dimples array.

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

10:30 - 11:00 am
Mastering the Art of Honing
Boris Zhmud, 1) Applied Nano Surfaces; 2) BIZOL Lubricants, Uppsala, Sweden

Honing is a stock removal process intended to perfect bore geometry and size by removing a minimal metal layer while generating a finish pattern to provide optimum lubricant retention. The hone process produces extremely tight tolerances in straightness, roundness, size, and surface finish of cylindrical bores. The process expands abrasive stones of suitable grit and grade, under controlled pressure against the work surface while being rotated and reciprocated in the part. Combining these motions produces a cross-hatch pattern in the surface of the part being honed. In this presentation, we will show that the outcome of the honing process – not only in terms of the GD&T but also the tribology of the finished component – depending on a great number of parameters including the machine type, working conditions, tools, process fluid, and most importantly the operator experience. We will also demonstrate advantages of mechanochemical finishing versus conventional mechanical finishing.

11:00 - 11:30 am
Texture and Microstructure Refinement in Surface Severe Plastic Deformation of Strain Hardening Materials
Christopher Saldana, Georgia Institute of Technology, Atlanta, GA

In the present study, gradient microstructure and texture development in wedge-based high friction surface sliding of oxygen-free high conductivity copper was investigated. Microstructural response and evolution of crystallographic texture in severe surface plastic deformation was shown to be controllable in terms of both magnitude and gradient through control of the incident wedge angle and sliding parameters. Equiaxed ultra-fined grains and elongated grains were produced in the subsurface region, which is indicative of dynamic recrystallization at large strains in the subsurface. Subsurface regions exhibited a significant fraction of shear texture along 110 partial fibers. Texture evolution simulated using the visco-plastic self-consistent framework revealed variations in strain level controlling different mechanisms for

rotation of these partial fibers. These results allude to fundamental limits in material processing by severe shear using scalable deformation configurations.

11:30 am - 12:00 pm
Bi-Gaussian Stratified Feature of Impregnated Graphite Surfaces after a Laser Treatment
Songtao Hu, Shanghai Jiao Tong University, Shanghai, China, Tom Reddyhoff, Imperial College London, London, United Kingdom, Weifeng Huang, Tsinghua University, Beijing, China, Xi Shi, Zhike Peng, Shanghai Jiao Tong University, Shanghai, China, Xiangfeng Liu, Tsinghua University, Beijing, China

Graphite materials are increasingly applied to tribological pairs such as thrust bearings and mechanical seals due to its excellent self-lubrication. Laser technology is conducted as an effective effort to improve the lubrication by modifying surface topography and chemical composition. Researchers tried to explain the lubrication improvement arising from a surface-topography modification. However, current works are only focused on a single-stratum surface viewpoint, lacking a bi-Gaussian stratified surface perspective, which has been successfully used on plateau-honing and worn surfaces. In this paper, resin-impregnated graphite surfaces are processed by low- and high-energy laser treatments, leading to hydrophobicity and hydrophilicity, respectively. The bi-Gaussian stratified feature is disclosed on both laser-treated surfaces. Functional performance can be further optimized by controlling the bi-Gaussian stratified surface feature based on the choice of laser parameters.

7K Cumberland 5

Lubrication Fundamentals VII

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Impact of Solvent Dilution Technique on Soft Particle Detection by Laser Particle Counter
Lin Wang, David Holt, Derek Selby, Exxonmobil, Annandale, NJ

There are two types of particles found in lubricants, hard and soft. Hard particles such as dirt, are detrimental to equipment life. Soft particles, such as antifoam additives, are not detrimental to equipment life. Antifoam are designed to be insoluble in the lubricant to enhance their effectiveness and protect the equipment. Consequently, there is a need for an effective lubricant particle count method that can effectively discriminate between the harmful hard particles from the benign/useful particles. The laser particle count methods that are widely used today, unfortunately cannot discriminate between hard and soft particles thus providing inaccurate numbers that lead to unnecessary maintenance decision/work. We have found by use of appropriate solvents to pre-dilute the oils samples, it is possible to solubilize the soft particles. The careful selection of solvent and influence of antifoam chemistry is discussed here.

8:30 - 9:00 am
Influence of Base Oil Ageing on Viscosity Modifiers Behavior
Eliane Gendreau, Hugh Spikes, Janet Wong, Imperial College, London, United Kingdom, Robert Taylor, Neal Morgan, Shell Global Solutions, London, United Kingdom

Effective viscosity modifiers are crucial for the improvement of fuel economy, as they enable the development of low viscosity lubricants. Viscosity modifiers are high molecular weight polymeric additives used to enhance the temperature-dependant viscosity of the oil. Their properties are also shear dependent. As the oil ages, its properties change and its viscosity may be impacted. This work investigates the influence of base oil ageing on viscosity modifiers. The quantification of shear thinning, which is the temporary or permanent decrease in viscosity at high shear rate, is examined. Fluid viscosity measurements will be presented, using friction and film thickness measurements. Local viscosity in the rubbing contact will be studied using fluorescence spectroscopy. The relationship between viscosity

results from friction/film thickness measurements and those from fluorescence spectroscopy will be discussed.

9:00 - 9:30 am
Lubrication of a Stretchable Sheet at the Tool Tip-Sheet Interface in Single Point Incremental Forming (SPIF)
Tao He, Dohyun Leem, Xin Zhang, Newell Moser, Northwestern University, Evanston, IL, Hirotaka Miwa, Toshikazu Nanbu, Murakami Ryou, Nissan Research Center, Kanagawa, Japan, Jian Cao, Qian Wang, Northwestern University, Evanston, IL

Incremental forming is one of the rapidly developing manufacturing techniques for making complex sheet metal parts, in which a tool moves along a controlled path and forms the sheet blanks to a desired shape. Lubrication is considered as an effective way to reduce the tool tip-sheet friction; it may be significantly affected by sheet stretching during the forming process. The current work is focused on modeling the lubrication in SPIF, which includes the Reynolds equation considering surface stretching in different directions, tool tip surface elastic deformation calculated through influence coefficients (ICs) and the discrete convolution and fast Fourier transform (DC-FFT) method, and the sheet surface deformation obtained from finite element method (FEM). Cases are analyzed to reveal the influences of forming parameters, such as tool speed, cone radius, wall angle, and incremental depth, on the best design of SPIF lubrication.

9:30 - 10:00 am - **Open Slot**

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

10:30 am - 11:00 am
Effects of Bearing Material Choice and Engine Oil Viscosity on Journal Bearing Durability in Stop/Start Environments
Annie Ward, Infineum UK Ltd, Abingdon, Oxon, United Kingdom

Ever tightening limits of engine emissions have led to a trend towards lower and lower SAE viscosity grade oils. This decrease in viscosity presents a challenge for oil manufacturer and OEMs alike when considering the balance between fuel economy and engine durability. This problem is exacerbated by the introduction of stop/start technology which increases the level of boundary contact between engine parts. One of the engine contacts most affected by this change is the journal bearing. This paper investigates the effect of viscosity grade and journal bearing material choice on wear using a rig designed to mimic an engine's lifetime of stop/start events. It is clear from the results that with substantial decreases in viscosity grade that a solution is required, either via more complex journal bearing structures or novel oil additive chemistry.

11:00 - 11:30 am
Benchtop Level Testing of Lubricants and Surfaces for Reciprocating Applications: High Frequency Reciprocating Rig.
Giovanni Ramirez, Kora Farokhzadeh, Steven Shaffer, Ivo Miller, Bruker Nano Surfaces, San Jose, CA

Development of new lubricants and surfaces to be employed in reciprocating systems such as engines and compressors always comes with challenges. Among them are how to precisely measure their wear and friction at the laboratory scale before performing more intensive component level tests. High frequency reciprocating rigs have been used for many decades to simulate those systems, and different standard protocols and configurations are conventionally used in lubrication research and development. Here, we present an optimized tribometry setup enabling time effective screening of lubricants and materials at the benchtop scale using the UMT TriboLab. The samples can be tested under simulated conditions to rank the performance of lubricants and surfaces, while monitoring small changes in friction. We also present the critical importance of the calculation method employed to analyze the data obtained by high frequency reciprocating tests.

11:30 am - 12:00 pm
Ball Milled Graphite Nanoplatelets as a Biolubricant Additives for Friction and Wear: An Attempt to Develop a 'Green' Lubricant
Emad Omrani, University of Nevada - Reno, Hillsboro, OR, Pradeep Menezes, University of Nevada, Reno, Reno, NV, Pradeep Rohatgi, University of Wisconsin - Milwaukee, Milwaukee, WI

Role of ball milled graphite nanoplatelets (GNPs) as an oil additive is investigated. The main objective of this study is to investigate and explain the enhancement mechanisms of GNPs at the contact surface during tribological testing. Effect of GNPs concentration and applied load are studied. Remarkably, the experimental analysis demonstrates the feasibility of the ball milled GNPs influential in a notable improvement in tribological performance of nanolubricants. The proposed mechanism to describe the effect of GNPs in boundary lubrication condition is "reduced direct metal-metal contact area" at the contact surface that is confirmed by cancerization of worn surface where a graphite nanoplatelets which has low shear strength layers sits between two contacting surfaces and separates the two sliding metal surfaces with no actual contact between them. This means that there is less formation of asperity junctions between the two surfaces.

7L Cumberland 6

Condition Monitoring II

Session Chair: TBD
Session Vice Chair: TBD

8:00 - 8:30 am
Root Cause Analysis of Varnish Generation in Lube Systems
Jatin Mehta, Cristian Soto, Fluitec International, Bayonne, NJ

Varnish formation has plagued many lube systems. The formation of varnish is a common phenomenon, but still one uncovers various forms of varnish formed in the lubricating systems such as compressors, gas and steam turbines which are unusual and not derived due to the in-service fluid. This paper will showcase various root cause analysis of the deposit formation as observed in the real field scenario. This paper also describes how regular condition monitoring fails to detect early symptoms of the varnish formation in the system.

8:30 - 9:00 am
Development of an Oil Split Test Method for Emulsions without the Use of Strong Oxidizing Acids
Jon Lewis, Quaker Chemical Corp., Conshohocken, PA

Fluid concentration of in-use metalworking coolants is often monitored by acid split testing using strong oxidizing acids (such as nitric and/or sulfuric acids). While effective, this test method results in the generation of hazardous waste and has a high potential to result in severe chemical burns or inhalation of toxic fumes during the course of testing. An alternative oil split method was developed utilizing a combination of a magnesium sulfate (Epsom salts) solution and a quaternary ammonium chloride polymer to achieve the split. This new method provides similar splitting of a coolant's lipophilic components to the traditional acid split methods without the need for strong oxidizing acids. Implementation of this method for routine monitoring of metalworking fluids in Quaker's lab has resulted in a significant reduction in hazardous waste generation and improved worker safety.

9:00 - 9:30 am
Identification of Unknown Elements in a Lubricant Sample and High Throughput Wear Metals Analysis by ICP-OES
Autumn Wassmuth, PerkinElmer, Shelton, CT

When in service lubricants show an increase in concentration of key wear metals it can be an indication that maintenance is required. The elemental content of additives and contamination that signify that maintenance is needed are normally known and trended over time. For a lubricant with unknown composition, ICP-OES instruments can take an elemental fingerprint of the sample without calibrating for concentration. This elemental fingerprint can reveal what elements are present by allowing the user to see each element at multiple wavelengths simultaneously. During analysis the same simultaneous measurement of elements can lead to a measurement time that is less than the time required for sample uptake and washout. By adding a sampling valve to an ICP-OES instrument, the uptake and washout times are reduced allowing the sample to sample time to be around 25 seconds, without reducing data quality. While other advancements will increase sample throughput throughout the lab.

9:30 - 10:00 am
Determination of Total Base Number in In-Service Lubricants Using FT-IR
Ariel Bohman, PerkinElmer Inc., Shelton, CT

The Total Base Number or TBN is a measure of the base reserve of a lubricant. This base reserve is used to neutralize acidic compounds that are generated as the result of combustion. These acidic compounds must be neutralized to prevent and reduce corrosion. Current wet chemistry methods involve the titrimetric determination of TBN which are time consuming and involve the use of hazardous chemicals which pose both safety and disposal concerns. FT-IR spectroscopy coupled with chemometric modelling can be used to develop a rapid and reagent-less method for the determination of TBN for in-service lubricants that can be implemented into existing infrared oil analyses. This presentation will discuss the development and implementation of chemometric models for the determination of TBN and provide examples of developed models for the analysis of in-service lubricant TBN.

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

10:30 - 11:00 am
In-Situ Analysis of Degraded Gear Oils Using Ultrasonic Reflectometry
Tomos Brenchley, Michele Schirru, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Piezoelectric transducers can be used to measure the viscosity of oil by monitoring the amplitude of the reflection of an ultrasonic shear vibration that is in contact with the oscillating quartz. Applying this approach in an engine is restricted due to the harsh conditions which degrade the oscillator. Recent developments have overcome these limitations by making the sensor remote from the lubricant by employing a thin matching layer. This approach can be used to build a simple viscometer; in addition by exciting the transducer at different frequencies we can vary the shear rate applied to the oil. An oil was aged in an environmental unit assembly and was tested using this novel viscometer. Tests found the viscometer can measure the viscosity of lubricating oils and more specifically, the high frequency components of the ultrasonic spectrum can indicate the sudden change in base oil structure, while the lower frequency component is indicative of the whole lubricant performance.

11:00 - 11:30 am
Oxidation Analysis of Lubricants Using Ambient Pressure Differential Scanning Calorimetry (DSC) Techniques to Determine Antioxidant Performance
Keith Schomburg, PerkinElmer, Magnolia, TX

The ability to monitor oxidation properties in lubricants is an important laboratory analysis for any lubrication monitoring program. The oxidative stability of lubricating fluids is typically evaluated using Rotating Pressure Vessel Oxidation Test (ASTM D2272), Linear Sweep Voltammetry (ASTM D6971) and other oxidation analysis techniques. In most oxidation tests, copper is used as an oxidation catalyst. Recent studies show copper can be used for the oxidative analysis of lubricants using Differential Scanning Calorimetry (DSC) techniques. The use of copper as an oxidation catalyst in DSC has the effect of reducing the oxidation temperature allowing ambient pressure DSC techniques to be used for antioxidant studies. In this presentation, new and in-service lubricant samples were tested using copper

and ambient pressure DSC techniques to determine the Oxidation Onset Temperature (OOT) and Oxidation Induction Temperature (OIT) values for evaluation of the remaining useful fluid life.

11:30 am - 12:00 pm
Chemical Investigations of Lubricant Degradation
Simon Eiden, OWI, Herzogenrath, Germany

In the tribological system, the grease underlies a variety of different degradation mechanisms. Beside the mechanical stress, the thermo-oxidation is one of the occurring degradation reactions. The aim of this project was the characterization of grease formulations via Chemiluminescence-method or thermo-gravimetrical analysis. The investigations of greases sampled from a failed rolling bearing showed a partly thermo-oxidative degradation. It seems, that the thickener stability is a significant origin during grease related failures. The chemical analysis via Fourier-Transformation-InfraRed Spectroscopy was able to detect thickener components in the grease matrix. A degradation of thickener during rolling bearing application was shown. The results were correlated with the activation energies determined via thermo-gravimetric analysis and calculated according Ozawa, Flynn and Wall with non-isothermal measurements.

8A Legends D

Rolling Element Bearings IV

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
A Mathematical Emulation of Bair's High Pressure Visualization Cell and Improved EHL Traction Analysis for Heavily Loaded Rolling Contacts
Coda Pan, Rensselaer Polytechnic Institute, Millbury, MA, Daejong Kim, University of Texas at Arlington, Arlington, TX, Michael Khonsari, Louisiana State University, Baton Rouge, LA

Observation of shear bands in rheological studies suggests existence of a shear stress threshold limitation in thin film flows of a Newtonian viscous fluid. The phenomenon is relevant to (1) interpretation of experimental observations found in a High Pressure Flow Visualization Cell (HPFVC) and (2) use of Barus viscosity law in EHL studies. The Mohr-Coulomb failure criterion, fashioned after the practice of soil mechanics, was suggested to identify a **L**imiting **S**hear **S**tress **T**hreshold (LSST). LSST can also be associated with the theory of failure for ductile materials in terms of the threshold limitation of distortion energy. Two draft manuscripts are undergoing peer review for publication in STLE Transactions. Derivation of the LSST constitutive equation is described in the 1st manuscript entitled “Shear Bands in High Pressure Flow Visualization Cell”. The 2nd manuscript deals with “Influences of Barus-Newton Threshold on Ertel-Grubin Analysis”.

2:00 - 2:30 pm
Numerical and Experimental Performance Analysis of an Aircraft Engine Roller Bearing Using under Race Lubrication Method
Rami Kerrouche, University Saad Dahlab of Blida 1, Blida, Algeria, Azzedine Dadouche, Mahmoud Mamou, National Research Council Canada, Ottawa, Ontario, Canada, Salah Boukraa, University Saad Dahlab of Blida 1, Blida, Algeria

This paper studies the air-oil two-phase flow characteristics inside a cylindrical roller bearing as well as the temperature distribution and power loss. Numerical simulations have been performed to determine the oil distribution inside the bearing cavity and its effect on bearing temperature under different rotational speeds and oil flow rates. Under-race lubrication method was considered in this study. A commercially-

available computational fluid dynamic (CFD) software was used to model the bearing and run the simulations. Experimental measurements of bearing temperature and friction torque have been carried out on a high speed rolling bearing test rig. The rig allows a smooth control of speed, load, and oil supply temperature to the test bearing. The rig runs at speeds up to 35,000 rpm with the capability of applying radial loads up to 4,500 N.

2:30 - 3:00 pm
Real-Time Modeling of Thermal Interactions in Cryogenic Ball Bearings
Pradeep Gupta, PKG Inc, Clifton Park, NY, Howard Gibson, NASA/MSFC, Marshall Space Flight Center, AL

Real-time modeling of thermal interactions in cryogenic ball bearings for liquid oxygen turbopump applications is based on classical differential equations of motion of bearing elements and step-wise time-averaging of transient heat generations. As the thermal interactions converge the time-varying temperature fields approach steady values. Bearing performance simulations are modeled in real-time over experimental time cycles. Steady-state solutions are independent of initial conditions as expected from stable time domain integrations. Model predictions of bearing heat generations are in good agreement with experimental measurements for both all steel and hybrid ball bearings. Under prescribed applied load and speed, while the ball/race contact stress is higher in a hybrid bearing, the contact heat generation is significantly lower in comparison to that in an all steel bearing, particularly under heavily loaded high-speed conditions.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Modeling Heat Generation in Turbine Engine Rolling Bearings
Jared Taketa, Craig Price, Rolls-Royce Corp, Indianapolis, IN, Pradeep Gupta, PKG Inc, Clifton Park, NY

An updated dynamics model is presented to couple bearing element motion with thermal interactions in rolling bearings. Although lubricant churning and drag constitute majority of heat generation in most turbine engine bearings, lubricant traction becomes significant as the applied load increases. While churning and drag effects are based on classical laminar and turbulent flow theories, independently measured lubricant rheology, including shear dependence of viscosity, is used to model lubricant traction. Transient heat generations are time-averaged over thermal time step to compute time varying temperature fields in the bearing, which alter properties of bearing materials, operating bearing geometry and rheology of the lubricant. As the transient solutions converge to stable operating temperatures, bearing heat generation approaches the expected steady-state value. Heat generation predictions for both ball and rolling bearings are in good agreement with measured experimental data.

4:00 - 4:30 pm
Thermal Conductivity and Flash Temperature of Bearing Steel
Tom Reddyhoff, Imperial College, London, United Kingdom, Aaron Schmidt, Massachusetts Institute of Technology, Cambridge, MA, Hugh Spikes, Imperial College, London, United Kingdom

Calculation of flash temperatures of tribological components requires values of the thermal conductivity of the contacting materials. These values are rarely measured by researchers or designers, who instead rely upon values taken from the literature or from suppliers. This presentation describes measurement of the thermal conductivities of three materials of tribological interest 52100 bearing steel, zirconia and tungsten carbide. A Frequency Domain Thermoreflectance method is employed that is able to measure near-surface thermal conductivity from finished components including those with curved surfaces such as ball bearings. For most materials studied the thermal conductivity measured is close to that suggested by suppliers and in handbooks. However for AISI 52100 the value measured is less than half that generally stated in the literature. The possible reasons for this and its implications are discussed.

4:30 - 5:00 pm
Measurement of Free Volume of Lubricants from Pressure Dependence of Bulk Modulus
Bo Zhang, Toshifumi Mawatari, Saga University, Saga-shi, Saga, Japan

The free volume of a liquid gives the liquid with fluidity. In spite of its paramount importance the only existing measurement technology of the free volume is for a solid and no for a liquid since the mobility of the free volume in the liquid. In this paper it is proposed that the free volume of a liquid may be measured through measuring the dependence of the bulk modulus of the liquid on the pressure. Since the volume of a liquid consists of the occupied volume and the free volume the bulk modulus can be expressed as $1/K=-dV/Vdp=-(dV_f+dV_o)/Vdp=f/K_f+1/K_o$ (1) where is the fractional free volume. Assuming that is independent of the pressure we have $f=f_0\exp(-p/K_f)$ (2) $K=K_fK_o/(K_f+fK_o)=K_fK_o/(K_f+K_of_0\exp(-p/K_f))$ (3) Equation (3) was used to extract the parameters of the bulk modulus of the free volume, the bulk modulus of the occupied volume and the initial fractional free volume for the lubricant KTF1. It was found that K_f=0.29 GPa, K_o=10 GPa, and f_o=0.18.

5:00 - 5:30 pm
Investigation of the Synthetic Stiffness for Elastohydrodynamically Lubricated Cylindrical Roller Bearings
Zeliang Xiao, Xi Shi, Shanghai Jiao Tong University, Shanghai , China

The cylindrical roller bearing generally operates in elastohydrodynamic lubrication line contacts and its dynamic responses are closely related to the stiffness of lubricated contacts. The synthetic stiffness for elastohydrodynamically lubricated cylindrical roller bearing is derived from the oil film stiffness and contact stiffness of bearing. The oil film stiffness is calculated according to the relationship of pressure and film thickness of viscoelastic fluid while the contact stiffness of bearing is computed by using a contact mechanics approach. Effects of bearing applied load and rotation speed on the synthetic stiffness are investigated. The results show that the oil film stiffness is larger than the contact stiffness of bearing and the synthetic stiffness mainly depends on the latter. However, the oil film stiffness is of benefit to impact resistance and vibration reduction of bearings.

8B Music Row 1

Biotribology III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Contact Mechanics for Characterization of Hydrogel Material Properties
Michelle Oyen, East Carolina University, Greenville, NC

Indentation techniques have recently been adapted for the study of hydrated materials, including biological tissues and hydrogels. Both natural and synthetic hydrogels have been characterized using indentation and nanoindentation across a wide range of experimental length-scales. The material response is shown to be greatly dependent on the chemical bonding within the hydrogel, i.e. whether the network is physically or chemically cross-linked. Hydrogels in particular are an attractive system for studying structure-properties relationships, as the water fraction can be systematically varied for a single polymer, and different polymers with the same water fraction can be compared. Based upon knowledge of the properties of each individual component, composite hydrogels can be created to mimic the overall response of complex biological materials to create multi-component tissue engineering scaffolds.

2:00 - 2:30 pm
Shear-Induced Cellular Death Response
Samuel Hart, Juan Urueña, Angela Pitenis, Padraic Levings, WG Sawyer, University of Florida, Gainesville, FL

The design of soft-implants is a very arduous task in which many factors must be considered to prevent or minimize a biological response. Yet, despite these efforts recent work has shown that sub-clinical inflammation may occur during soft contact lens wear in the eye. This study characterizes the contributions of frictional shear stress to sterile inflammation and cell death in vitro. Shear induced cell death was studied in human telomerase-immortalized corneal epithelial (hTCEpi) cells stained with apoptosis and necrosis markers. Additionally, actin, ZO-1, and nucleus stains provided further insight into the cytoskeletal and cellular death responses to shear stress. Tribological experiments were performed on a fluorescence microscope in which a soft hydrogel probe slid against cells to provide a range of shear stresses. It is evident that among the many factors considered during the design of soft implants, surface shear stresses must also be taken into account.

2:30 - 3:00 pm
Mitigating Cartilage Strain and Shear by Simulating Activity Regimes with In-Situ Cartilage Explants
Steven Voinier, Brian Graham, Axel Moore, Christopher Price, David Burris, university of Delaware, Newark, DE

Although the public understands regular exercise benefits overall health, recent epidemiological studies have also demonstrated cartilage integrity necessitates routine activity. One of the most likely contributors is articulation-induced cartilage rehydration: articulation actively restores hydration and its dependent biomechanical outcomes such as thickness, interstitial pressure, load support, mechanical stiffness, and lubrication. In this study, we leverage the tribological rehydration phenomenon to elucidate how both activity intermittency and volume affects the biomechanical functions of cartilage under well-controlled sliding conditions. We quantified the biomechanical response of explants in the cSCA configuration over size-adjusted 'equivalent days' of varying intermittent-activity patterns and total daily activity volume. Through this approach, we can deduce an optimal volume of intermittent activity pattern that maximizes interstitial pressure while minimizing shear stress.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Effect of Shoe Outsole Backing on the Coefficient of Friction
Arian Iraqi, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Footwear with high coefficient of friction (COF) against lubricated floor may mitigate slipping accidents. COF varies considerably across and within shoes brands. This variation may be due to the supporting midsole that affects contact area. This study investigated the effect of this support system on the COF. Eleven pairs of shoes with outsole tread were tested on a ceramic and laminate tile with canola oil using a robotic shoe tribometer. The contact area of the tread was used as a metric to identify between outsole backings that either fully or partially brought treads into the contact region. The outsole designs were similar between shoes with good and poor support system. The shoes with the good support system had 15.5% and 26.7% higher COF on ceramic and laminate tile, respectively, compared to shoes with poor support. The suboptimal design of shoe outsole backing negatively impacts COF by reducing the contact area.

4:00 - 4:30 pm - **placeholder 1 for late submitted abstracts**

4:30 - 5:00 pm - **placeholder 2 for late submitted abstracts**

Power Generation II

Session Chair: M. Hobbs, EPT, Calgary, Alberta, Canada
Session Vice Chair: S. Rea, Lanxess Corp., Perkasie, PA

1:30 - 2:00 pm
Fluorescence Spectroscopy for Online Condition Monitoring of Machinery Lubricants
Pooja Suresh, Oleg Sosnovski, Gastops, Ottawa, Ontario, Canada

Lubricating oils contain antioxidant additives in order to protect the base oil from thermal oxidation, thereby preventing loss of lubricity and formation of oxidation products and deposits such as sludge and varnish. Monitoring the antioxidant levels provides early indication of oxidative degradation of the lubricant, allowing for condition-based maintenance ahead of potential damage to the equipment. This translates to lower cost of maintenance and improved equipment availability, which are key drivers for the power generation industry. Current techniques for measuring antioxidant additive content require expensive laboratory-grade equipment, sample preparation, consumables and operation by trained personnel, making them unsuitable for online monitoring. This presentation discusses the application of an alternative technique using fluorescence spectroscopy technology that allows for real-time, online monitoring of antioxidant additive levels.

2:00 - 2:30 pm
Consequences of Incorrect EHC Fluid Maintenance and Opportunities for Improvement
Peter Dufresne, EPT, Calgary, Alberta, Canada

EHC systems are one of the most critical hydraulic applications in power plants operating steam turbines. Despite their importance, common fluid maintenance practices often fail to keep the EHC fluid in acceptable condition. With a number of recent catastrophic failures, OEMs and insurance companies have become increasingly interested in oil quality to confirm that sites are operating within established industry specifications. Site managers, therefore, need to appreciate the implications of poor fluid condition and the importance of effective EHC fluid maintenance. Only then can they ensure that effective maintenance programs are in place with sufficient budgets established. This paper will review common issues observed and review opportunities that leverage technology to improve fluid quality in EHC applications.

2:30 - 3:00 pm
Understanding EHC Fluid Condition Monitoring

Ken Brown, Canoil, Mississauga, Ontario, Canada, Matthew Hobbs, EPT, Calgary, Alberta, Canada

Triaryl phosphate esters have been used as fire-resistant hydraulic fluids in the control systems of steam turbines for over 50 years. These fluids significantly reduce the risk of fire but their maintenance has been problematic at some stations. This is a combination of many factors ranging from system design to failure to keep up to date with current operating procedures and best maintenance practices. Some turbine manufacturers have also been slow to revise fluid condition monitoring requirements including recommended tests and their limits. This presentation will cover a number of root causes of fluid degradation in addition to more recent test methods and fluid conditioning/remediation options.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Evaluation of Turbine Oil Performance
Jatin Mehta, Fluitec International, Bayonne, NJ
Significant advancements have been made in the last two decades in turbine oil formulations, utilizing superior base stocks and antioxidant chemistries. The result is that turbine oils used in even the most thermally stressful gas turbines can provide long-life and good performance provided they are maintained properly. Turbine oils are evaluated using various oxidations test under oxidative, thermal, hydrolytic and catalytic conditions. The test methods used in the industry are D943, D4310, and D7873 in additional to OEM specific tests. The Turbine Oil Performance Prediction test helps to determine the long-term performance of the turbine oil in steam and gas turbines. This paper will assess the oxidation resisitance, antioxidants stability, varnish potential/sludge formation and various performacne properties of the turbine oils. This paper will describe the performance of commercially available oils using Turbine Performance Prediction Tests.

4:00 - 4:30 pm - **Business Meeting**

8D Music Row 4

Seals I

Session Chair: T. Lai, John Crane
Session Vice Chair: K. Malik, Ontario Power Generation

1:30 - 2:00 pm
Impact of Natural Surface Texture on the Lubrication of Mechanical Face Seals
Noel Brunetiere, Institut Pprime, Futuroscope Chasseneuil cedex, France

Some of the materials used for the seal faces exhibit porosity whose characteristics depends on their manufacturing process. The pore on the seal surface can be considered as dimple-like natural surface texture. Compared to artificial surface texture, their size and location are random. In this paper, the influence of these pores on the lubrication of mechanical face seals is numerically studied. The model solves the Reynolds equation coupled with a mass-conserving cavitation algorithm. The influence of the statistical parameters of the pore size and location distributions on the lubrication are analyzed.

2:00 - 2:30 pm
Wear and Surface Fatigue of Rubbers for Static Seals in Reciprocating Sliding Contact
Joichi Sugimura, Hiroyoshi Tanaka, Kyushu University, Fukuoka, Fukuoka, Japan

This paper describes a study on the effect of contact conditions on wear and surface fatigue of rubbers for high-pressure gas seals in reciprocating sliding. Reciprocating sliding tests are conducted with NBR and EPDM rubbers filled with different fillers and AISI 316L stainless steel in hydrogen, air and in vacuum by using a pin-on-disk type friction test rig. Fillers include carbon black and silica. The rubbers exhibit two different failure modes of wear and cracking depending on sliding conditions and filler materials. Some rubbers filled with larger carbon black and silica tend to be damaged by cracking rather than wear. The relationship of damage modes with the conditions and the mechanics involved in the deferent behaviors are discussed.

2:30 - 3:00 pm
Frictional Properties of Diamond Coated (and UNCD® coated) Silicon Carbide and Tungsten Carbide Mechanical Seal Faces
Mark Lapansie, Charles West, Jon Hohol, Advanced Diamond Techologies, Inc., Romeoville, IL

Hard ceramic mechanical seal face materials, such as silicon carbide and tungsten carbide (cemented carbide), are frequently used in pumping applications involving aggressive media or poor lubrication.

However, high friction between these materials causes increased rotational torque and excessive heat generation. An ultrananocrystalline diamond (UNCD®) coating on these materials significantly reduces the coefficient of friction (CoF) in seal rotation, resulting not only in less torque and heat generation, but also reduced energy consumption and therefore reduced running costs. In this study, mechanical seal rings, both with and without UNCD coating, are evaluated in an apparatus which allows direct torque measurement of a multi-spring mechanical seal. The coefficient of friction (CoF) of each material pair in deionized water is reported, and a model of energy savings based on the coefficient of friction is proposed.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Effect of Combined Mechanical Stress and Salt Spray Aging on Dynamic Friction Behavior of O Rings
Jian Wu, Haohao Li, Youshan Wang, Benlong Su, Zhibo Cui, Zhe Li, Harbin Institute of technology,Weihai, Weihai, Shandong, China

Rubber seals has become one of the key components in industry sealing devices. However, environment becomes more severe due to ocean application fields. Thus, a combined salt spray and mechanical stress test platform was developed for studying aging process of rubber materials. Then, influence of mechanical stresses and salt spray aging on dynamic friction behavior of rubber materials have been investigated, and the coupled aging mechanism of rubber materials have been studied by Nicolet 380 ATR-FTIR and DSX510. Finally, a friction finite element model of O ring have been developed, which considered the effect of combined mechanical stress and salt spray aging. It can be seen that combined salt spray and mechanical stress aggravate rubber aging reaction; contact pressure decreases obviously, when aging time and tensile strain increases. The method based on accelerated aging test and finite element method provides a basis for design and optimization of rubber seals.

4:00 - 4:30 pm
Dynamic Behavior of a Fractional Viscoelastic Seal with Solid Contact
Arne Leenders, Leibniz University Hannover, Hannover, Germany

An important topic in computer aided simulations of seals concerns dynamical effects close to reality, like starting processes and states, where impulsive loads affect the seal. Aspects such as properties of the sealing material and also the nonlinear contact between seal and shaft have to be considered. Seals made of elastomers possess viscoelastic characteristics. The mathematical description of viscoelasticity is often made by Prony parameters. To describe the material with a lower number of parameters, that fit the measured material even better, we will use fractional derivatives. A seal must keep closed contact to the shaft under every operating condition. We will formulate the contact state as a linear complementarity problem. This method is able to handle contact with friction. Methods of model order reduction are used to lower the computational effort. This created simulation can be applied for transient effects of seals with unlubricated contact in an efficient way.

4:30 - 5:00 pm
Simulation of Mixed Friction between a Surface Textured Seal and a Smooth Rod
Markus Brase, Matthias Wangenheim, Leibniz University Hannover, Hannover, Germany

Improved friction behavior is an important design objective in the development process of dynamic sealing systems. Surface texturing is one possibility to lower friction in the sealing contact by reducing the area of contact and increasing the lubrication gap. In this study, mixed friction between a surface textured seal and a smooth rod is simulated. The simulation model is based on a coupled fluid mechanics and contact mechanics analysis. The surface texture is applied to the seal surface in the form of deterministic micro-dimples. For the first time, a wide range of different dimple sizes is considered, which are suitable for mass production by injection molding or vulcanization. The impact of different dimple diameter, distances and depths on the friction force is analyzed. In order to find a surface with most friction reduction potential, mixed friction of the textured seals is compared to the corresponding friction of a

smooth seal.

5:00 – 5:30 pm - **Seals Business Meeting**

8E Music Row 3

Tribochemistry - Materials Tribology and Nanotribology Joint Session III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Synthesis and Characterization of Novel Ni-Matrix Composites
Surojit Gupta, Maharshi Dey, Matt Fuka, University of North Dakota, Grand Forks, ND, Nikhil Murthy, Stephen Berkebile, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD

This paper reports the synthesis and characterization of novel Ni-MAX composites by adding 5 vol% , 10 vol% , 20 vol% and 30 vol% MAX (Ti3SiC2 Ti3AlC2, and Cr2AlC) particulates in the Ni-matrix. Detailed SEM investigation showed that the MAX Phases are dispersed well in the Ni-matrix with minimal interfacial reactions. The mechanical and tribological behavior of these samples were further characterized . From SEM investigations, it was construed that the tribology of these composites are governed by the formation of tribofilms. A comparative analysis of the effect of different MAX phases on mechanical and tribological behavior will be documented as a part of this study.

2:00 - 2:30 pm
Tribofilms in Wet Clutch Applications
Darryl Williams, Afton Chemical, Richmond, VA

Anti-shudder durability performance in a clutch friction system is a key driver in current and future transmission fluid development. We have developed surface analysis techniques that have uncovered important relationships between the surface morphology and chemistry of wet clutch materials and anti-shudder durability. Recently it has been found that tribofilm formation on the steel plates in wet clutches play a role in preserving the surface of the steel during a durability test. This effect is related to preservation of the friction level and anti-shudder performance of the wet clutch. Characteristics of tribofilms formed in wet clutches will be described.

2:30 - 3:00 pm
Wear of Diamond in Scribing of Multi-crystalline Silicon
Arkadeep Kumar, Lawrence Berkeley National Lab, Berkeley, CA, Shreyes Melkote, Georgia Institute of Technology, Atlanta, GA

Challenge in slicing of low-cost multi-crystalline silicon (mc-Si) by diamond wire sawing (DWS) is increased wire consumption due to greater wear of the diamond compared to slicing more expensive mono-crystalline silicon (mono-Si). We present scribing of mc and mono-Si with two diamond indenters of the same geometry. We find that the forces generated in scribing of mc-Si are higher than in scribing of mono-Si, consistent with the corresponding higher tip radius of curvature (due to wear) of the diamond on mc-Si compared to diamond on mono-Si. Scanning electron microscopy and confocal microscopy of the diamond indenters show that wear is primarily due to physical micro fracture and blunting of the diamond. Raman spectroscopy shows evidence of stress-induced phase transformation of the diamond and the formation of compressive residual stress in the diamond. Plausible reasons, including the role of material inhomogeneity in mc-Si, for the wear of diamond during scribing are given.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Effect of Lubricants on Friction Properties of the Steel/PEEK Contact
Go Tatsumi, Monica Ratoi, University of Southampton, Southampton, United Kingdom, Yuji Shitara, Kiyomi Sakmoto, JXTG Nippon Oil & Energy Corporation, Yokohama, Japan, Brian Mellor, University of Southampton, Southampton, United Kingdom

Polymers and polymer-based composites are becoming preferred materials in many tribological applications because of their lightweight, reduced noise and self-lubricating properties. Poly-ether-ether-ketone (PEEK) has better mechanical properties and higher thermal stability than other conventional polymers and therefore is recommended for applications with severe conditions. PEEK can be used unlubricated but lubrication has the potential to further reduce friction and wear. To elucidate the effect of lubrication and especially that of some ubiquitous friction modifiers and anti-wear additives, this study carried out tribological tests using PEEK discs and steel balls with a smooth or rough surface. It was found that lubrication with poly−α−olefin significantly reduced friction in all lubrication regimes compared with unlubricated tests, regardless of the surface roughness. On the other hand, the effect of friction modifiers and anti-wear additives was dependable on surface roughness.

4:00 - 4:30 pm
Electric Field Effect on the Lubrication Performance of Cus Nanoparticle Additive
Chenxu Liu, Tsinghua University, Beijing, China, Ofir Friedman, Ben-Gurion University of the Negev, Be'er-Sheva, Israel, Yu Tian, Tsinghua University, Beijing, China, Yuval Golan, Ben-Gurion University of the Negev, Be'er-Sheva, Israel, Yonggang Meng, Tsinghua University, Beijing, China

Active control of friction has been a goal pursued by scientists for many years. Here we use electric potentials to investigate the lubrication performance of CuS nanoparticle additive in ester lubricant for the friction pair of ZrO_2 ball and copper plate. When the potential of the copper plate is lower than -14 V, the friction coefficient decreases from 0.18 to 0.05 after an induction period of running-in, the time of which is shorter if the voltage is lower. The significant friction reduction is attributed to the excess of positively charged nanoparticles in the vicinity of the negatively charged surface.

4:30 - 5:00 pm
Analysis of the Tribochemical Absorbed Films on Steel Surfaces Lubricated with 1,3-Diketone
Shumin Zhang, Chenhui Zhang, Xinchun Chen, State Key Laboratory of Tribology, Tsinghua University, Beijing, China, Ke Li, Intelligent Transport Systems Research Center, Wuhan University of Technology, Wuhan, China

The tribological properties between steel surfaces with a ball-on-disc geometry in a rotating contact using 1,3-diketone and polyalphaolefin (PAO2) lubricants are investigated. Compared with PAO2, an ultralow friction coefficient of 0.007 is achieved with 1,3-diketone. It is found that a tribochemical reaction occurs between diketone molecules and steel surfaces, which lowers the contact pressure dramatically. Moreover, chemically adsorbed films are formed on the rubbing surfaces, and can stably exist at low contact pressure. In addition, a well-developed conformal contact surface morphology is generated between two friction pairs, which can be helpful to the realization of ultralow friction. The results of this study reveals that 1,3-diketone lubricant has a good lubricating performance on steel surfaces, and can be extended to industrial applications for its enormous potential.

8G Cumberland 1

Grease II

Session Chair: S. Crawford, Primrose Oil Company,
Session Vice Chair: W. Zhang, NanoMech, Springdale, AR

1:30 - 2:00 pm

Grease Evaluation for the Continuous Caster Bearings: Development of an Innovative Technique to Accurately Measure Water Content in These Greases)

Kuldeep Mistry, Carl Hager, Nigel Los, The Timken Company, North Canton, OH, Jill Myers, The Timken Co., Nortth Canton, OH, Raj Shah, Koehler Instruments, Holtsville, NY, Hank Levi, Scientific Gear LLC, Fairfax, VA

The continuous caster is one of the most challenging environments for bearings from the ladle, down through the bender and segments, to the discharge area. Many critical positions are subject to high loads and low rotational speeds, often at elevated temperatures, in an environment heavily contaminated with water, steam and scale. The selection of the bearings, lubrication, seals, and maintenance practices, are critical to address a variety of customer requirements.
In this study, we will discuss grease selection for the continuous caster bearings. The following grease performance attributes were included in this investigation, including: load carrying capacity, wear protection, water resistance, corrosion resistance, thermal stability and grease mobility. These properties are crucial for service life of the bearings and are very much dependent on the grease formulation. The other goal of this study was to develop an accurate procedure to measure the water content of lubricating grease.

2:00 - 2:30 pm

Use of High Temperature Oven Aging to Determine COF of Candiate Greases as Oil Loss within the Grease Occurred

Bryan Johnson, Arizona Public Service, Tonopah, AZ

Standby operation of a machine located in a high temperature environment required qualification prior to use. An simple innovative oven aging process was designed that would stress the grease chemically while also reducing its percentage of oil. A Pin and Vee block combination was used to test COF of the three candiadate greases as they were aged. The pins were drilled and a thermocouple added to allow continuous temeperature monitoring of the pin and vee tests as the COF was measured with increasing loads applied by the instrument. New grease samples from each of the three candiadates considered were tested at different temperatures to establish baselines prior to the oven aging. Aged candiate greases were then tested in a full scale valve stem/stem nut. The presentation will discuss details of the aging process used, the set up of the Pin and Vee instrument to include temperature measurements and the results from full scale testing of a valve stem/stem nut application.

2:30 - 3:00 pm

A New Anti-Wear Grease Containing Nanoparticles

Yan Chen, Xuezhen Wang, Abraham Clearfield, Hong Liang, Texas A&M University, College Station, TX

Galling wear is one of the common wear mechanisms in oil and gas exploration and metal forming. One way to reduce galling was to use grease lubricant. In this research, a new grease is developed containing α-zirconium phosphate (ZrP) nanoparticles. Experiments showed that by adding those nanoparticles, the friction between steels (4130 against P530) was reduced by 10%. More significantly, the areas being galled were reduced by 80% with the addition of 0.5%wt particles. This presentation discusses mechanisms of anti-galling induced by adding nanoparticles.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm

When Your Supply of Grease Ceases and You Need a Replacement, What Do You Do?

Michael Moneer, Peter Lee, Southwest Research Institute, San Antonio, TX

A very large gear set for an external crane was using a grease that was to be discontinued. In order to find a replacement that would do the job, rheological and characterization of the grease was undertaken using a rheometer and an MTM. This presentation will cover the work undertaken including the test profile developed for the MTM and results for different greases tested.

4:00 - 4:30 pm
Biolubricant Enhancement Using Combined Raw Carbon Nanostructures
Andrey Pérez, Cinvestav, Querétaro, Querétaro, Mexico

We propose using high viscosity vegetable oils additivated with different unpurified or raw Carbon nanostructures such as; MWCNTs, Graphene Oxide and Nanopearls. We aim at meeting the requirements to replace traditional products derived from non-renewable sources while using Carbon Nanostructures to obtain desired Friction coefficients. Unpurified Carbon Nanostructures containing nanoparticles such as Fe, Ni and Co constitute a simple option to improve the tribological properties of biolubricants; this approach avoids both purification and functionalization thus diminishing production costs. Tribological testing was performed using pin-disc, twin-disc and 4-Ball machines for a complex ester and a linseed oil additivated with raw Carbon Nanostructures. SEM/STEM characterization helped assess morphology and structure of Carbon Nanostructures and worn metal surfaces. XRD, FTIR and ICP analyses were used to characterize the Carbon Nanostructures used to additivate biolubricants.

4:30 - 5:30 pm - **Grease Business Meeting**

8H Cumberland 2

Materials Tribology V

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Environmental Sensitivity and Aging of Composite Solid Lubricant Coatings
Michael Dugger, Brendan Nation, Sandia National Laboratories, Albuquerque, NM, John Curry, Sandia National Laboratory, Albuquerque, NM

Solid lubricants offer predictable friction and wear behavior over a wide range of temperatures, pressures and sliding speeds, but most also exhibit some form of environmental sensitivity. This can take the form of well-known variations in friction and wear behavior that are dependent upon the operating atmosphere, or long-term aging in the presence of species in the environment that alter the film's chemistry and performance. Many composite solid lubricants have been developed in recent decades to mitigate environmental sensitivity and aging. In the family of MoS_2-based materials, for example, this has included co-depositing the solid lubricant with Sb_2O_3, Ti, Au or other species. In this presentation several potential mechanisms of friction variation during aging will be discussed. The performance and composition changes exhibited by several composite films when exposed to an accelerated aging environment will be described.

2:00 - 2:30 pm
Improving Tribological Performance of PDA/PTFE Thin Film by Incorporating Ag Nanoparticles in the PDA Underlayer
Dipankar Choudhury, Isabelle Niyonshuti, Jingyi Chen, Min Zou, University of Arkansas, Fayetteville, AR

Polytetrafluoroethylene (PTFE) coating adhesion strength to a metallic substrate is poor. Polydopamine (PDA) can adhere PTFE to a substrate strongly and therefore PDA/PTFE coating has a significantly higher durability. In this study, various percentages (1 to 2 wt.%) of cubic-shaped silver nanoparticles (AgNPs) were incorporated in the PDA film, resulting in an increased roughness and thus adhesion strength of the PTFE coating to the PDA underlayer. Linear reciprocating tests revealed 3.5 times increase in the durability of PDA/PTFE coating by incorporating only 2 wt.% of AgNPs compared to PDA/PTFE. The wear progression and scratch tests revealed the fundamental mechanism of these improvements.

2:30 - 3:00 pm
Improved Wear Life of 60NiTi by PDA/PTFE + Graphite Solid Lubricant Coatings
Dipankar Choudhury, Charles Miller, Min Zou, University of Arkansas, Fayetteville, AR

The aim of the study is to fabricate a bioinspired polydopamine (PDA)/polytetrafluoroethylene (PTFE) + graphite particles (GrP) solid lubricant coating on 60NiTi substrates to improve the dry lubrication performance. The durability tests were conducted at 2-N normal load (contact pressure 586.7 MPa) in a linear reciprocating motion against 6.35-mm diameter Si_3N_4 balls and the scratch tests were performed using linearly increasing loads (0.5 to10 N and 10 to 18 N). The PDA/PTFE + 0.25 wt.% GrP coating increased the durability 2.4 times compared to the PDA/PTFE coating. The scratch tests showed an improvement of coating adhesion. The atomic force microscopy images revealed a morphological change in the PTFE + GrP fibrils. The transferred film of nickel and PTFE were identified on the counterface balls, and these films were enhanced when rubbed against PDA/PTFE + 0.25 wt% GrP coatings.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Tribological Behavior of the WSC Coated Silicon Carbide in Vacuum and Air
Kosta Simonovic, Czech Technical University, Faculty of Electrical Engineering , Prague 6, Slovenia, Albano Cavaleiro, Univerisyt of Coimbra, Coimbra, Portugal, Tomas Polcar, Czech Technical University, Faculty of Electrical Engineering , Prague 6, Slovenia

In this work we explore the tribological properties of the PVD produced self-lubricating W-S-C coting [1] on the Silicon Carbide (SiC) substrate. Two series of coatings have been produced, both having thickness of 1.5 µm and for both of the coatings surface chemical composition (in at%) was measured by XPS. Series A (hardness 4.9 GPa) having the at. % of W, S and C at 38.7, 36.3 and 17.3 respectively and Series C (hardness 7.6 GPa) having the at. % of W, S and C at 47.3, 24.0 and 23.5 respectively. Two types of tribological test have been performed. First one where load was set to 10N, sliding speed to 10 cm/s and number of cycles to 10000. Second type was the loading/unloading test in which the load was gradually increased in steps of 5N until the value of 20N was reached. Next, load was gradually decreased in 5N steps until it reached initial value of 5N. Each load step was tested for 500 cycles at 10 cm/s sliding speed. All of the tests have been performed both in air and vacuum.

4:00 - 4:30 pm
Low Friction Behaviors of Ag-Doped γ-Fe_2O_3@SiO_2 Coatings under a Wide Range of Temperature Conditions
Qunfeng Zeng, Xi'an Jiaotong University, Xi'an, Shaanxi, China

In the present paper, the Ag-doped γ-Fe_2O_3@SiO_2 coatings deposited on the steel were prepared by sol-gel method. The results show that there is the core-shell microstructure in the Ag-doped γ-Fe_2O_3@SiO_2 coatings and Ag nanoparticles were distributed in coatings. The tribological properties were investigated by tribometer at temperatures of RT, 100 ^oC, 300 ^oC, 500 ^oC and 600 ^oC. It is found that the coatings exhibit low and stable friction (from 0.25~0.06) from RT to 600^oC. The coefficient of friction (CoF) of the friction pair decreases with the increase of temperature. XRD, Raman spectra and SEM measurements show that the anti-friction behaviors of the friction pair are owed to the soft noble metal Ag below 600^oC and involved in the transformation between α-Fe_2O_3 and γ-Fe_2O_3 at 600^oC during sliding. The γ-Fe_2O_3 is beneficial to form low shear interface and achieve high temperature low friction. The core-shell microstructure of coatings inhibits γ-Fe_2O_3 changing into α-Fe_2O_3.

4:30 - 5:00 pm
Study on the Tribological Properties during Drilling of CFRP with Carbide Tool
Xiong Liang, Wu Dan, State Key Laboratory of Tribology, Tsinghua University, Beijing, 100084, China, Beijing, China

This paper investigated the tribological behaviors of carbon-fibre-reinforced polymer (CFRP) against tungsten carbide under dry friction conditions. The friction coefficient was measured and the effects of

normal load, temperature and sliding speed on the friction coefficient were studied. The results show that the friction coefficient increased with the increase of normal load, but the effect of normal load on the friction coefficient seems to have a threshold. The effect of temperature on friction coefficient is not a simple linear relationship, which is mainly related to the fact that the resin matrix in CFRP melts at high temperatures and act as a lubricant. In addition, sliding speed and temperature have a comprehensive effect on the friction coefficient due to the friction heat during the sliding process.

5:00 - 5:30 pm
Tribological Behaviors of Highly Oriented Pyrolytic Graphite Under Wide Temperature Domain (10K~295K) in Macroscale
Pu Wu, Chenhui Zhang, Jianbin Luo, Tsinghua University, Beijing, China

With the development of superlubricity, the requirement for the accuracy of measuring super low friction force under different environment becomes more and more important. In this work, we built a unique home-made tribometer with high vacuum and ultra-low temperature test environment. The tribometer can regulate the temperature range from 5 K to 300 K, and the highest vacuum of the chamber is better than 5 x 10-5 Pa. The resolution of friction force is 7 x 10-5 N by using a dual frequency laser interferometry system and the maximum applied normal load is 1 N. In addition, experiments were performed to investigate the tribological behaviors of highly oriented pyrolytic graphite under wide temperature domain (10K~295K) in macroscale. And the lubricating mechanisms also have been analyzed through several characterization methods.

8I Cumberland 3

Contact Mechanics II

Session Chair: D. Garcia, Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL

1:30 - 2:00 pm
Theoretical and Finite Element Analysis of Static Friction between Multi-Scale Rough Surfaces
Robert Jackson, Auburn University, Auburn, AL, Xianzhang Wang, Tsinghua University, Beijing, China, Yang Xu, Auburn University, Auburn, AL

The current work considers the multi-scale nature of roughness in a new model that predicts the static friction coefficient. This work is based upon a previous rough surface contact model, which used stacked elastic–plastic 3-D sinusoids to model the asperities at multiple scales of roughness. A deterministic model of a three-dimensional deformable rough surface pressed against a rigid flat surface is also carried out using the finite element method (FEM). The accuracy of the deterministic FEM model is also considered. A spectral interpolation is used to smooth the geometry in between the original measured nodes. The effects of normal load and plasticity index on static friction are then analyzed. The results predicted by the theoretical model are also compared to other existing rough surface friction contact models and the FEM results. They are in a good qualitative agreement, especially for higher loads and higher plasticity indices.

2:00 - 2:30 pm
Investigating the Effect of the Evolution of the Radius of Curvature during Elastic-Plastic Contact of Asperities
Eoghan O'Neill, Hamid Ghaednia, Gregory Mifflin, Matthew Brake, Rice University, Houston, TX

The study of elastic-plastic contact mechanics is fundamental to understanding the multi-scale behavior of mechanical systems. The evolution of the radius of curvature during elastic-plastic contact and its effects on contact parameters has been neglected in previous studies. The typical approach for the elastic-plastic regime is to apply the equivalent radius of curvature from Hertzian theory. To assess the applicability of this assumption, contact between two spheres is modeled with FEA. For two spheres, the

ratio of the radii of curvature and the material models are varied; purely elastic, elastic-plastic, and rigid material models are considered. After normalizing the FEA data with Hertz and Jackson-Green contact models, trends are observed showing that the equivalent radius of curvature assumption does not satisfy the complexities involved in elastic-plastic contact. Finally, a new formulation for the evolution of the radius of curvature during elastic-plastic contact is proposed.

2:30 - 3:00 pm
When Does Roughness Affect Elastic-Plastic Contact?
Senyo Ahadzie, Hamid Ghaednia, Matthew Brake, Rice University, Houston, TX

Rough surface contact has been an ongoing challenge in mechanical engineering. The present work investigates the effect of surface roughness and lubrication in predicting the aftermath of low speed impact of aluminum samples by stainless steel spheres of multiple radii. The collisions were recorded with a high-speed camera and analyzed with MATLAB® to calculate coefficient of restitution. Following these experiments, optical profilometry was used to measure the peak plastic deformations of the plastically deformed regions. Results showed that for a given initial impact velocity of less than 3 m/s, coefficient of restitution varied by less than 10% for surface roughness ranging from 80 to 1500 grit for both lubrication conditions. However, roughness had a significant effect on the permanent deformation from the impacts: a 55% and 125% increase in the depth of the permanent deformation was observed for a change in roughness from 80 to 1500 grit for dry and lubricated impact conditions.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
An Elastoplastic Finite Element Study of Unidirectional Cylindrical Sliding Contact for Steel/Steel and Inconel617/Incoloy800H
Huaidong Yang, Itzhak Green, Georgia Institute of Technology, Atlanta, GA

The work employs a plane strain finite element analysis to investigate the unidirectional sliding contact between a deformable half cylinder and a deformable flat block. The sliding is displacement-controlled where the materials are identical steels, and then Inconel 617/Incoloy 800H. A normal interference (indentation) is applied, which is then followed by unidirectional sliding. The von-Mises stress, plastic strain, junction growth, normal force, tangential force, effective coefficient of friction (COF), and scars on the surface of the block are obtained during the sliding motion.The large plastic strain is found on the surface of the block, which forms a “pocket” shape under the surface. The direction of the growth is in the same direction of the tangential force that the weaker material experiences. The forces and the effective COF are found to stabilize after a certain sliding distance. Pileup is found on the surface of the block after a sufficient unidirectional sliding distance.

4:00 - 4:30 pm
Feasibility Study of Impedance Analysis for Measuring Rolling Bearing Loads
Tobias Schirra, Georg Martin, Marcel Neu, Eckhard Kirchner, Technical University of Darmstadt, Darmstadt, Hessen, Germany

Electrical properties of rolling bearings have been the key to measure lubrication film thickness for many years. Another usecase of this physical effect is determining the loads on rolling bearings by measuring the electrical impedance. Enhancing rolling bearings with a load-sensing function is beneficial in many applications. For example, it facilitates condition-based maintenance in transmissions by improved lifetime estimation through actual load data. The underlying electrical model of the rolling contact is a plate capacitor, whose capacity depends on the dimensions of lubrication film in the hertzian area. This paper investigates accuracy, limits and disturbances of the proposed load measuring system. The electrical model of the rolling contact has to be critically scrutinised and refined, taking disturbances into account, in order to increase the accuracy of a reliable in-situ measuring load sensor.

4:30 - 5:00 pm
A Study of Noise Prediction in Interior Materials of Automotive during Friction Process
Juho Park, Youngze Lee, Sungkyunkwan University, Suwon-si, Gyeonggi-do, Korea (the Republic of)

In this study, we aimed to evaluate the correlation between noise and friction variation through an analysis of data obtained from relative motion of headlining and panel. Tests were conducted using headlining and panel specimens cut from the actual vehicle, the effect of surface roughness and real contact area on noise is investigated by comparing textured headlining A with non-textured headlining B. In order to investigate the effect of friction variation and acceleration on the noise caused by stick - slip, the load was changed from 1800g to 4900g and the sliding distance was changed from 1mm to 2mm. Through experiments, we propose a method to predict and prevent noise generation by mapping various contact conditions according to the degree of stick-slip.

5:00 - 5:30 pm - **Contact Mechanics Business Meeting**

8J Cumberland 4

Surface Engineering IV

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Tribological and Physical Properties of PTFE Micropowder-Filled NBR Rubber under Water Lubrication
Yanfeng Han, Wei Feng, Jiaxu Wang, Chongqing University, Chongqing, Chongqing, China

Polytetrafluoroethylene (PTFE) and PTFE composites have shown excellent tribological performance as solid lubricants. In this work, PTFE was used to improve the tribological performance of nitrile butadiene rubber (NBR)The tribological and physical properties (friction coefficient, morphology, and wettability) of NBR filled with diffident percent of PTFE micropowders have been investigated. The experimental results indicate that the PTFE addition can improve the tribological properties of NBR under different lubricating conditions signficantly, and the improvement will be more effectively with increased percent of PTFE addition. NBR-PTFE composites exhibited better tribological behaviors under water lubricating condition because scanning electron microscopy (SEM) of the corresponding PTFE micropowder-filled NBR composites suggest that agglomerates morphology, dispersion and interfacial compatibility with NBR are the key factors influencing tribological and physical properties.

2:00 - 2:30 pm
Experimental Comparison of Conventional and Textured Dynamic Seal Surfaces
Johan Bothe, Leibniz University Hannover - Institute of Dynamics and Vibration Research, Hannover, Germany

Dynamic seals prevent mass transfer across system boundaries while allowing relative motion of the corresponding sealing surfaces. Dynamic seal friction decreases overall efficiency of machines, therefore reducing dynamic seal friction is economically and ecologically desirable. Textured sealing surfaces are a promising and economically feasible approach to reduce seal friction. For this presentation, a dynamic seal with a conventional sealing surface is compared experimentally to an otherwise identical dynamic seal with a textured sealing surface. The texture consists of dimples arranged in a grid and is applied to the sealing surface during seal production using textured moulds. Results include start-up as well as long-term performance.

2:30 - 3:00 pm

The Deterioration Characteristics and Mechanism of Polishing Pads and Slurry in Chemical Mechanical Polishing (CMP) of Fused Silica

Chengxi Kang, Guoshun Pan, Dan Guo, Xin Zhang, Tsinghua University, Beijing, China

The polishing pads and slurries are the essential consumable materials in chemical mechanical polishing (CMP). In our research, we studied the deterioration characteristics of the typical polishing pad and slurry in CMP of fused silica. With the polishing time increasing, the hardness of the pad increases, but the modulus of elasticity decreases. And the surface roughness of the pad increased first and then decreased after the extensive glazed areas appeared. Also, slurry pH and particle size of ceria decreased, but particle size of silica changed a little bit. Meanwhile, we investigated the chemical changes of the pad and slurry to illustrate the deterioration mechanism. The results show the quantity of the active sites of the pad is the decisive factor influencing the removal rate of fused silica. And the deterioration mechanism of slurry containing different kinds of polishing nanoparticles is not the same.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm

Chemical Mechanical Polishing Behavior of PS/Sio$_2$ Nanospheres with Different Shell Thickness on Fused Silica

Xin Zhang, Dan Guo, Guoshun Pan, Tsinghua university , Beijing, Beijing, China, Chengxi Kang, Tsinghua University, Beijing, China

This work demonstrates the feasibility of core-shell structured PS/SiO_2 composite nanospheres as abrasives for planarization fused silica. The surface morphologies of PS/SiO_2 monodisperse nanospheres were characterized with scanning electron microscopy(SEM), transmission electron microscopy(TEM) and the atomic force microscopy(AFM). The mechanical properties of nanospheres were studied with nanoindentation on the basis of AFM. Meanwhile the elastic moduli of PS/SiO_2 and PS nanospheres were obtained with the JKR models. The chemical mechanical polishing(CMP) performance of FS when applied the as-prepared nanospheres with different shell thickness was characterized by 3D white light interference surface topography instrument. It's found that the material remove rate of the FS when applied PS/SiO_2 with shell thickness reducing has shown a trend of rising first and then falling down. And we have given a semi-quantitative explanation for this phenomenon using Hertz contact theory.

4:00 - 4:30 pm

Dynamical Characterization of Micro Cantilevers by Different Excitation Methods in Dynamic AFM

Xinfeng Tan, Dan Guo, Jianbin Luo, Tsinghua University, Beijing, China

An atomic force microscopy (AFM) experimental setup was modified to analyze the differences between the piezoelectric excitation and the photothermal excitation (PTE) for three types of cantilevers, including two aluminum (Al) coated cantilevers and one uncoated single-crystalline silicon cantilever. The results show the PTE is a direct and localized excitation method to yield smooth and clean frequency spectra without the coupling with mechanical components. The 1st and 2nd order flexural vibration amplitudes of coated cantilever are easily and efficiently excited by the PTE method, mainly due to the bimetallic effect and a high photothermal efficiency. The energy conversion and absorption efficiency comparison has been analyzed for different cantilevers by the PTE method. The spurious effects can be avoided by the PTE method which clearly reflects dynamic characteristics of the cantilever, and the scanning image quality can be improved.

4:30 - 5:00 pm

Ultralow Friction of Concentrated Polymer Brushes Sustained by Surface Texturing

Mayu Miyazaki, Takahiro Tsuchiya, Yokohama National University, Yokohama-shi Hodogaya-ku, Kanagawa, Japan, Chiharu Tadokoro, Saitama University, Saitama-shi, Japan, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan, Keita Sakakibara, Yoshinobu Tsujii, Kyoto University, Uji-shi, Japan, Ken Nakano, Yokohama National University, Yokohama-shi Hodogaya-ku, Kanagawa, Japan

Concentrated polymer brushes (CPBs) have been extensively studied in tribological fields because of their ultralow friction. By applying them to sliding surfaces, attempts are being made to improve the lifetime and efficiency of various mechanical systems. The authors utilized a parallel-grooved glass plate as a substrate, on top of which a PMMA-CPB was formed, and found that parallel grooves drastically improved the lifetime of PMMA-CPB, which shows an ultra-low friction under a sliding condition lubricated by MEMP-TFSI. To clarify the mechanisms of improving its lifetime and lubrication, further studies are being done to investigate mechanical properties of PMMA-CPB formed on grooved glass surfaces.

5:00 - 5:30 pm
The Unsatisfied Effect of Plateau Honing on the Friction and Wear of Cylinder Liners
Eunseok Kim, Youngze Lee, SungKyunKwan Univ., Suwon-si, Gyeonggi-do, Korea (the Republic of)
To improve the performance of the engine, it is important to control interacting surfaces optimally in designing the surfaces of cylinder liners. The plateau honing technology has been used on the cylinder liners. It is a cross-hatch pattern of valleys for oil repository. However, the valley produced by honing functions hinders the formation of fluid dynamic pressure on interacting surfaces.

The friction and wear tests with reciprocating motion were performed to compare the lubricity of sliding cylinder liner surfaces with different plateau honing marks on the different surface roughness. The effectiveness of different depth of profiles on the surface wear was compared with those of different surface roughness. From the tests the deep grooved honing marks, it was found that the severe interactions due to asperity contacts and formation of relatively thin films produced larger amounts of wear volumes than the test with the smooth surface.

8K Cumberland 5

Engine & Drive Train V

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
The Effect of MoDTC on Friction Between Piston Ring and Cylinder Liner with Several Surface Treatment
Kenji Yamamoto, Yifang Hsieh, Tsuyoshi Hiramatsu, ADEKA Corporation, Tokyo, Japan

Authors pointed out the effect of MoDTC for improving fuel economy of passenger car especially with low viscosity engine oils, and indicated MoDTC generate MoS2 on rubbed surface with calcium and magnesium type detergent formulated engine oils in past study presented at STLE. Friction test and surface analysis are carried out to estimate the effect of MoDTC and surface treatment including DLCs, nitrides and metal plating for piston related friction. Friction test results with oscillating friction tester and floating liner apparatus will be shown with XPS surface analysis, and the effect of MoDTC on friction reduction and surface treatment for tribofilm generation will be discussed.

2:00 - 2:30 pm
Computational Fluid Dynamics (CFD) Modeling of Torque Converter and Experimental Validation
Farrukh Qureshi, The Lubrizol Corporation, Wickliffe, OH, William Liou, Western Michigan University, Kalamazoo, MI, David Whitticar, The Lubrizol Corporation, Wickliffe, OH, Yang Yang, Western Michigan University, Kalamazoo, MI, Michael Huston, The Lubrizol Corporation, Wickliffe, OH

The torque converter in automatic and powershift transmissions is used as the fluid coupling between the engine’s output shaft and transmission’s input. Torque converter efficiency is important from the standpoint of managing parasitic losses and is impacted by the fluid selection. This work explores the impact of transmission fluid physical properties on torque converter performance characteristics. A torque converter commonly used in construction machinery was selected for this study. Lubrizol worked with

Western Michigan University's Center for Advanced Vehicle Design and Simulation (CAViDS) to develop a model based on torque converter design and fluid properties using computational fluid dynamics (CFD) approach. The efficiency and k-factor for this specific torque converter were measured at two laboratories, situated in Europe and United States. Development of this model, test results and comparison of predicted and measured results will be presented and discussed.

2:30 - 3:00 pm
Numerical and Experimental Analysis of Lubricant Transport
Rathesan Ravendran, Benny Endelt, Jesper deClaville Christiansen, Aalborg University, Aalborg, Denmark, Nikolaj Kristensen, Hans Jensen Lubricators, Hadsund, Denmark

This study present both theoretical and experimental investigation of the lubricant transport across the piston rings in a large two-stroke engine. The lubricant between the piston rings and cylinder liner is modelled using a one-dimensional Reynolds equation, which includes parameters of the geometry, viscosity, pressure and surface velocities. The experimental work is performed on a newly developed test rig with reciprocating liner and stationary piston rings. The lubrication oil is injected as a spray on the liner surface. This setup imitates the conditions inside the engine. Furthermore, proximity sensors are installed along the liner to measure oil film thickness. The paper presents unique findings of the quality and stability of the lubrication oil film on the cylinder liner, and how operating conditions influence the oil film. Test of different lubrication feed-rates, lubricant viscosities and injection strategies have been performed and the results are reported and discussed.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Non-Invasive Monitoring of Free Surface Thin Film Layer Spread Using an Ultrasonic Continuously Repeated Chirp Longitudinal Wave
Joseph Kanja, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Thin film layers are seen in many applications such as the oil distribution around a gearbox casing and the oil that forms ahead of an approaching piston ring.Measuring thickness of these films provides essential information useful for performance control and monitoring. Performing these measurements can prove to be difficult.However,ultrasound enables measurement indirectly.Piezoelectric transducers on a component back face emit ultrasound waves and receive the waves that bounce off the front face.The magnitude of the reflected wave is dependent on the film thickness at the front face.Pulse-echo ultrasound technique is usually used to perform these measurements.However,as the film becomes thinner,the reflected echoes overlap.In this work,we propose the use of an ultrasonic continuously repeated chirp longitudinal wave to magnify the effect of the film.Multiple reflections occur within the component to form a standing wave whose amplitude spectrum is dependent on the film thickness.

4:00 - 5:30 pm - **Additionall Abstracts**

8L Cumberland 6

Condition Monitoring III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
Single Lubricant Solution for Natural Gas and Diesel Engines
Isabella Goldmints, David Brass, Infineum USA, Linden, NJ

The drive to lower fleet emissions, coupled with increased availability of natural gas, have led to recent

interest in natural gas engines for heavy duty vehicles and have propelled developments in mobile natural gas engine hardware. Considering that most gas engine vehicles operate in mixed fleets with Diesel engines, they can present a challenge for fleet operators; requiring them to stock different lubricants and prevent misapplication. This challenge creates an opportunity for lubricant suppliers to provide a multifuel oil to protect both natural gas and Diesel fueled engines. Here we present a new multifuel oil additive technology, formulated to protect both natural gas and diesel engines, despite disparate lubrication requirements, and demonstrate its excellent performance in both as measured by multiple parameters such as oxidation and nitration resistance, wear protection and durability, cleanliness, and soot dispersancy in engine dyno and fleet field tests.

2:00 - 2:30 pm
Oil Conductivity as an Early Indicator of Oil Oxidative and Additive Thermal Degradation Processes.
John Duchowski, Timo Lang, Valérie Diehl-Klein, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany

A suitable diagnostic property to be employed for online oil condition monitoring purposes has been long sought after. Several recent investigations of oil and additive degradation processes suggest that the oil electrical conductivity could lend itself for this purpose. It has already been reported that oil conductivity increased by nearly a factor of twenty in the course of two years for a hydraulic oil employed in a large automotive press. Similar observations were made on a hydraulic power unit driving a train break system. Most recently this behavior was observed on a free standing hydraulic test stand. The last case proves most intriguing because an increase in conductivity has been noted there in the form of a single, early indicator without concomitant changes in other fluid properties. In view of these observations, we propose that oil conductivity represents a potential candidate for online tracking of the oil ageing processes at an early stage in industrial systems.

2:30 - 3:00 pm
Correlating Acoustic Emission Signals with the Tribological Behavior of Steel
Tom Reddyhoff, Imperial College, South Kensington, United Kingdom, Zhe Geng, Suzhou Institute of Industrial Technology, Suzhou, China

Acoustic emission (AE) signals were recorded during reciprocating ball-on-disc tribological tests on 52100 steel under a range of conditions. Time domain AE signals were transformed to the frequency domain using a Fast Fourier Transform and parameters such as power, RMS amplitude, mean frequency, median frequency and energy were analysed and compared with the coefficient of friction and wear volume. Results suggest that different acoustic frequencies can reflect the friction and wear respectively. If frequencies are chosen correctly, the correlation between AE and friction signals can be very high (Pearson coefficients 0.8~0.9). SEM and Raman analysis of the worn surfaces revealed how oxide debris affect the friction, wear and AE and the interactions between them. Since an AE signal contains more information than the CoF and wear volume and is more sensitive to changes in wear mechanism, it can become a powerful tool to monitor tribological behaviour of in-service components.

3:00 - 3:30 pm - **Break**

3:30 - 4:00 pm
Fast and Efficient Quality Control of Lubricants and Its Foaming Tendency by FoamDDI, an Upgraded, Fully Automatized Detection Imaging Apparatus
Aaron Mendez, Ayalytical Instruments, Houston, TX

We reported earlier at this forum the role of Digital Detection Imaging techniques in measuring the adverse effects of foam formation and foam stability on machinery, pumps and other equipment. Uncontrolled foam brake fluid films increasing wear and oxidation risks, cause cavitation in pumps, vary fluid flows, introduce pressure changes in hydraulic systems and promote loss of fluids. The foaming formation speed and its collapse can reliably be measured, plotted and displayed in real time since heating and cooling speeds have been optimized. The common tests used to evaluate luboils foaming

tendency and foaming stability are ASTM D892 in all its three sequences and the High Temperature method D6082 which can now be easily performed with the benefits of being an unattended software-controlled procedure with potential for developments like air release and evaluation of antifoam performance tailored to specific lubricants. The new FoamDDI design allows for more efficient foam control.

4:00 - 4:30 pm

Detecting WEC Formation in an Electrical Environment Using Electrostatic Monitoring Techniques

Kamran Esmaeili, Ling Wang, Terry Harvey, Neil White, Walter Holweger, University of Southampton, Southampton, Hampshire, United Kingdom

White etching crack (WEC) remains one of the most critical bearing failure modes. Recent publications suggest that electrical discharging, due to the presence of electrical current and a dielectric lubricant, is one of the drivers for WEC formation. To date, only limited research has been conducted to characterise the influence of operating parameters on the electrical discharges (EDs), their contributions to WEC formation and most importantly in developing a robust technique for the monitoring of EDs and WEC formation. Using electrostatic sensing techniques, this study investigates the influence of operating conditions such as load, speed, temperature and slip-to-roll ratios on EDs. The results show that responses of the electrostatic sensors are correlated with the electrical potentials measured across the two-disc contact on a TE74 twin-roller machine. Further experiments are being conducted to explore the feasibility of electrostatic sensors in detecting WEC bearing failures.

9A Exhibit Foyer

Student Posters

Polymer-Enhanced Fluid Effects on Mechanical Efficiency of Hydraulic Pumps

Pawan Panwar, Michelle Len, University of California, Merced, Merced, CA, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI, Ashlie Martini, University of California, Merced, Merced, CA

The mechanical efficiency of hydraulic pumps is affected by the properties of the hydraulic fluids, and particularly by polymeric viscosity modifiers used as additives. However, the mechanisms by which polymers affect efficiency are still poorly understood. Here, a well-characterized isobutylene polymer was blended with (poly)alphaolefin base stocks to produce simple, high-purity hydraulic fluids for analysis using molecular dynamics simulation, rheological testing, and dynamometer evaluations. The simulations were used to understand the polymer's response to shear and the effect on viscosity. The dynamometer incorporated a variable displacement axial piston pump with torque, speed, pressure and flow sensors to measure mechanical and volumetric efficiency under various pressures and speeds. The fluids were also characterized by their permanent and temporary shear thinning. The results provide insight into the relationship between non-Newtonian fluid viscosity and hydraulic efficiency.

Optimization of CNC milling parameters and TiO2 nanoparticle in lubricants for lowering wear of cutting inserts

Octavio Muñiz-Cepeda, Héctor de la Fuente, Laura Peña-Parás, Universidad de Monterrey, San Pedro Garza García, Nuevo León, Mexico

Optimization of milling parameters of an AISI 4340 steel performed by Computer Numerical Control was done in this work. Cutting inserts suffer wear during milling operations thus lowering their useful tool life and increase the energy consumption by the process. Nanoparticles of TiO2 were added to a mineral oil cutting fluid with the purpose of reducing the contact between the cutting tools and the workpiece. Preliminary laboratory experiments in a four-ball tribotester showed that a concentration of 0.05 wt,% TiO2 is able to reduce wear scar diameter and surface roughness of steel balls. Subsequently, a Box Behnken design of experiments was performed to optimize the input milling parameters of cutting speed,

depth of cut, feed rate as well as nanoparticle concentration in order to minimize the responese parameters of wear of inserts, spindle load, and surface roughness of steel plates.

Effects of Temperature and Flow Rate on Varnish Removal by Chemical Flushes
Daniel Sanchez Garrido, Mike Ades, University of California, Merced, Merced, CA, Elizabeth Montalvo, Zhen Zhou, Chevron, Richmond, CA, Ashlie Martini, University of California, Merced, Merced, CA

Varnish is an oxidative byproduct of lubrication that forms on the surfaces of mechanical components. Varnish buildup reduces clearances on precision parts increasing wear and reducing efficiency during operation. Varnish is often removed using chemical flushes. However, there is no standard method for evaluating the efficacy of various chemicals under different operating conditions. We have developed a custom test rig that enables quantitative characterization of varnish removal rates under controlled conditions. Here, the test rig is used to characterize the effects of fluid temperature and flow rate on varnish removal for an example chemical cleaner. The results show that varnish removal increases with increasing temperature and flow rate, and demonstrate the utility of the newly developed test rig and method for chemical cleaner characterization.

Grease Lubrication of Self-Mated 60NiTi Bearing Materials
Azhar Vellore, Nicholas Walters, Ashlie Martini, UCMerced, Merced, CA

60NiTi, an intermetallic alloy of nickel and titanium, exhibits a unique combination of properties, including comparable hardness yet twice the elasticity of steel, high corrosion resistance, and tensile strength comparable to ceramics. These properties are very desirable for bearing materials, especially those used in space applications where components must operate efficiently and reliably in harsh conditions. However, despite the fact that most bearings are grease lubricated, there has not been a systematic study of the tribo-performance of greases for 60NiTi lubrication. To address this, we compare the wear and friction of self-mated 60NiTi lubricated by different greases, including those currently used in space missions and general-purpose grease, in boundary lubricated contact. The results provide valuable information to guide selection of grease for 60NiTi contacts as well as lay the groundwork for possible development of new greases specifically for 60NiTi tribo-contacts.

Investigation of Modern Automotive Lubricants
Wyatt Peterson, Steven Lorenz, Purdue University, West Lafayette, IN

With increasing global awareness of greenhouse emissions, calls for lower fossil fuel consumption have driven the automotive industry to re-analyze parasitic losses in drivetrains which were once considered nominal. To further improve vehicle efficiency, it is suggested that a better understanding is necessary of the frictional power losses associated with rolling element bearings (REBs). Friction coefficients for REBs cover a wide array of values. In practice, however, an imprecise friction coefficient is typically calculated based on generalized curve-fit equations. The purpose of this work is to experimentally observe REB performance in modern automotive lubricants for a set of conditions. These experimental values are then compared against industry standard friction models to assess the validity of their approximations. Based on these observations, conclusions are drawn to determine a more accurate span of friction coefficient values for the REBs and lubricants in question.

Friction Test of Cylinder Liner-Piston Ring Pair with the Lubricating Oil Diluted by Fuel
Bo Xu, Bifeng Yin, Xin Kuang, School of Automotive and Traffic Engineering, Jiangsu University, Zhen Jiang, China

To investigate the wall-wetting effects on ring/liner frictional property, the viscosity test is conducted firstly by mixing diesel into lubrication oil. Then based on several typical wall-wetting ratios, the reciprocating friction tests are carried on to measure the instantaneous friction force of Cylinder Liner-Piston Ring(CL-PR) pair. The experimental results show that the lubrication state of ring/liner is affected by viscosity and loads. Under hydrodynamic lubrication state, the viscosity difference between several wall-wetting ratios has little effects on CL-PR friction, but the reduction of lubricant viscosity may cause the lubrication condition of friction pair to transfer from hydrodynamic lubrication to mixed lubrication, deteriorating the

tribological performance of CL-PR. At low or high loads, the fiction force of CL-PR pair raises with more fuel diluting oil, which indicates the viscosity reduction induced by fuel diluting oil will deteriorate the lubrication of CL-PR.

Non-Invasive Monitoring of Free Surface Thin Film Layer Spread Using an Ultrasonic Continuously Repeated Chirp Longitudinal Wave.

Joseph Kanja, Rob Dwyer-Joyce, Xiangwei Li, University of Sheffield, Sheffield, United Kingdom

Thin film layers are seen in many applications such as the oil distribution around a gearbox casing and the oil that forms ahead of an approaching piston ring.Measuring thickness of these films provides essential information useful for performance control and monitoring. Performing these measurements can prove to be difficult.However,ultrasound enables measurement indirectly.Piezoelectric transducers on a component back face emit ultrasound waves and receive the waves that bounce off the front face.The magnitude of the reflected wave is dependent on the film thickness at the front face.Pulse-echo ultrasound technique is usually used to perform these measurements.However,as the film becomes thinner,the reflected echoes overlap.In this work,we propose the use of an ultrasonic continuously repeated chirp longitudinal wave to magnify the effect of the film.Multiple reflections occur within the component to form a standing wave whose amplitude spectrum is dependent on the film thickness.

Probing the Friction Behavior of BCC Metals Using Molecular Dynamics

Adam Hinkle, John Curry, Nicolas Argibay, Michael Chandross, Sandia National Laboratories, Albuquerque, NM

We have recently developed a model of friction for FCC metals that accurately predicts the bounds for high and low friction regimes by directly linking interfacial grain structure and its evolution with the macroscopic friction coefficient. Further investigations have revealed similar friction regimes in BCC metals. We present results of atomistic simulations and experiments on BCC metals with the goal of elucidating the structure-property relationships responsible for frictional behavior, allowing for the development of a general framework for the tribological response of both FCC and BCC metals.
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Stochastic Models for Turbulent Lubrication of Journal Bearing with Rough Surfaces

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The turbulent lubrication model of an isotropic rough surface was generally used in current turbulent lubrication analysis of journal bearing with rough surface. However, the scope of this model is too narrow to use for solving the turbulent lubrication problems of rough surface with directional characteristics. Based on the stochastic laminar lubrication theory of Christensen and the turbulent lubrication theory in the form of zero-equation, the stochastic turbulent lubrication models suitable for the turbulent lubrication analysis of journal bearing with rough surface are derived. The stochastic turbulent lubrication models can be conveniently applied to the turbulent lubrication analysis of rough surfaces with directional characteristics. Moreover, the stochastic turbulent lubrication models are not only suitable for the turbulent lubrication analysis of journal bearing with rough surface, but also for the turbulent lubrication research of other friction pairs with rough surface.

Investigation on Tribological Behaviors of MoS_2/WS_2 Quantum Dots as Lubricant Additive in Ionic Liquids under Severe Conditions

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Despite excellent tribological behaviors of ionic liquids (ILs) as lubricating oils, the friction reducing and wear protection need to be improved when they are used under severe conditions. Here, MoS_2 and WS_2 quantum dots (QDs) are prepared by a facile and green technique, and both of them can disperse in 1-buty-3-methylimidazolium hexafluorophosphate ([BMIm]PF_6) and form homogeneous dispersions that

exhibit long term stabilities. Tribological test results indicate that the addition of MoS_2/WS_2 QDs in ILs can significantly enhance the friction reducing and anti-wear ability of neat ILs under a constant load of 500 N, and a temperature of 150 ^oC. The exceptional tribological properties of MoS_2/WS_2 QDs in ILs are attributed to the formation of boundary lubrication film, which can be generated not only by the physical entrapment of MoS_2/WS_2 QDs at the ball-disk contact surfaces, but also by tribochemical reaction between MoS_2/WS_2 and the iron atoms/iron oxide species.

Reconstructing Rough EHL Contacts: Measuring Counterface Topography in Ball-on-Flat Experiments

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We have redesigned the counterface holders of a commercial tribometer such that one can determine which portions of counterface A interact with which portions of counterface B to within the length scale of surface asperities by constraining the relative positions of the ball and disc. This allows for easy location of the wear tracks and for proper deterministic simulation of the real contact of two rough counterfaces. The goal is to probe the relationships between surface stress, surface chemistry and plasticity. Analysis involves AFM & optical profilometry, Auger electron spectroscopy, and numerical contact simulation.

The Effect of Laser Surface Texturing to Prevent Stick-Slip Phenomenon

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Stick-slip phenomenon in some mechanical structures especially in machine tools should be eliminated or prevented. In this study, different kinds of surface textures were carried out on the lower samples of the pin-on-disc contact. The starting process of the machine tools was simulated at an Rtec-Multi Function Tribometer. The stick-slip phenomenon was observed in each kind of samples. However, the stick-slip phenomenon of smooth sample is larger than the textured samples. What's more, different texture densities of bulge textured surfaces all show excellent anti-stick-slip effect, the critical stick-slip speed of bulge textured surface is almost 20 times lower than the smooth surface. It can be predicted that the bulge textures can eliminate stick-slip phenomenon when processed in the surface of the machine tool for the bulge textures can effectively improve frictional state and avoid the slip of the contact surfaces.

Interfacial Assembly Structures and Nanotribological Properties of Lubricating Molecules

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Saccharides have been recognized as potential bio-lubricants, but their interfacial structures are rarely studied and the molecular details of interaction mechanisms have not been well understood. In this work, the supramolecular assembly structures of two saccharic acids, mediated by hydrogen bonds, were successfully constructed on the HOPG surface by introducing pyridine modulators and were explicitly revealed by STM. Furthermore, friction forces were measured in the saccharic acid/pyridine co-assembled system by AFM, revealing a larger value than a pristine saccharic acid system, which could be attributed to the stronger tip-assembled molecule interactions that lead to the higher potential energy barrier needed to overcome. The effort on saccharide-related supramolecular self-assembly and nanotribological behavior could provide a promising way to explore the interaction mechanisms underlying friction and reveal the structure–property relationship at the molecular level.

Analysis of Hydrodynamic Pressure Effect of Grinding Bearing Steel with Corundum Grinding Wheel

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A steady-state micro-thermal elastohydrodynamic lubrication grinding wheel model was established to study the hydrodynamic pressure effect of ceramic corundum grinding wheel on bearing steel, based on the theory of elastic hydrodynamic lubrication.Firstly, the hydrodynamic pressure effect of ceramic

corundum grinding wheel under different grinding fluids is studied. Secondly, comparison and analysis with and without the influence of thermal effect.Finally, the effect of surface topography on the hydrodynamic pressure effect in grinding area is analyzed. The results show that the emulsion is chosen as the grinding fluid when considering various factors.The pressure and film thickness are reduced when considering the thermal effect.The amplitude of roughness has a greater influence on the hydrodynamic pressure effect in the grinding area.The larger the amplitude, the larger the pressure, the smaller the film thickness, while the wavelength is not significant.

Transient TEHL Numerical Analysis of Spur Gears under Fluid Ferrofluid Lubrication
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The thermal elastohydrodynamic lubrication model of fluid ferrofluid involute spur gears is established to carry out the numerical simulation with multigrid method based on the Reynolds equation considering thermal effect.The transient oil film thickness, pressure profile distribution,oil temperature rise and frication cofficient with different based fluid ferrofluid are compared.The further research of ester-based H01 fluid ferrofluid is studied and the influence of the speed and load on lubrication film are discussed.Results show that the pressure at inlet region and the film thickness of H01 fluid ferrofluid is smallest. The frication cofficient and oil temperature rise are decreased with the increase of speed and the pressure peak and the film thickness are increased with the increase of speed. The pressure peak,frication cofficient and oil temperature rise are increased with the increase of load and the film thickness are decreased with the increase of load.

Decreasing Radial Contact Area Results in a Higher Coefficient of Friction on Articular Cartilage
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Joints are well known for their ability to withstand high loads with minimum damage. Articular cartilage is a main element providing lubrication in joints. Multiple lubrication mechanisms are observed within joints. It is important to understand how joint friction works for disease purposes. Measuring the coefficient of friction (COF) of a sample of cartilage under specific conditions can help explain friction mechanisms in a joint. There were two hypothesis for this study: A smaller radial contact area on the articular cartilage will produce a higher COF under varying pressures and constant force, and a smaller radial contact area on the articular cartilage will produce a higher COF under varying force and varying pressure.

Behaviors of the Molecule in Chemisorption Layer
Haoyu Li, Liran Ma, Jianbin Luo, Tsinghua University, Beijing, China

The difference of surface-enhanced Raman spectroscopy (SERS) spectrum and original Raman spectrum of a chemical is not clear yet. In this work, the Raman peak shift of 4-MBA molecules on different SERS substrates are investigated. This study has shown that different surface topography results in the notable peak shifts of COO^- stretching and symmetric v(CC). These shifts are believed as absorption of the end functional group (carboxyl), which was believed as free on silver in the past. Further understandings are investigated through SERS substrates prepared by different methods. Using charge transfer theory, these shifts are attributed to the direct absorption of carboxyl on silver. This result and method may shed light on the understanding of the behaviors of small molecule on a structured surface.

Influence of Fluctuating Water Supply Pressure on the Elastohydrodynamic Lubrication of Water-Lubricated Hybrid Bearing during Acceleration
Yinong Xie, qingdao university of technology, Qingdao, China

The elastohydrodynamic lubrication(EHL) model of the water-lubricated hydrostatic bearing during the acceleration process was established. The different fluctuation modes of the water supply pressure and the change of the water supply pressure were considered. The numerical simulation of the process was carried out and the elastohydrodynamic lubrication was analyzed. The results show that the fluctuation trend of the water supply pressure is the same as that of the contact zone film thickness, while the pressure change of the contact zone is opposite. When the water supply pressure is low, the fluctuation with 0° phase is more favorable for lubrication, and the fluctuation with 180° phase makes the film

formation difficult, and even the bearing is in dry contact state. Simultaneously, the greater the frequency of the fluctuation, the more failure of the bearing . Within a certain range, accelerating under a large water supply pressure is more conducive to lubrication.

STLE 2019 Author Index
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