2020 STLE Annual Meeting & Exhibition

Hyatt Regency Chicago
Chicago, Illinois

2020 Preliminary Technical Program
Updated as of Nov. 25, 2019

2020 STLE Annual Meeting Program At A Glance

Preliminary as of 11/25/2019

Sunday, May 3, 2020

Registration
7 am – 6 pm – Grand Ballroom Foyer

Education Course Speakers Breakfast
7 – 7:45 am – Grand Ballroom A

Education Courses - 8 am - 5 pm

Advanced Lubrication 301 – Columbus CD
Advanced Tribology 310: Nanotribology – Columbus EF
Metalworking Fluids 240 – Metal Fluids – Columbus GH
Basic Lubrication 101- Columbus IJ
Synthetic Lubricants 204 – Columbus KL
Gears 101 – Columbus AB
NLGI – Grease 101 – Randolph 1

Course F&B Breaks – Columbus Foyer

Student Networking Reception - 6:30 – 8 pm – Plaza Ballroom

Monday, May 4, 2020

Registration
7 am – 6 pm –Grand Ballroom Foyer

Monday Speakers Breakfast
7 – 8 am – Grand Ballroom AB

8 am – 1 pm – STEM Camp – Riverside Center

Technical Sessions - 8 am - 10 am

1A – Commercial Marketing Forum I – Columbus AB
1B – Metalworking Fluids I – Columbus CD
1C – Rolling Element Bearings I – Columbus EF
1D – Biotribology I – Columbus G
1E – Seals I – Columbus H
1F – Lubrication Fundamentals I – Columbus IJ
1H – Grease I – Randolph 1
1I – Tribochemistry I Superlubricity & Mechanochemistry of Carbon Based Solid Lubricants– Randolph 2
1K – Engine & Drive Train Special Session on Electric Vehicles I – Michigan 1
1L – Contact Mechanics I – Michigan 2
1M – Nanotribology I – Michigan 3

10 – 10:30 am Beverage Break in Grand Foyer

Opening General Session - 10:30 am – 12 Noon

Keynote Address: *Overall Theme: 21st Century Challenges for the Tribology and Lubricants Community* – Grand Ballroom

Lunch on your own - 12 Noon – 1:30 pm

Commercial Exhibits and Student Posters -
12 Noon – 5 pm – Riverside Center

Technical Sessions - 1:30 pm – 6 pm

2A – Commercial Marketing Forum II – Columbus AB
2B – Metalworking Fluids II – Columbus CD
2C – Rolling Element Bearings II – Columbus EF
2D – Biotribology II – Columbus G
2E – Seals II – Columbus H
2F – Lubrication Fundamentals II – Columbus IJ
2H – Grease II – Randolph 1
2I – Tribochemistry II: Tribocatalysis of Additives – Randolph 2
2K – Engine & Drive Train Special Session on Electric Vehicles II – Michigan 1
2L – Contact Mechanics II – Michigan 2
2M – Nanotribology II – Michigan 3

3:30 – 4 pm Beverage Break in Exhibit Hall – Riverside Center

Welcome Reception
6:30 – 8 pm – Grand Ballroom

Tuesday, May 5, 2020

Registration
7 am – 6 pm – Grand Ballroom Foyer

Tuesday Speakers Breakfast
7 – 8 am – Grand Ballroom AB

Commercial Exhibits and Student Posters -
9:30 am – 5:30 pm – Riverside Center

Technical Sessions - 8 am – 12 Noon

3A – Commercial Marketing Forum III – Columbus AB
3B – Metalworking Fluids III – Columbus CD
3C – Rolling Element Bearings III – Columbus EF
3D – Biotribology III – Columbus G
3F – Lubrication Fundamentals III – Columbus IJ
3G – Materials Tribology I: Solid Lubricants for Extreme Applications – Columbus KL
3H – Grease III – Randolph 1
3I – Tribochemistry III: Tribofilm Growth - Modeling & Characterization – Randolph 2
3J – Condition Monitoring I – Randolph 3
3K – Engine & Drive Train I – Michigan 1
3L – Contact Mechanics III – Michigan 2
3M – Lubrication Fundamentals Special Session: 42 years of the Patir-Cheng Average Flow Model – Michigan 3

10 – 10:30 am Beverage Breaks in Exhibit Hall – Riverside Center

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

Technical Sessions - 2 pm – 6 pm

4A – Commercial Marketing Forum IV – Columbus AB
4B – Metalworking Fluids IV – Columbus CD
4C – Rolling Element Bearings IV – Columbus EF
4D – Biotribology IV – Columbus G
4E – Surface Engineering I: Additive Manufacturing – Columbus H
4F – Lubrication Fundamentals IV – Columbus IJ
4G – Materials Tribology II: Protective Thin Films & Coatings – Columbus KL

4H – Grease IV – Randolph 1
4I – Tribochemistry IV: Perspectives & Applications – Randolph 2
4J – Condition Monitoring II – Randolph 3
4K – Engine & Drive Train II – Michigan 1
4L – 2D Materials – Materials Tribology & Nanotribology Joint Session I – Michigan 2
4M – Lubrication Fundamentals Special Session: 42 years of the Patir-Cheng Average Flow Model II – Michigan 3

3 – 4 pm Beverage Break in Exhibit Hall – Riverside Center

Wednesday, May 5, 2020

Registration
7 am – 6 pm – Grand Ballroom Foyer

Wednesday Speakers Breakfast
7 – 8:00 am – Grand Ballroom AB

Commercial Exhibits & Student Posters -
9:30 am – 12 Noon – Riverside Center

Education Courses - 8 am - 5 pm

Automotive 202 – Grand Ballroom C North
Basic Lubrication 102 – Grand Ballroom D North
Metalworking Fluids 105 – Grand Ballroom E
Advanced Lubrication 302 – Grand Ballroom F

Technical Sessions - 8 am – 12 Noon

5A – Commercial Marketing Forum V – Columbus AB
5B – Environmentally Friendly Fluids I – Columbus CD
5C – Rolling Element Bearings V – Columbus EF
5D – Fluid Film Bearings I – Columbus G
5E – Tribology of Biomaterials: Biotribology & Materials Tribology Joint Session I – Columbus H
5F – Lubrication Fundamentals V – Columbus IJ
5G – Materials Tribology III: Hard to Soft Fluoropolymer Composites & Hydrogels – Columbus KL
5H – 2D Materials Tribology & Nanotribology Joint Session II – Randolph 1
5I – Surface Engineering II – Randolph 2
5J – Condition Monitoring III – Randolph 3
5K – Engine & Drive Train III – Michigan 1
5L – Tribotesting I – Michigan 2
5M – Lubrication Fundamentals Special Session: 42 years of the Patir-Cheng Average Flow Model III – Michigan 3

Beverage Break - 10 - 10:30 am – Riverside Center

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

Technical Sessions - 1:30 pm - 6 pm

6A – Commercial Marketing Forum VI – Columbus AB
6B – Nonferrous Metals I: Biobased & Synthetic Lubricants – Columbus CD
6C – Synthetic Lubricants & Hydraulics I – Columbus EF
6D – Fluid Film Bearings II – Columbus G
6E – Wear I – Columbus H
6F – Lubrication Fundamentals VI – Columbus IJ
6G – Materials Tribology IV: Advanced Engineering Polymers – Columbus KL
6H – 2D Materials – Materials Tribology & Nanotribology Joint Session III – Randolph 1
6I – Surface Engineering III – Randolph 2
6J – Condition Monitoring IV – Randolph 3
6K – Engine & Drive Train IV – Michigan 1
6L – Tribotesting II – Michigan 2
6M – Nanotribology – Michigan 3
6N – REB Roundtable Discussion – Grand Ballroom A

3 – 3:30 pm Beverage Break in Foyer – Columbus & Michigan Foyers

Thursday, May 6, 2020

Registration
7 am – 12 Noon – Grand Ballroom Foyer

Thursday Speakers Breakfast
7 – 8 am – Grand Ballroom AB

Certification Exams
8:30 am – 12:30 pm – Roosevelt 1

Technical Sessions - 8 am – 12 Noon

7A – Synthetic Lubricants and Hydraulics II – Columbus AB
7B – Nonferrous Metals II: Lubricants Analysis and Filtration – Columbus CD
7C – Environmentally Friendly Fluids II – Columbus EF
7D – Fluid Film Bearings III – Columbus G
7E – Wear II – Columbus H
7F – Lubrication Fundamentals VII – Columbus IJ
7G – Materials Tribology V: Metallic Materials Fundamentals & Extreme Applications – Columbus KL
7H – Gears I - Randolph 1
7J – Power Generation I – Randolph 3
7K – Engine & Drive Train V – Michigan 1
7L – Tribotesting III – Michigan 2
7M – Nanotribology IV – Michigan 3

Begins at 9:00 am
7N – Engine & Drive Train Joint Session: Bridging the Gap Between Bench & Engine I – Michigan 1

Beverage Break - 10 – 10:30 am – Columbus & Michigan Foyers

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

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

8B – Nonferrous Metals III: Lubricants Additives and Tribology – Columbus CD
8C – Environmentally Friendly Fluids III – Columbus EF
8D – Fluid Film Bearings IV – Columbus G
8E – Wear III – Columbus H
8F – Lubrication Fundamentals VIII – Columbus IJ
8G – Materials Tribology VI: Additives & Fluid Lubricated Contacts – Columbus KL
8H – Gears III – Randolph 1
8J – Wind Turbine Tribology I – Randolph 3
8K – Engine & Drive Train & Lubrication Fundamentals Joint Session: Lab to Field: Bridging the Gap Between Bench & Engine II – Michigan 1
8L – Tribotesting IV – Michigan 2
8M – Nanotribology – Michigan 3

Beverage Break - 3 – 3:30 pm - Columbus & Michigan Foyers

Monday, May 4, 2020

1A — Columbus AB

Commercial Marketing Forum I

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8 - 8:30 am - Open Slot

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

9 - 9:30 am - **Zschimmer & Schwarz**

9:30 - 10 am - **ANGUS Chemical Company**

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

1B — Columbus CD

Metalworking Fluids I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3273531: Oil Soluble Polyglycol on Semi-Synthetic Metalworking as Multifunctional Enhancer Synthetic Polymeric Additive Proposal
Eduardo Lima, Dow Brazil, Jundiai, São Paulo, Brazil

On a constant search for innovative solutions, also considering all demands and challenges on Metalworking Fluids formulations, besides to meet demands progressively needed for differentiated fluids performance, multifunctional products can increasingly be a pathway to challenging historical issues, so either the use of oil-soluble polyglycols represents a synthetic polymeric potentially represents a strong proposal on enhanced properties in side formulation as: foam control, superior lubricity, additives compatibility, formulation stability, ferrous corrosion, emulsion stability, across others. This study has a proposal to present a detailed evaluation on different aspects for deepening on all potential functionality from use of this differentiated chemistry, from practical and molecular aspects and the intention to improve a typical semi-synthetic fluid formulation.

8:30 - 9 am
3279542: Systematic Investigation of Phosphorous Compounds in Metal Working Fluids by Mixture Screening DoE
Yixing Philip Zhao, Alexandra Goode, Shilpa Beesabathuni, Houghton International, Norristown, PA, Yan Zhou, Houghton International, Oak Ridge, TN

Phosphate esters are important extreme pressure (EP) lubricity additives in metal working fluids (MWF). They can provide good EP lubrication at relatively low activation temperatures and form a tribofilm. However, phosphate esters can foam a lot and decrease emulsion stability in hard water due to soap formation. It is essential to use an optimal phosphate ester(s) to enhance product performance. Design of Experiments (DoE) is a systematic method to investigate different properties and performances of additives in formulas. In this presentation, we will discuss the use of Mixture Screening DoE to test and evaluate six phosphate esters in a soluble oil MRF formula. We will show the correlations of these esters with lubricity, foam and emulsion stability from the test results and statistical analysis such as ANOVA, which helped us to choose a suitable phosphate ester for product development.

9 - 9:30 am

3279198: Adenylate Energy Charge – New Tool for Determining Metalworking Fluid Microbial Population's Sublethal Response to Microbicide Treatment

Frederick Passman, Biodeterioration Control Associates, Inc., Princeton, NJ, Peter Küenzi, Blaser Swisslube, Hasle-Ruegsau, Switzerland, Jordan Schmidt, Luminultra Technologies, Ltd., Fredericton, New Brunswick, Canada

Adenylate energy charge (AEC) is computed from the ratios of three energy molecules found in all living cells: adenosine triphosphate (ATP), adenosine diphosphate (ADP), and adenosine monophosphate (AMP). The AECs of robust microbial communities range from 0.7 to 0.95. When populations are stressed, the AEC decreases – reflecting the relative depletion of ATP and accumulation of ADP and AMP concentrations within cells. The paper reports the impact of lethal and sub-lethal microbicide treatments on AEC in microbially contaminated emulsifiable oil and semi-synthetic metalworking fluids. The results demonstrate the utility of AEC testing to determine the physiological state of microbial contaminants in water-miscible metalworking fluids. This capability is becoming increasingly important as metalworking fluid move from microbicide use to reliance on bioresistant functional additives.

9:30 - 10 am

3279916: Low Foam Emulsifiers for Semi-Synthetic Metalworking Fluids

Jocelyn Zhao, DOW Chemical Investment Co., Ltd, Shanghai, China

The semi-synthetic fluids are widely used in the lubrication of metal cutting and forming to reduce the friction and remove the heat. Emulsifiers in the semi-synthetic fluids are used to disperse based oil into water. The presence of a large amount of fatty acid ethanolamine soap and anionic emulsifiers generates high foam during the metalworking process. This unexpected foam formation causes insufficient lubricity, overflow of the fluid bath and worse shelf life of pumps due to cavitation. An alternative way is to develop low foam nonionic emulsifiers in the formulation. In this study, two new low foam emulsifiers are developed to help control the foam and make the semi-synthetic fluids a stable emulsion. With a structure of C16-C18 alkyl fatty alcohol as the hydrophobic group, extended with propylene oxide chain, and ethylene oxide chain as the hydrophilic group, these two anionic emulsifiers contribute to balance the low foam control and emulsification capability property.

10 - 10:30 am – Break

Rolling Element Bearings I

Session Chair: Nikhil Londhe, The Timken Company, Canton, OH
Session Vice Chair: Daniel Merk, Schaeffler Technologies, Schweinfurt, Bavaria, Germany

8 - 8:30 am
3278343: Replenishment of the EHL Contacts in a Grease Lubricated Ball Bearing
Piet Lugt, SKF Research and Technology Development, Houten, Netherlands, Hui Cen, Xuchang University, Henan, 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. However, grease lubricated bearings are often running under starved lubrication conditions and the films are therefore thinner. We have done numerous film thickness measurements on an axially loaded ball bearing, varying the number of balls, grease type, cage type, speed and load. We found that the film thickness as a function of the operating conditions in a grease lubricated bearing can be described by a unique combination of grease and bearing properties.

8:30 - 9 am
3285585: Characterization of the Channeling Behavior of Lubricating Greases in Rolling Bearings
Sathwik Chatra Kalsanka Ramakrishna, SKF B.V., Nieuwegein, Utrecht, Netherlands, Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

The channeling behavior of lubricating greases was found to be correlated to the early stage temperature profiles in grease lubricated rolling bearings. It will be shown that grease undergoes a microstructural change during the channeling/churning phase. Channeling behavior depends on the operating conditions. It can already be observed at medium speed, but is most pronounced at higher speeds, where the drag forces can be very large. Good channeling greases show a very short churning phase and will maintain their microstructure, whereas poor channeling greases will undergo a severe degradation mainly due to a longer period of churning at a higher temperature.

9 - 9:30 am
3322067: Starvation in Rolling Bearings: From Single Contact Devices to Rolling Bearing Simulators
David Kostal, Josef Fryza, Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czechia

Grease lubrication represents a major way for rolling bearings. It provides maintenance-free operation and low friction over wide area of speeds. However, grease lubricated bearing may suffer from severe starvation which is given by balance between loss and replenishment mechanisms of lubricant available in a track. Our understanding of film thickness formation provided by certain lubricant available at the contact inlet is known well at present stage. Contrary, there is a limited knowledge about mechanisms responsible for lubricant replenishment in real bearing under operation. This is a point where simulation of elastohydrodynamic contact in standard ball-on-disk devices could not necessarily be example of conditions in real bearings. Film thickness and starvation severity between classical ball-on-disk and real

bearing simulator with optical insight are compared in this study. Results of lubricant distribution on the contacting surfaces by fluorescence techniques are presented.

9:30 - 10 am
3316427: Effect of Lubricant Properties and Contact Conditions on False Brinelling Damage
Rachel Januszewski, Amir Kadiric, Imperial College, London, United Kingdom, Victor Brizmer, SKF RTD, Houten, Netherlands

False brinelling is a type of surface damage that can occur in rolling bearings when the contacts between the rolling elements and bearing rings are subjected to small amplitude oscillatory rubbing motion. The damage manifests itself as relatively deep craters on the bearing rings. This paper attempts to provide new insight into the mechanisms of false brinelling. Experiments were conducted with a reciprocating ball-on-flat configuration to study the influence of stroke length, oscillation frequency, lubricant formulation and surface properties. An optical set-up was used to visualize the contact in-situ to allow observation of the initial onset of damage on the local level and its subsequent spread throughout the contact. The trends found suggest that lubricant resupply to the oscillating contact is an important factor in controlling the level of damage. In view of this finding, potential preventative measures are explored including optimization of surface roughness structure.

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

1D — Columbus G

Biotribology I

Session Chair: Angela Pitenis, University of California, Santa Barbara, CA
Session Vice Chair: Alison Dunn, University of Illinois, Urbana, IL

8 - 8:30 am
3283332: Remarkable Wear and Fracture Properties and Unique 3D-Microstructure of Enamel in the Dentition of the Hadrosaurid Dinosaur
Tomas Grejtak, Tomas Babuska, Brandon Krick, Lehigh University, Bethlehem, PA, Stephen Hendricks, Gregory Erickson, Florida State University, Tallahassee, FL, Soumya Varma, Manish Jain, Yi Lee, Siddhartha Pathak, University of Nevada, Reno, Reno, NV, Mark Norell, American Museum of Natural History, New York, NY

The ceramic-like enamels of grinding teeth are biomechanical marvels able to withstand millions of loading cycles. The secret to these tissues' biomechanics lies in their complex, hierarchical, three-dimensional microstructures. Hadrosaurids achieved grinding dentitions with Wavy Enamel, folded layers of parallel HPA crystallites separated by thin layers of inter-layer matrix. It has been demonstrated that Wavy Enamel exhibits damage tolerance and enhanced wear performance through channeled fracture propagation. In this work, for the first time, various microscopy techniques and micro-mechanical testing have been used to visualize the full 3D structure including both mechanical and chemical in order to understand the correspondence between the microstructure and the material behavior. Understanding Wavy Enamel biomechanics has the potential to reveal new design guidelines

for tough, wear-resistant materials with crack-steering capabilities.

8:30 - 9 am
3325025: Tribology of Tactile Perception - FE Modeling of Skin Aging
Marc Masen, Rikeen Jobanputra, Imperial College London, South Kensington, London, United Kingdom

This study focuses on investigating the underlying mechanics of tactile sensing. A FEmodel of the interaction of a product surface with the index finger was developed, that includes a model microstructure of the plantar skin based on hystological analyses. The model enables assessment of parameters such as the stress and strain at the location of the mechanoreceptors in the skin. The model was used to investigate the effects of aging skin (modeled in terms of microstructural and geometrical changes). Aging was modeled as a flattening of the dermal-epidermal junction (DEJ) , which causes both the shear stresses and the Von Mises stresses to be re-distributed away from the DEJ. Given that the DEJ is the location of the various tactile mechanoreceptors, this suggests an explanation perceptive ability reduces with age, Additional investigations will focus on other effects related to aging of the skin on the propagation of stimuli, such as changes in layer thickness and stiffness.

9 - 9:30 am
3292469: Effects of Contact and Shear on Corneal Epithelial Cell Mucus Layer
Jack Famiglietti, Eric McGhee, Juan Uruena, Padraic Levings, W. Gregory Sawyer, University of Florida, Gainesville, FL

Mucins form the first line of defense against tribological contacts on the corneal surface. Mucins form high-water content mucin gels that help increase the contact area, reduce contact pressure, and significantly decrease the shear stress at the interface. Membrane-bound mucins (MUC 1, 4, 16, 20) growth kinetics have been previously measured in-vitro [1], but this study was in the absence of sliding. In this work, the effects of contact and shear will be evaluated on the mucin layer. Concavalin A will be used to stain the mucins and measure the mucin layer thickness and kinetics inside and outside the wear track after frictional sliding. These measurements present an opportunity to relate frictional shear stresses with deficiencies of mucin growth and possibly relate this to conditions like dry eye.

9:30 - 10 am
3284256: Mechanical Regulation of Blood Flow Shear in Hemostasis Process
Xiangyu Hu, Tsinghua University, Beijing, China

The hemostasis is a physiological response to the vascular injury, during which the blood clots form to seal the wound and prevent blood loss. During hemostasis, the blood flow shear will have great influence, like other general fluid seal problem. The behavior of various blood components under different flow conditions remains to be studied. In this work, we used microfluidic technology to contrust a microfluidics hemostasis model to simulate vascular trauma, and the hemostasis process was real-time monitored. The physiological blood flow shear were realized in this model, from venule enviroment (~100/s), to arteriole environment (~1000/s), and finally to pathology environment (~2000/s). The results showed that the hemotasis processes were diffierent under different flow condition, and the aggregation of platelet and fibrin depended a lot on the the unfolding or fiber-forming behavior of vWF during exposure to pathological flows. This study may improve control methods for hemostasis.

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

1E Columbus H

Seals I

Session Chair: Khalid Malik, Ontario Power Generation, Pickering, Ontario, Canada
Session Vice Chair: Noel Brunetiere, Institut Pprime, Futuroscope Chasseneuil Cedex, France

8 - 8:30 am
3322475: Simulation of Transient Processes of a Hydraulic Seal with Elastohydrodynamic Lubrication
Arne Leenders, Leibniz University Hannover, Hannover, Germany

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

8:30 - 9 am
3269407: Shaft and Seal Wear Determination Using a TEHD-Simulation Model
Christoph Burkhart, Stefan Thielen, Bernd Sauer, TU Kaiserslautern, Kaiserslautern, Rhineland-Palatinate, Germany

Radial shaft seals (RSS) are a widely used machine element present in almost every transmission unit operated with a lubricant. The seals are used to ensure the technical tightness of the operated system. By the reason of the working principle of a RSS, the distortion hypothesis, seal and shaft are partially in contact during operation. As a result seal- and shaft in the sealing systems are subjected to continuous wear during their lifetime. In this study, an approach for the simulation of seal- and shaft wear based on the energetic theory of FLEISCHER is presented. A transient, thermal, elasto-hydrodynamic (TEHD) simulation model operating on the microscale of a seal and shaft system is therefore used. The simulation results are validated according to measurements on a shaft seal wear test rig. The focus is on single pairs of component surfaces in contact considering their roughness parameters, flow factors, specific wear coefficients and their solid body contact.

9 - 9:30 am
3293189: Leakage Characteristics of Static Seal under Pressure Cycling Condition
De Huang, Andreas Almqvist, Lulea Technology University, Lulea, Sweden, Chien Nguyen, Saint-Gobain, Bristol, RI

The leakage flow rate through a static seal varies when the contact load experiences a substantial pressure cycle[1,2]. Leakage flow rate hysteresis is due to the different response of surface waviness and roughness components under the contact load. That is, the surface features with shorter wavelength tend to deform plastically because of the local pressure concentration and leads to an increased permeability when the system is unloaded. An experiment apparatus is built to investigate the leakage hysteresis. We find that not only the hysteresis happens under the contact load cycle but also because of the pressure cycle at the fluid inlet, for which the plastic deformation may also play a role. A two-scale numerical model[3] is developed to simulate and investigate the phenomenon.

9:30 - 10 am
3286645: In Situ Observation of Three-Body Contact in Rubber Sealing Interface
Kun Qin, Qin Zhou, Kai Zhang, China University of Geosciences – Beijing, Key Laboratory of Deep Geodrilling Technology, Ministry of Land and Resources, Beijing, China

During the drilling process, sealing failure, serious leakage, caused by the intrusion of rock particles in the drilling fluid into the sealing interface frequently occur, which reducing the drilling efficiency and increasing the construction cost. In order to illustrate the sealing failure mechanism clearly, the micro-cave phenomenon lead by particles in sealing area has been directly observed with a custom-built experimental setup. Effect of the particles size on micro-cave area and further effect on contact rate of seal interface were investigated in detail. Findings from this work, hopefully, will provide experimental support for further systematic studies on the development of substitutions that provide better performances.

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

1F Columbus IJ

Lubrication Fundamentals I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3325112: The Effect of Chemical Structure on Tribological Behavior of Base Oils
Kun Qian, Zhijiang Ye, Cameron Timothy, Mark Sidebottom, Miami University, Oxford, OH

Most engineering lubricants are based on base oils. Each base oil group exhibits different tribological properties. In this study, we investigate the tribological behavior of group I to V base oils with ZDDP additive. A pin on disc experiment was designed for steel to steel Hertzian contact under boundary lubrication condition. The effect of temperate, shear stress, and contact pressure are investigated. The chemical structure of different group of base oils is characterized and correlated to the frictional performance and tribofilm formation.

8:30 - 9 am

3284374: Adsorption on Metal Oxides: An in Silico Design of Lubricants

Sarah Blanck, Sophie Loehle, Centre de Recherche Total de Solaize, Solaize, France, Carine Michel, Stephan Steinmann, University of Lyone, Laboratoire de Chimie, Lyon, France

Lubrication plays a major role in a wide range of key sectors from motors to metal working. Changes in formulations can lead to modifications of the wettability and the tribological properties. Therefore, it is important to better understand the interactions between the lubricant and the surface. Computational chemistry based on density functional theory was shown to be a powerful tool to describe those interactions. Here, we have determined the influence of different types of additives in the wetting process, by comparing their adsorption energies with their solvation energies in a model lubricant base oil [1]. As the additives are often large multifunctional molecules, we developed an automated workflow DockOnSurf to determine the most favorable adsorption site on both the molecule and the surface, as well as the most favorable conformation for the molecule. The possibility of film formation was also considered. [1] S. Blanck et al., submitted to Tribology International.

9 - 9:30 am

3284304: Molecular Dynamics Simulation of Lubricating Oil Flow in Porous Polyimide Retainers of Bearing

Wenbin Chen, Wenzhong Wang, Pengzhe Zhu, Beijing Institute of Technology, Beijing, China

Porous polyimide materials have been widely used as bearing retainers to improve lubricating oil supply performance. Understanding the lubricating oil supply process is of vital importance in bearing lubrication behavior. Different ways of lubricating oil supply have been explored. However, it's difficult to observe experimentally lubricant flow in the micropores. This work conducts the coarse-grained molecular dynamics modeling the oil flow in porous polyimide material which is used for bearing retainers. Different factors such as pore parameters and surface properties are considered to study the migration behaviors and efficiency of lubricant. The results show that the diameter of micropores has a significant effect on the oil inflow and outflow of micropores; the lubricant oil will migrate to the contact surface under rotating state and rotational speed will affect the lubricant migration efficiency. The purpose is to reveal the oil supply mechanism of the bearing retainer material.

9:30 - 10 am

3337146: Using Rheology, Colloid Force Microscopy and Mathematical Modeling for Understanding the Role of Associative Polymers in Lubrication

Eugene Pashkovski, Reid Patterson, The Lubrizol Corporation, Wickliffe, OH, Timothy Murdoch, Robert Carpick, Daeyeon Lee, University of Pennsylvania, Philadelphia, PA, Ilya Kudish, ILRIMA Consulting, Inc., Sarasota, FL

Associative polymers are widely used in lubricating fluids and impart elastic stresses which are not accounted for in traditional treatment as Newtonian fluids. Using mathematical modeling of hydrodynamic friction, we show that the polymer elasticity controls viscous energy losses in the tribological contact zone. Elastic forces are measured using capillary breakup extensional rheometry and depend on the chemical nature of associative groups. These groups promote the adsorption of macromolecules onto metal surfaces, forming thick polymer layers. Colloidal probe atomic force microscopy demonstrates that these polymer layers significantly reduce frictional forces between moving surfaces with quasi-static and dynamic normal force measurements providing additional insights into the structure of the adsorbed polymer network and its interaction with the solvent. This allows

further analysis using classical rheology in the linear viscoelastic regime.

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

1H Randolph 1

Grease I

Session Chair: William Tuszynski, The Unami Group, LLC
Session Vice Chair: TBD

8 - 8:30 am
3303461: Lubrication Condition Monitoring of Practical Ball Bearings under Grease Lubrication by Electrical Impedance Method
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 grease lubrication on tribological performances. However, monitoring of lubrication condition (e.g., grease film thickness) of practical bearings under the grease lubrication has not been accurate. 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 under the oil lubrication. Besides, it has been confirmed that the developed method, which is applicable to practical bearings, measures the oil film thickness with high accuracy comparable to the optical interferometry. Therefore, in the present study, the electrical impedance method has been applied to the lubrication condition monitoring of practical ball bearings under the grease lubrication. Finally, we investigated the differences between the oil and grease lubrication.

8:30 - 9 am
3319594: Tribology Bench Tests for the Development of Next-Generation Greases with Optimized Lubrication Properties
Rory McAllister, Marc Masen, Philippa Cann, Imperial College London, London, United Kingdom

Electrification of the automotive sector is putting even more emphasis on low-friction bearing lubricants, and the burgeoning battery market has driven up the price of lithium, a raw material in >70% of greases. The development of new non-lithium-based greases with optimized friction properties is therefore a priority for the lubricants industry. Tribology bench-tests that simulate bearing operation are less costly than full bearing tests. Friction and film thickness tests were performed for a range of greases using the MTM and EHD rigs at 80°C and from 10-1000mm/s. The same greases were also tested in the R0F+ bearing test rig for 100 hrs. The test methods are compared in terms of the insight they provide into lubrication performance, and the composition of the rolled tracks. The bench tests provided valuable information about the lubrication performance of the greases, enabling an informed development protocol, while undergoing the same thickener-depositing effect evident in bearings.

9 - 9:30 am

3279951: Contact Protection by Grease in Aeronautical Heavily Charged Oscillating Bearings

Lucas Frache, LaMCoS Laboratory , Villeurbanne, Rhône Alpes, France

Highly-loaded greased oscillating bearings are investigated. These unusual working conditions are encountered in specific applications as aeronautics (ailerons, actuators, etc.), manufacturing (repetitive robot motions), etc. In all those systems, while the oscillating motion imposes a starved lubrication regime, loads on the single bearing can be very high, inducing high contact pressures. Based on both experimentations [1] and simulations [2], preliminary researches have given a reconstruction of the bearing life evolution and proved that the grease presence and evolution within the contact interfaces are key factors for preserving the bearing integrity [1, 3]. To fulfill that comprehension, endurance tests on a laboratory test bench are supported by both topological and chemical analyses of the interacting surfaces of commercial bearings. It allowed to investigate the establishment of the greased interface along all the bearing lifecycle, under highly loaded oscillating movement.

9:30 - 10 am

3284996: Complementary Approach in Stick-Slip Analysis of a Lubricated Contact: From the Local Contact Behavior to the Dynamical Response of the System

Ilaria Ghezzi, Yves Berthier, INSA Lyon, Lyon, France, Davide Tonazzi, Francesco Massi, University of Rome La Sapienza, Rome, Italy, Michael Rovere, Cedric Le Coeur, SOMFY, Cluses, France

Mechanical systems with sliding contact interfaces can be subjected to the so-called Friction-Induced Vibrations [1, 2]. These can be undesirable and can cause excessive wear of components, fatigue failure, and noise [3]. The present work is focused on the stick-slip instabilities in a greased contact analysis. On one hand, experimental tests are carried out to understand the local frictional response of the greased contact. On the other, a lumped numerical model is created in order to take into consideration the system dynamic response. Introducing the information about the local contact behavior into the numerical model, the parameters for which the system is more predisposed to stick-slip are identified. The study is carried out referring to a real application case: a greased spring brake system used in electric tubular actuators. The possibility of understanding the conditions for which the system is more predisposed to stick-slip may allow it to prevent its appearance.

10 - 10:30 am – Break

Tribochemistry I - Superlubricity & Mechanochemistry of Carbon Based Solid Lubricants

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3285407: The Effect of Sliding Counterbodies on Tribological Properties of Nanocrystalline Diamond Film
Wei Qi, Tsinghua University, Beijng, China

We investigated the effect of counterbodies which change the friction and wear properties of DCD films. The structure and morphology of scratches on the surface of the NCD films and track on the surface of the balls have been characterized by optical microscope (OM), scanning white-light interferometer, Raman-effect spectroscopy, and transmission electron microscopy (TEM). The result shows that are highly crystalline with nanometer size grains and contain a very high fraction of sp3 carbon bonds. They exhibit high hardness and high elastic modulus. Interestingly, bearing steel ball shows low value of friction cofficient ~0.12 while low values of friction coefficient and ultra low values of wear volumn are obtained using Si_3N_4 ball counterbodies. Transfer of the film from the counter-body, oxidation of transfer film and mixing of transfer film with carbonaceous layer on the worn surfaces are responsible for such behavior.

8:30 - 9 am
3285508: Temperature Induced Structural Evolution and Superlubricity Mechanisms in Amorphous Carbon-Based Films
Muhammad Irfan Fareed, Tsinghua University, Beijing, China

In this study, hydrogenated amorphous carbon (a-C:H) and silicon doped amorphous carbon (a-C:H:Si) films were heat treated and their tribological performances were observed in dry and at ambient temperature conditions. Si-doped thin film is found to have sustained higher annealing temperatures without losing key characteristics due to fourth fold coordination of silicon, which promotes sp^3 hybridization. Si-doped DLC film has shown excellent tribological behavior as compared to its counterpart a-C:H film. The film bonding structural changes were investigated using Raman spectroscopy. A considerable increase in graphitic sp^2-C fraction has been observed from the spectrum taken from the wear scar of counterface surface of a-C:H. A very thin (~ 0.14 μm) tribolayer is observed from TEM and EDS analysis of the counterface surface. This tribolayer is mainly responsible for superlow friction of DLC films for extended cycles due to surface passivation.

9 - 9:30 am
3281530: Atomistic Simulation Revealing the Temperature Dependence of Frictional Property of Diamond-Like Carbon in Vacuum
Yang Wang, Koshi Adachi, Momoji Kubo, Tohoku University, Sendai, Miyagi, Japan

Generally, friction property of diamond-like carbon (DLC) is strongly affected by temperature. However, people have not fully clarified how surface temperature affects friction property of DLC yet because

experiments are hard to correctly monitor the temperature at real contact surface and elucidate the friction dynamics. Here, we perform atomistic simulations of DLC in vacuum to reveal why and how surface temperature changes the friction. We find that as the surface temperature increases, the number of interfacial bonds increases while the shearing force of each interfacial bond decreases, leading to a volcano-like temperature dependence of the total friction force under a constant load and sliding velocity. We further report that the temperature with the highest friction force decreases with lowering the sliding velocity, agreeing with the previous experiments.

9:30 - 10 am
3305924: Towards, Robust Superlubricity on Industrially Relevant Surfaces and Sliding Conditions
Anirudha Sumant, Kalyan Mutyala, Srilok Srinivasan, Jianguo Wen, Subramanian K.R. S. Sankaranarayanan, Argonne National Laboratory, Lemont, IL

Recent progress on achieving superlubricity at macroscale utilizing nanomaterials as a solid lubricant in an oil-free environment is very promising to explore its potential in real-world industrial applications. However, number of scientific and engineering challenges still needs to be overcome to realize the dream of achieving long-lasting superlubricity on industrially relevant surfaces. Here, we demonstrate that robust, long-lasting superlubricity is possible using nanomaterials as a solid lubricants on industrial grade rough steel surfaces using specific tribo-pairs sliding in a dry nitrogen environment at high contact pressures and at moderate sliding speed. We observed that an impervious tribolayer formed at the tribological interface led to enormous reduction of friction/wear leading to superlubricity. This represents a significant step towards devising sustained superlubricity on industrially relevant surfaces. I'll discuss mechanism responsible in detail.

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

1K Michigan 1

Engine and Drive Train Special Session on Electric Vehicles I

Session Chair: Babak Lotfi, ExxonMobil, Baytown, TX
Session Vice Chair: Dairene Uy, Shell Technology Center, Houston, TX

8 - 8:30 am
3274913: Study of Vibration Wear in Plug-In Hybrid Vehicle Engine
Weizi Li, Shell (Shanghai) Technology Limited, Shanghai, China, Yunfei Wang, Qinhao Fan, Zhi Wang, Tsinghua University, Beijing, China, Robert Taylor, Shell Global Solutions UK, London, United Kingdom

At times plug-in hybrid vehicle (PHEV) is powered only by electricity, hence engine does not operate and is not lubricated well, subsequently is under severe stress of vibration on road. Thus, this study initiated by Shell and Tsinghua University is aimed to identify possible lubrication challenge in such case. As first step, vibration data acquisition from a PHEV is done through dynamometer and real driving, amplitude and frequency characteristics of engine vibration are analyzed. Next, in order to simulate extreme conditions in pure electricity mode, the PHEV engine is installed on a specifically designed rig to produce accelerated aging resulting from vibration. Lastly, engine is teared down for measurement and rating.

The test results suggest fretting wear can be intensified in PHEV as we find corrosion-like wear pattern on the journal bearing close to fly wheel and scratches which indicated abrasive wear on con-rod bearings.

8:30 - 9 am
3284028: Thermal Management in Battery Electric Vehicle (BEV)
Dean Tomazic, FEV North America Inc., Auburn Hills, MI

In this presentation, an insight into EDU and battery thermal management techniques and challenges will be described in greater detail. Furthermore, an in-depth review of the advanced direct cooling techniques of EDU and Battery will be outlined. Additionally the advancements in integrated power electronics and high voltage conductors and the associated thermal management techniques will be presented. Towards the conclusion, the presentation will outline the future trends in EDU, power electronics and battery technology and how the thermal management is becoming a critical step in system design and optimization.

9 - 9:30 am
3340704: A Model for Prediction of Power Losses in Electric Vehicle Transmissions
Amir Kadiric, Joseph Shore, Imperial College London, London, United Kingdom

Transmission power losses provide a major contribution to the overall energy loss in an electric vehicle. In relative terms, this contribution is much larger than in an equivalent IC-powered vehicle. Consequently, the ability to predict and minimise transmission losses provides an important avenue for improving the efficiency and thus extending the range of EVs. This paper describes a model for prediction of EV gearbox efficiency including the influence of lubricant properties. The approach utilises a thermally-coupled gear lubrication model to accurately predict gear teeth friction as well as bearing and churning losses. The model uses experimentally obtained lubricant rheology parameters as input which allows it to differentiate between different lubricant formulations in terms of overall gearbox efficiency. Results are presented to illustrate the trends in transmission losses with a selection of oils and over a range of operating conditions typical of EV transmissions.

9:30 - 10 am
3316891: Test Facility to Investigate Function and Efficiency of the Speed4E Hyper-High-Speed Electromechanical Powertrain
Lukas Pointner-Gabriel, Hermann Pflaum, Karsten Stahl, Technical University of Munich, Garching, Bavaria, Germany

High-speed transmission concepts are increasingly used in BEVs (battery electric vehicles) to improve the power density of the whole drivetrain. Within the joint-project "Speed4E", an innovative drivetrain prototype capable of input speeds of up to 50,000 rpm is developed and will be installed in a BEV for road driving experience. In order to evaluate the overall function and efficiency of the drivetrain, extensive investigations on a test rig are planned. For this purpose, the powertrain is operated on a modern test rig and equipped with a variety of sensors. Especially the required high-precision input torque measurement at the above-mentioned speed range represents a major challenge. The presentation gives a detailed insight on the developed test rig concept as well as the used measurement methods.

10 - 10:30 am – Break

Contact Mechanics I

Session Chair: Morgan Jones, Sandia National Laboratory, Albuquerque, NM
Session Vice Chair: Kylie Van Meter, University of Florida, Spring Hill, FL

8 - 8:30 am
3278148: 3D Elastodynamic Frictional Contact Model
Xin Zhang, Q. Jane Wang, Northwestern University, Evanston, IL

Contact and friction in mechanical interfaces would induce crack initiation and contact fatigue due to high stress cycles; the elastodynamic influence may become significant when the mechanical components run at high speeds. This presentation reports a three-dimensional (3D) elastodynamic frictional contact model, including 1) derivation of fundamental solutions of displacements and stresses for a half-space subjected to a moving force, 2) application of numerical techniques such as the discrete convolution-fast Fourier transform (DC-FFT) algorithm for stresses and displacements formulation and the conjugate gradient method (CGM) for pressure searching. The proposed model is employed to study frictional contacts of an elastic ellipsoid sliding on an elastic half-space with a high constant sliding velocity. It is noted that the elastodynamic influence becomes significant when the sliding velocity is larger than 0.4 times of shear wave speed of materials.

8:30 - 9 am
3279700: Investigating the Effect of Radius of Curvature Evolution on Elastic-Perfectly Plastic Contact
Eoghan O'Neill, Matthew Brake, Rice University, Houston, TX, Hamid Ghaednia, Massachusetts General Hospital-Harvard Medical School, Boston, MA

The study of elastic-plastic contact mechanics is fundamental in understanding the multi-scale behavior of mechanical systems. The effects of varying the radius of curvature in elastic-perfectly plastic contact, and resulting impact on contact parameters, has been largely neglected in past studies. The conventional approach for elastic-plastic contact models is to assume the equivalent radius of curvature from Hertzian theory is valid in this regime. To assess the applicability of this assumption, contact between two spheres is modeled with Finite Element Analysis. For two elastic-perfectly plastic spheres, the radii of curvature and material models are varied to span the range of flattening to indentation scenarios. Comparisons to contact models are made indicating the radius of curvature's effect on contact force, area, and material hardness in elastic-perfectly plastic contact. Finally, a formulation for contact parameters as a function of radii of curvature in contact is proposed.

9 - 9:30 am
3302964: Digital Image Correlation Based Subsurface Stress Measurements in Hydrogels
Alexander McGhee, Jack Famiglietti, Eric McGhee, University of Florida, Gainesville, FL

The stress distribution due to hemispherical indentation is measured using digital image correlation (DIC). Traditionally, only surface displacements and strain fields are measured since DIC requires a random arrangement of dots on a 2D plane to correlate displacements. Here a novel method of gelling a 2D plane of randomly oriented dots within the body of the hydrogel is used to make nondestructive and

repeatable full field displacement and strain measurements within arbitrary sections of the hydrogel. Measured data is compared to the the Hertz contact stress field for a sphere on flat.

9:30 - 10 am
3324921: Adhesion Hysteresis in Soft Contacts
Kyle Schulze, Auburn University, Auburn, AL, Alexander Bennett, University of Pennsylvania, Philadelphia, PA

We find generally for soft samples that low strain, low strain-rate indentations that traditional contact models hold well but beyond these bounds these materials have signifigant adhesion hysteresis and fits to these models can be difficult and the results questionable. Here we probe the mechanisms of adhesion hysteresis in soft samples with compressive moduli less than 3 MPa (PDMS) using in situ microscopy and controlled indentation of smooth and rough surfaces via experimentation. By systematically varying indentation variables such as strain, strain rate, indenter size, indenter shape, and material moduli a image of the governing properties that drive hysteresis can be compared across an individual sample. Computer modeling methods of the material were used to compare against the experimental data to tease out any additional trends in the indentation sets.

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

1M Michigan 3

Nanotribology I

Session Chair: Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL
Session Vice Chair: Zhijiang Ye, Miami University, Oxford, OH

8 - 8:30 am
3287020: Friction and Wear Behavior of Confined Surrogate Fuels
Judith Harrison, Sabina Maskey, Brian Morrow, United States Naval Academy, Annapolis, MD, J. D. Schall, North Carolina A&T State University, Greensboro, NC

The application of carbon-based coatings to engine components has become increasingly more common. Coatings, such as ultrananocrystalline diamond (UNCD) and amorphous carbon (a-C:H) can have a wide-range of properties but are generally attractive due to their wear resistance. At the same time, alternative fuels with slightly different hydrocarbon compositions are being developed. Because these fuels are complex, surrogates for these fuels have been developed so that impacts of changes in composition on properties and combustion can be studied. To date, little effort has been devoted to the study of the interactions of these fuels with engine coatings or examining the way the mixture composition impacts friction. The results of molecular dynamics (MD) simulations that examine the interaction of surrogates fuels with carbon-based engine coatings will be presented. The dependence of this behavior on the potential energy function, load, and fuel composition will be examined.

8:30 - 9 am

3282147: In Situ Study of the Lubrication Mechanism of Phosphonium Phosphate Ionic Liquid in Nanoscale Single-Asperity Sliding Contacts

Filippo Mangolini, Zixuan Li, Oscar Morales-Collazo, Hugo Celio, Andrei Dolocan, Joan Brennecke, The University of Texas at Austin, Austin, TX, Jerzy Sadowski, Brookhaven National Laboratory, Upton, NY

Phosphonium phosphate ionic liquids (PP-ILs) have attracted considerable attention in tribology owing to their high thermal stability, good miscibility in hydrocarbon fluids, and excellent lubrication performance. Despite the scientific weight of previous macroscale tribological studies of PP-ILs, a fundamental understanding of the nanoscale lubrication mechanism is still lacking. Here, we used atomic force microscopy (AFM) to evaluate the processes occurring at sliding interfaces in situ, in single-asperity contacts. The AFM experiments, in which a diamond tip was slid on steel in PP-IL, indicated a reduction in friction only after the removal of the native oxide layer from steel. Based on laterally-resolved ex situ analyses of the surface chemistry of steel by X-ray photoemission electron microscopy, low energy electron microscopy, and time-of-flight secondary ion mass spectrometry, a phenomenological model will be proposed to account for the observed tribological behavior.

9 - 9:30 am

3325316: Nanorheology of Ionic Liquids Probed by an extended Surface Forces Apparatus

Mengwei Han, Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL

Leveraging on the chemical stability and non-volatility, ionic liquids (ILs) are considered as good lubricants or lubricant additives. Different from conventional molecular lubricants, the presence of strong interionic Coulombic forces and the interactions between the ions and a charged substrate complicate the mechanisms that govern lubrication mediated by ILs. Previously, we shed light onto the time scales of (physical) bonding and relaxation of nanoconfined ILs via lateral force microscopy (LFM). However, the intrinsic limitations of LFM, such as the arbitrarily defined film thickness, introduce uncertainties in the proposed explanations. In the present study, we apply our extended surface forces apparatus (eSFA) with a lateral-force attachment to measure the tribological and rheological response of nanoconfined ILs as a function of the lateral velocity are examined to obtain molecular-level understanding of the relaxation of ILs in confinement.

9:30 - 10 am

3304839: Polarized Light Microscopy for Visualizing Liquid Crystal Lubricants in EHD Contacts

Robert Elkington, Monica Ratoi, University of Southampton, Hampshire, United Kingdom

The layered, lamellar phase of lyotropic liquid crystals (LLCs) display promising tribological properties possessing low shear strength between layers and, solid like elasticity and high load carrying capacity perpendicular to their layered structure. Being able to visualize and study the behaviour of LLC in high pressure contacts at a range of speed, SRR and temperature conditions can facilitate the understanding of the mechanism of action behind their low friction properties. This study has focused on building a setup mounted on an EHD tribometer which can achieve this aim while demonstrating the challenges of using a polarized light microscope to yield high contrast images of the behavior of LLCs at the EHD contact. The technique is capable of visualising the film formation, bulk alignment, and flow of liquid crystal containing lubricants. The effect of velocity, load and shear on triethanolamine/oleic acid lamellar LLCs in a glass/steel EHD contact will be investigated.

10 - 10:30 am – Break

2A Columbus AB

Commercial Marketing Forum II

1:30 - 2 pm - **Clark Reliance Corporation**

2 - 2:30 pm - **Lockhart Chemical Co.**

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

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

4 - 4:30 pm - **Kao Chemicals GmbH**

4:30 - 5 pm - **BASF Corporation**

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

2B Columbus CD

Metalworking Fluids II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3283179: Machining of Aluminum Alloys – Effects of Composition & Microstructure on Machinability
Robert Evans, Quaker Houghton, Conshohocken, PA

Aluminum alloys have become one of the most heavily used classes of metals for production of automotive engine components. The mechanical properties and higher strength to weight ratios of aluminum alloys, offer a desirable means for achieving lighter weight and increased fuel efficiency. While aluminum alloys are considered to be a very machinable class of metals, they do present challenges during machining. These challenges arise from the high elasticity, thermal expansivity, and high silicon content of these materials, which often requires specific design features and performance capabilities with the metalworking fluid used. This presentation will discuss the microstructural features as well as compositional and mechanical properties, of commonly used automotive cast aluminum alloys, and how these properties and features impact material machinability and the design requirements of the metalworking fluid used.

2 - 2:30 pm
3283602: Lubrication and Machining of Hard Wear-Resistant Materials
Bailey Decker, Quaker Houghton, King of Prussia, PA

There is a current trend in automotive engine manufacturing to utilize hard, thin coatings, applied via thermal methods, as engine cylinder liners. Such hard thin coatings show improved wear resistance and increased weight reduction, relative to conventional cast iron cylinder sleeves. While offering such benefit, these coatings also present machining challenges, with regard to tool life and surface quality obtained. This presentation will discuss the machinability and properties of various hard wear-resistant materials currently used. In addition, as studied under high speed continuous cutting conditions, the performance and lubrication requirements of the metalworking fluids used for these materials will be discussed.

2:30 - 3 pm
3286000: Comparing Forming Fluids Using a Cup Drawing Hydraulic Press
Joseph Schultz, Daniel Banks, Britt Minch, Lubrizol Corporation, Wickliffe, OH

Effectively evaluating forming fluids in a laboratory setting has been a challenge without the proper equipment. The few existing methods consist of tribotests such as the twist compression test (TCT). This test generally creates similar lubrication conditions that exist in the metal forming process, is a good screening tool and has often correlated to actual field results. However, it unfortunately does not provide actual metal movement. In contrast, the cup draw test (CDT) uses a hydraulic press to push a metal blank through a die to form a cup shape. Lubricants applied to the blank and/or dies can be ranked by measuring: 1) the various forces applied and transmitted during the forming process and 2) the dimensions and surface finish of the formed cup. Results of an assortment of lubricants on various metals will be presented. This work will also explore the relationship among cup draw, twist compression and field trial data.

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

4 - 4:30 pm
3287711: Investigation of Metalworking Fluids on Titanium Alloys
Yan Zhou, Jeff Larsh, Yixing Philip Zhao, Quaker Houghton, Conshohocken, PA, Junhui Ma, Javad Mohammadi, Olufisayo Gali, Reza Riahi, University of Windsor, Windsor, Ontario, Canada

Titanium alloys are perceived as materials that are difficult to machine, due to their low thermal conductivity, high alloying tendency, work hardening characteristics, high surface damage susceptibility, and low elastic modulus. It is critical to design suitable metalworking fluids that can overcome the difficulties above. More importantly, the evaluation methods have to be representative and comprehensive. Here, we employed a range of lubricity testing techniques, including CNC machining, that effectively cover the range of different operations. We were able to show the correlation between the chemical components of the fluids and the lubricity testing results, such as torque and tool wear.

4:30 - 5 pm
3286129: A New Ferrous Corrosion Inhibitor (CI) Reinforcing Oil-Based Industrial Lubricants in the Battle against Corrosion
Ryan Weber, Brett Wessler, Samantha Lauro, Christina Brancel, Britt Minch, The Lubrizol Corporation, Wickliffe, OH

Industrial lubricating and process fluids are essential to ensuring the smooth operation of a modern industrial world. However, in a world where steel reigns supreme and oxygen lurks around every corner, corrosion poses a constant insidious threat to global industry and infrastructure. Without the support of

corrosion inhibitors (CIs), industrial lubricants alone cannot win the battle against this relentless foe. Although myriad CIs exist for water-based fluids, formulators of oil-based industrial fluids have a more limited toolbox of CIs at their disposal. Imidazolines are facing increased regulatory scrutiny and traditional sulfonates alone often fall short on performance. This talk discusses a new versatile CI based on enhanced calcium sulfonate chemistry that provides excellent corrosion inhibition to a range of oil-based industrial fluids. Examples of formulations including industrial gear oil, hydraulic fluid, grease, and straight-oil metalworking fluid are detailed.

5 - 5:30 pm
3286352: Polyglykol as Performance Wear Lubricant and Synergism with Extreme Pressure Additives on Net Oil Metalworking Fluid
Eduardo Lima, Dow Brazil, Jundiai, São Paulo, Brazil

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

5:30 - 6 pm
3286526: Theoretical and Practical Deficiencies of Non-Si Defoamer Technology for Aqueous Metalworking Fluids
Ernest Galgoci, Munzing NA LP, Bloomfield, NJ, Justin Mykietyn, Munzing, Bloomfield, NJ

For aqueous metalworking fluids, the main defoamer technologies employed are siloxane, organo-modified siloxane, or non-Si (e.g., mineral oil or glycol). In certain applications (e.g., aviation and automotive), non-Si defoamer technology is often specified due to concerns that Si-containing products might impart coating defects. Although this concern has some merit, it has been demonstrated both experimentally and in decades of field application that properly formulated types of siloxane defoamers are washable and paintable (i.e., impart no coating defects). An often-overlooked aspect of the specification to use non-Si products is that the defoaming performance of non-Si technology is inherently inferior to that of siloxane-based technologies. This paper will demonstrate the above claim through a detailed analysis of the theoretical defoaming thermodynamics and show how that manifests itself in the significant deficiencies of non-Si defoamers in practical metalworking fluid systems.

Rolling Element Bearings II

Session Chair: Hannes Grillenberger, Schaeffler Technologies AG & Co KG, Herzogenaurach, Bayern, Germany
Session Vice Chair: Nikhil Londhe, The Timken Company, Canton, OH

1:30 - 2 pm
3287171: Innovative Bearing Solutions for E-Mobility Applications
Jitesh Modi, Schaeffler Group USA, Troy, MI

The electrified drivetrains for E-mobility applications pose discrete challenges for the bearings to satisfy critical requirements of high speeds, durability, efficiency, NVH and reliability. The standard bearings are not adequate to fulfill these requirements which necessitates the need for innovative and engineered bearing solutions. These solutions utilize unique design approach, advanced material technologies, special processes including surface treatments and value-added integration features. On the basis of specific examples, innovative bearing concepts and arrangements in electrified drivetrains are described. These include e-Smart bearings for high performance, efficiency and monitoring of electric motors and drivetrains. In addition, the bearing solutions to address unique challenges of creep, electric currents, slippage and high speeds are discussed.

2 - 2:30 pm
3287182: Electric Current Effects on Wind Turbine Rolling Element Steel
Robert Erck, Benjamin Gould, Nicholaos Demas, Aaron Greco, Argonne National Laboratory, Argonne, IL

A three-ring-on-roller benchtop test rig, PCS model MPR, was configured to investigate the effect of electrical currents on the formation of white etching crack (WEC) failures in bearing steels. Ring/roller current was imposed using slip-rings. The type 52100 steel ring and roller counterfaces, with 1-mm-wide contact area, were slid at 500 N, variable slide-to-roll ratio, at 100 °C, in commercial wind turbine lubricants. Failure was defined when machine vibration reached a predetermined limit or ran out at 300 million contact cycles. At high currents, the roller failed suddenly due to gross macropitting after typically tens of millions of contact cycles. No failure occurred at 300 million cycles with no current. At intermediate currents, longer durations elapsed before test failure, and at low current, the failure mechanism was found to be either surface damage or micropitting, Optical post-test examination showed that tribochemical film density was enhanced by current density.

2:30 - 3 pm
3285517: Voltage Induced Roller Bearing Fatigue
André Harder, Tobias Schirra, Eckhard Kirchner, Technical University of Darmstadt, Darmstadt, Hessen, Germany

The emergence of electric mobility increases the number of electric actuators in vehicles, particularly traction drives. A common failure mechanism for electric actuators is the damage of the roller tracks in roller bearings due to an electrical current between the inner ring, the rolling elements and the outer ring, e.g. EDM-current. Literature shows that an increased electrical current reduces the remaining

lifetime of roller bearings. So far, research focused on the fatigue of the roller bearing as part of an electric actuator on a systemic level. This paper intends to investigate the influence of an electric load on the mechanical load capacity of a roller bearing directly on a machine element level. A novel test rig is presented to apply combined mechanical and electrical loads on the machine element in order to determine the impact of varying parameters like voltage amplitude and frequency on the remaining lifetime and first experimental results are shown.

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

4 - 4:30 pm
3279905: Load Sensing Bearing – Influence of Damage Progression on the Electric Bearing Impedance
Tobias Schirra, Georg Martin, Eckhard Kirchner, Technical University of Darmstadt, Darmstadt, Hessen, Germany

Bearing loads are interesting data regarding predictive maintenance especially in terms of the progressing Industry 4.0. The use of load data leads to lifetime estimations based on real operating loads, another application is process monitoring like continuously measuring the preload of a belt drive. To address these tasks a load sensing bearing concept is being developed and presented by the authors. For this purpose, the connection between operating condition and electric impedance is investigated to continuously assess load data by measuring electric properties. This presentation deals with the influence of progressing damage and different types of contact geometry of roller bearing. The measurement impedance data prevail a running-in behavior, which leads to a drop in impedance. Further insights are an almost constant impedance behavior during most of the run-time and a changing behaviour with upcoming failures to be used to better predict the need for roller bearing replacement.

4:30 - 5 pm
3324286: Novel and Traditional Techniques for Detection of Subsurface Damage in Bearing Steel
Monica Ratoi, Brian Mellor, University of Southampton, Southampton, United Kingdom, Hiroyoshi Tanaka, Joichi Sugimura, Kyushu University, Fukuoka, Japan

Bearing steels suffer from a degradation in mechanical properties and shortening of fatigue lives when atomic hydrogen originating from fuel cells or lubricant diffuses into the steel and generates subsurface cracks. While the measurement of various hydrogen species absorbed in steel after the RCF tests is easily achievable with Thermal Desorption Spectroscopy, the detection and measurement of the subsurface damage is a challenge which has still to be overcome. This is because the diameter of the cracks can be below the resolution threshold of commercially available micro CT equipment for high density materials like steels. On the other hand, the traditional serial sectioning technique is destructive and tedious to use. This study investigates the ability of various novel techniques to detect, visualize and quantify wear track subsurface cracks in ball and race specimens, compares the results which those produced by the traditional techniques and discusses the advantages and drawbacks.

5 - 5:30 pm
3318097: Progress of Rolling Machine Elements
Hirotoshi Aramaki, NSK Ltd., Fujisawa, Japan

As rolling machine elements, rolling bearings have a history of evolving to meet the needs of the times. There are new needs for rolling bearings to respond to the electrification of machines and IoT. Similarly, the range of applications for ball screws has also expanded to include steering mechanisms and brake

mechanisms for automobiles, as well as vibration prevention mechanisms that greatly improve riding comfort in railway vehicles. We will introduce these and reliability improvement technologies that support expanded applications for rolling machine elements, with a particular focus on the key IoT era technologies of condition monitoring and damage prediction.

2D **Columbus G**

Biotribology II

Session Chair: Dipankar Choudhury, University of Arkansas, Fayetteville, AR
Session Vice Chair: Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

1:30 - 2 pm - **Invited Talk**

2 - 2:30 pm
3322474: Cartilage and Joint Mechanics: New Insights into the Conditions of the Buried Interface
David Burris, University of Delaware, Newark, DE

After nearly a century of research, we have yet to answer the most basic questions about cartilage and joint function. For example, it is unclear if friction forces are attributable to classical adhesive interactions or fluid shear stresses, if rough interfaces are permeable or impermeable, or if its extreme roughness has a function. In this talk, I will review our most interesting findings about the tribology of cartilage and what they suggest about the conditions of the interface. For example, we have shown that sliding in a hydrodynamic environment induces fluid recovery by the cartilage within the loaded contact area at a rate matching that of unloaded cartilage exposed directly to a bath. Additionally, we have shown that cartilage adheres to other surfaces with the tenacity of the best adhesives in nature. I will conclude by presenting a hypothetical tribological rehydration framework to explain these observations, the conditions of the interface, and the function of cartilage.

2:30 - 3 pm
3340959: The (Cartilage/Cartilage) Friction: A Model Explaining The Relation Between Charged (+/+), (-/-) and Neutral (±/±) Surfaces
Zenon Pawlak, Tribochemistry Consulting, Salt Lake City, UT, Tomasz Kaldonski, Krzysztof Gocman, Tadeusz Kaldonski, Military University of Technology, Warsaw, Poland, Marek Macko, Kazimierz Wielki University, Bydgoszcz, Poland

The amphoteric character of the bovine articular cartilage surface is used to explain friction relation between charged (positively or negatively) and neutral biological surfaces. By measuring the friction coefficient (f) of (cartilage/cartilage) pair vs. pH, shown influence of charge (+/+) and (-/-) pair on friction. Study of interfacial energy of spherical lipid bilayer vs. pH amphoteric character of cartilage surface was verified. The isoelectric point, IEP was obtained by studying friction of (cartilage/cartilage) pair and interfacial energy of a model membrane of spherical lipid bilayers which is expressed by “bell-shaped curve”. Interfacial energy serves as a membrane model displaying electrostatic repulsion of the cartilage surfaces enabling friction curve interpretation. This experimental fact has not been highlighted in the literature of natural lubrication.

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

4 - 4:30 pm
3279450: Investigation on the Superlubricity and Nanomechanics of Liposome Adsorption on Titanium Alloys
Yuhong Liu, Tsinghua University, Beijing, China

Liposomes have been considered as the boundary lubricant in natural joints. They are also the main component of bionic lubricant. In this study, the tribological properties and mechanical properties of liposomes on Ti6Al4V/polymer surface were studied by atomic force microscope (AFM) at the nanoscale. The superlubricity with a friction coefficient of 0.007 was achieved under the maximal pressure of 15 MPa, consisting with the lubrication condition of natural joints. Especially, when the AFM probe was hydrophilically modified and preadsorbed, the friction coefficient and load bearing capacity could be further improved. The optimal lubrication model of liposomes was established and the critical force for superlubricity was also proposed. It was the boundary between elastic deformation and plastic deformation for vesicles. Besides, the mechanical properties were evaluated under repeated loading and unloading, suggesting a better reversibility and resistance of gel phase liposomes.

4:30 - 5 pm
3281562: Insight into the Lubrication Behavior of Phospholipids Pre-Adsorbed on Silica Surfaces at Different Adsorption Temperatures
Shaofei Feng, Yuhong Liu, Tsinghua University, Beijing, China

Phospholipids are one of the main components existing in joint synovial fluid and play a dominate role in joint lubrication. Using an AFM, we examined the normal and shear forces between two opposing silica surfaces bearing three different phospholipids in pure water at ambient temperatures. The results showed that vesicles were absorbed on silica surfaces when the pre-adsorption temperature was below phospholipid phase transition temperature (T_m) and the super-lubricity was achieved when the load was less than the critical load. In contrast, when the pre-adsorption temperature was above T_m, it became bilayer structure with many defects that covered the silica surfaces. The lubrication performance became much worse than that of vesicles with higher friction coefficient. This work gains insight into the influence of structure and temperature on the lubrication mechanism of phospholipids as bio-lubricants, which may help us design artificial joint synovial fluid.

5 - 5:30 pm
3278081: Increased Utilized Friction during Walking Predicts Shoe Wear Rates: Insights into the Wear Mechanism
Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Shoe wear leads to an increased risk of slipping [1]. This study assessed the relationship between gait kinetics on shoe wear rate to achieve insights into the wear mechanism. Fourteen participants wore two shoe brands (of three included in the study). A gait assessment was performed to measure ground reaction forces. Peak normal force and required coefficient of friction (RCOF) were measured. Participants then wore the shoes in the workplace and then returned to the research team. Wear rate (shoe tread wear/distance walked) was correlated with the RCOF ($p=.022$), but not the normal force or shoe type. This finding suggests that wear is caused by fatigue failure instead of Archard's wear relationship. The principal tensile stress is associated with shear forces, which may be causing failure in elastomers under cyclic loading [2].

[1] Beschorner, et al. (2014). J Biomech 47(2): 458-463.
[2] Mars, et al. (2004). Rubber Chem & Tech 77(3): 391-412.

5:30 - 6 pm
3309331: Shoe Tread Wear Rate May Not Necessarily Be Associated with Material Hardness
Sarah Hemler, Claire Tushak, Paul Walter, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Shoe tread wear impacts shoe traction and performance [1]. Material hardness is believed to contribute to its wear resistance [2]. In this post-hoc analysis, data from three shoe wear studies were used to assess the impact of shoe hardness on wear rate. Analysis included a total of six shoe brands and 40 shoes using two accelerated wear (AW) protocols and one natural wear (NW) protocol. Wear rate was defined as the volumetric heel tread loss divided by the 1) distance the shoes were slid on abrasive paper after 2 wear cycles, 1120 m (AW) or 2) distance walked in the shoes using step trackers (NW). For the NW data, tread loss was collected for the first month after the participants walked at least 100 km. For all data, there was no trend between the wear rate and hardness. This finding suggests that other material parameters besides hardness might contribute more significantly to shoe wear. 1. Hemler, et al (2019). App Ergo, (80) 35-42. 2. Archard, J (1953). J. Appl Phys, 24 (8), 981-8.

2E — Columbus H

Seals II

Session Chair: Bo Tan, University of Kentucky, Lexington, KY
Session Vice Chair: Jorge Pacheco, John Crane Inc., Morton Grove, IL

1:30 pm - 2:00 pm
3302009: Gas Seal Face Optimization Using a Scalable Parallel Simulation Environment
Michael LaPresti, FPoliSolutions, Pittsburgh, PA

Seal face design is a computationally-intensive process involving simultaneous simulation of various physical processes including fluid dynamics, contact mechanics, heat transfer, and structural mechanics. A scalable multiphysics simulation technique for parallel simulation of numerous design options across many CPUs is presented. A TEHL approach employing a finite element model coupled with a hydrodynamic solver based on Reynolds Equation is employed. A demonstration analysis consisting of parallel simulation of several thousand design variations of a spiral groove gas seal face is included. Performance characteristics such as leak rate, heat generation, film stiffness, and face temperature are characterized as a function of design inputs such as spiral angle, groove depth, number of grooves, seal dam radius, and surface roughness. The resulting dataset is then used to select an optimal configuration that maximizes film stiffness while minimizing leak rate and face temperature.

2 - 2:30 pm
3323410: New Dry Gas Seal Material for Enhanced Wear Resistance during Contact
Christina Twist, Jiao Yang, Marwan Jahchan, Kanza Amanullah, Ian Goldswain, John Crane, Chicago, IL

Dry gas seals are an advanced solution designed to maintain pressure while minimizing emissions of turbomachinery such as compressors. They must reliably perform under all operating conditions encountered by the compressor, including slow roll, in which both speeds and pressures are low, inducing contact between the rotating and stationary components of the seal. The materials chosen for this interface are therefore of particular importance to the reliability of the seal. John Crane tested a new material combination comprised of a solid lubricant additive dispersed within a carbon graphite stationary ring against a silicon carbide rotating ring. Pin-on-disc, disc-on-disc and full-scale seal tests were utilized to assess the tribological performance of the new material combination. Correlations between the various test results are discussed. This material pair is observed to provide lower wear rates in full-scale testing compared to other materials commonly used in the sealing industry.

2:30 - 3 pm
3285338: A Method of Direct Measurement of Mechanical Seal Wear in Pumps and Compressors
Mark Slivinski, Carbide Derivative Technologies, Tucson, AZ

The ability to measure mechanical seal wear or predict end of life or failure in-situ has confounded the Industry since the invention of the mechanical seal in the 1940's. Recent advances in computing power and signal processing have spurred the search to do this, using networks of sensors for the monitoring of temperature, pressure, motor current, acoustics/ultrasonics and vibration. While this may ultimately lead to a solution, the R&D investment required to arrive at a producible solution is prohibitive for most companies and the resulting solution will be complex and expensive to the point of it being limited to niche applications. This paper will present a method to directly measure seal wear by electrical means in a system that is inexpensive and simple enough to be considered for the entire range of seal applications.

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

4 - 4:30 pm
3304823: Effects of Radial Force on the Sealing Performance and Tribology Behavior of Rotary Lip Seals
Bingqi Jiang, Fei Guo, Tsinghua University, Beijing, China

In this work, an experimental study on the effects of radial force on the sealing performance and friction torque of rotary lip seals was carried out. Varies of radial forces will change the contact state of the sealing lip, and will also change the thickness and distribution of the oil film, which can affect the reverse pumping of rotary lip seals. In this work, the radial force was changed by adjusting the length of metal strings on the lip seals. The leakage rate and friction torque were measured using a bench test machine. The aim of this work was to study the application scope of the reverse pumping mechanism in the rotary lip seals.

4:30 - 5 pm - **Seals Business Meeting**

Lubrication Fundamentals II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3309106: Tribological and Tribochemical Evaluation of Various Lubricants on Steel as well as WC–DLC Coating under Extreme-Pressure Boundary Lubrication Conditions: Bench Test: Part 1
Kuldeep Mistry, Carl Hager, Thierry Ruzicka, Praveen Pauskar, The Timken Company, North Canton, OH

Diamond-like carbon (DLC) coating has demonstrated excellent results for sliding–rolling contact parts, especially for the components subjected to extreme pressure conditions and severe boundary lubrication. The coating help to increase scuffing load capacity and prolong component durability. The commercially available lubricants (oils and greases) are compatible with ferrous surfaces, but normally have not been optimized for coatings. In the present work, the tribological properties of tungsten carbide doped DLC (WC-DLC) against steel ball with various lubricants in boundary lubrication conditions have been evaluated on bench test. The effect of lubricant was correlated with the wear performance. The wear measurements were conducted at small time-intervals along with the examination of the chemistry of the tribofilm using surface sensitive techniques: XPS and SEM/EDS. The surface reactions between the additive-coating surface significantly influence its tribological performance.

2 - 2:30 pm
3309230: Tribological and Tribochemical Evaluation of Various Lubricants on Steel as well as WC–DLC Coating under Extreme-Pressure Boundary Lubrication Conditions: Rig Test: Part 2
Kuldeep Mistry, Carl Hager, Doug Lucas, Praveen Pauskar, The Timken Company, North Canton, OH

Diamond-like carbon (DLC) coating has demonstrated excellent results for sliding–rolling contact parts, especially for the components subjected to extreme pressure conditions and severe boundary lubrication. The coating help to increase scuffing load capacity and prolong component durability. The commercially available lubricants (oils and greases) are compatible with ferrous surfaces, but normally have not been optimized for coatings. In the present work, the tribological properties of tungsten carbide doped DLC (WC-DLC) against steel ball with various lubricants in boundary lubrication conditions have been evaluated on bench & rig test. The effect of lubricant was correlated with the wear performance. The wear measurements were conducted at small time-intervals along with the examination of the chemistry of the tribofilm using surface sensitive techniques: XPS and SEM/EDS. The surface reactions between the additive-coating surface significantly influence its tribological performance.

2:30 -3 pm
3285602: Designing a Simple Test to Measure Lubricant Efficiency
Marc Ingram, Ingram Tribology Ltd, Carmarthen, United Kingdom, Izzy Roots, Clive Hamer, PCS Instruments, London, United Kingdom

The ability of a lubricant to reduce friction and increase efficiency is one of its key functions. However, a standardized lab scale efficiency test for lubricants does not exist. In this work we take a common tribometer and design a test sequence to allow the efficiency rating of any lubricant to be quickly and accurately measured. The user simply enters the KV40 and KV100 value for the lubricant being tested. The test software then calculates the entrainment speeds to maintain the same test severity for each lubricant, regardless of viscosity. Lubricants are then rated for efficiency in terms of their ability to maintain low friction in the boundary, mixed and EHD regimes, using data from the normalized Stribeck curves. The method is being designed with repeatability in mind, across the entire range of common lubricant grades. This new method simplifies efficiency measurement, helping the development and qualification of new lubricants.

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

4 - 4:30 pm
3287631: Running-In of Rough Surface EHL Contacts
Jonny Hansen, Marcus Björling, Roland Larsson, Luleå University of Technology, Luleå, Sweden

New machine elements such as e.g. gears are typically allowed to undergo an initial setting period before fully loaded. The process, which generally is termed running-in, may either enhance fatigue and scuffing resistance, but it may also be detrimental and cause premature loss of service life. In this study, a WAM ball-on-disc machine with rough surfaces was operated under heavily loaded rolling/sliding conditions to explore the mechanisms involved in running-in. Electrical contact resistance (ECR) and friction were simultaneously monitored to track the continuous relieve in contact intensity until surface lift off occurred. In particular, a 3D surface re-location procedure was developed to enable for asperity level details of changes at the same area before and after test. Results showed that surfaces were required to undergo complex transformations in order for the lubricating quality to shift from boundary or mixed lubrication, into full film EHL.

4:30 - 5 pm
3318394: Friction Increase in Starved EHL Contact
Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czechia

Nowadays, we are driven by demand to increase machine efficiency for sustainable society development. For optimized engineering design, it is necessary to predict friction in elastohydrodynamic contact (EHL). Despite large amount of research made on friction, our capabilities of EHL friction modelling are still limited. Common statement is that main part of sliding friction is produced in the central zone while inlet has no major effect on friction. Friction in starved contact increases significantly, where the size of inlet meniscus is limited which leads to thinner film and higher shear rate under a rolling-sliding conditions. Nevertheless, higher shear rate is not full explanation of the friction increase. This contribution includes in-situ film thickness and friction measurements on ball-on-disk device showing abnormalities of friction in starved contact. It demonstrates the role on contact inlet on EHL friction.

5 – 5:30 pm
3309028: A Novel Iteration Method for Mixed Lubrication
Chen Shi, Zhinan Zhang, Shanghai Jiaotong University, Shanghai, China, Xiaojiang Cai, Shanghai Key Laboratory of Aerospace Intelligent Control Technology, Shanghai, China

The mixed lubrication exists widely in both rolling and thrust bearings at low speed, which has significant impact on the momentum wheel performance. In this work a novel iteration method for investigating the characteristics of mixed lubrication is established. It reconsiders the hydrodynamic effect according to time order. Because the hydrodynamic term of last moment acts on the present flow rate in the Reynolds equation actually, instead of the current derivative of film thickness. As a validation, a point-contact model with an asperity was simulated within the respective iterative process. The relative error was calculated after the end of each iteration step, divided by the maximum absolute value of the four terms of the equation. Results showed that low calculation error was obtained in the contact area, suggested that the proposed method is efficient in the mixed lubrication problem.

5:30 - 6 pm
3282852: Correlation of EHD Friction With Molecular Structure of Highly Refined Hydrocarbon Base Oils
Hak Mook Kim, SK innovation, Daejeon, Republic of Korea, Hugh Spikes, Imperial College, London, United Kingdom

The molecular compositions of a range of low viscosity hydrocarbon base oils spanning API Groups II to IV have been quantified using 13C NMR and correlated with base oil elastohydrodynamic (EHD) friction. A strong correlation has been found between the proportions of paraffin, linear and branched carbons and EHD friction, with a high proportion of linear and paraffinic carbon atoms contributing to low EHD friction but branched carbons contributing to high EHD friction. Correlation equations have been developed to predict EHD friction based on base oil composition. For Group IV polyalphaolefin, the correlation must be extended to account for the very high proportion of linear carbons originating from linear alkene oligomerization. The correlations developed in this study can be used to guide the design of low EHD friction base oils.

2H — Randolph 1

Grease II

Session Chair: Wenyang Zhang, Tesla, Palo Alto, CA
Session Vice Chair: TBD

1:30 - 2 pm
3285676: Do Polymers Affect the Mechanical Stability of Grease?
Erik Willett, Functional Products Inc, Macedonia, OH

Polymer additives are routinely called on to improve the performance of grease in areas such as resistance to water spray-off and wash-out, static oil bleed, adhesion, and tackiness. The role of grease polymers in the ‘mechanical stability’ of grease is less known. Mechanical stability refers to low changes in consistency after mechanical shearing by methods like worked cone (ASTM D217) and roll stability (ASTM D1831). Data collected over the years indicates that certain polymers reduce consistency loss with higher molecular weight polymers providing higher improvement. Surprisingly, that trend in grease performance opposes the well-known convention in lube oil that lower molecular weight polymers are required for high mechanical stability in gear oil and hydraulic fluid. This study seeks to 1) investigate

how polymer structure influences the mechanical stability of grease, and 2) explain why high MW polymers contribute shear stability in grease but instability in lube oil.

2 - 2:30 pm
3284674: Back to the Basics, Part II: Fundamental Building Blocks of Grease Formulation – The Next Story
Joseph Kaperick, Afton Chemical Corporation, Richmond, VA

Previous work focused on evaluation of common additives and additive systems in a simple lithium base grease. Some routine and less common performance tests were used to evaluate differences between different types of additives and packages as well as looking at the impact of additive combinations. The focus was on antiwear (AW), extreme pressure (EP), antioxidant (AO) and borate components along with performance packages containing different component combinations. This current work explores the differences observed with these same components and tests when the base grease used is a lithium complex thickener.

2:30 - 3 pm
3284232: Effect of Tribofilm Component on Preventing White Etching Crack in Grease Lubricated Ball Bearings
Takeshi Tsuda, Yurie Yamashita, Kouji Yoshizaki, Takanori Kurokawa, Hirokazu Arai, JTEKT Corporation, Kashiwara, Osaka, Japan

White etching crack (WEC) has been observed in rolling bearings for electrical system of automobiles for over 30 years. Although several studies have been discussed in WEC formation, preventing method of the WEC formation has not been established. As hydrogen is suspected one of the factors for the WEC formation, we focused on hydrogen generated by decomposition reaction of grease or water on nascent metal surface, and its permeation into bearing rings or rolling elements via nascent metal surface. In this study, tribofilm containing crystalline zinc particles was formed as a synergy effect of zinc-based additives, calcium-based additives and sulfur-based additives. It is suggested that the crystalline zinc particles in the tribofilm have a positive effect to prevent the WEC formation.

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

4 - 4:30 pm
3278125: Enhanced Performance Characteristics in Greases with Alkylated Naphthalenes
Ross Dworet, Amanda Harris, Maureen Hunter, King Industries, Norwalk, CT

Global grease markets continue to shift towards higher performance and extended life greases intended to improve equipment life, production uptime, and respond to a variety of operational and environmental/temperature extremes. Developments in refined base stocks and synthetics continually contribute to satisfying such demands, but there are still limitations to meeting performance targets. Alkylated napthalenes (AN) inherently have desirable characteristics, including intermediate aniline point, hydrolytic stability, and high performance thermo-oxidative stability. In grease systems, ANs can be used as base stock modifiers with avariety of thickener systems to impart necessary high-performance properties, such as extended composition life, high temperature, and thermo-oxidative stability without negatively impacting other grease characteristics. Through data generated by industry standard testing, AN base stock modification provides an advantage to meet formulation targets.

4:30 - 5 pm
3308601: Polymer Grease Flow Behavior under Low- and High-Pressure
Josep Farré, UPC - Technical University of Catalonia, Terrassa, Spain, Lars Westerberg, Luleå University of Technology, Luleå, Sweden, Gemma Camp, UPC , Riells del Fai, Spain, Jasmina Casals-Terré, Universitat Politècnica de Catalunya, Terrassa, Spain

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

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

2I Randolph 2

Tribochemistry II - Tribocatalysis of Additives

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3316033: Nature of ZDDP Tribofilm, Part A: Effect of Relative Humidity
Pourya Parsaeian, Abdel Dorgham, Ardian Morina, Anne Neville, University of Leeds, Leeds, United Kingdom

Wear/friction performance of any tribological system can be influenced in a complex way by water contamination. Water can be the cause of steel corrosion which, in turn, can accelerate wear. A key novelty of this study is to investigate the effect of relative humidity and the tribochemical changes on the tribological performance (wear/friction) and tribofilm characteristics of boundary lubricated systems by means of designing a humidity control system integrated to the Mini Traction Machine (MTM) and Spacer Layer Interferometry Method (SLIM) for the first time. The experimental results suggest that Firstly, humidity appears to be able to deteriorate the long chains polyphosphates (weaker phosphate chains formed), which can be easily depolymerised into shorter ones. Secondly, humidity hinders the polymerisation of shorter chain polyphosphates and therefore the longer chain polyphosphates cannot be generated from the beginning of the test.

2 - 2:30 pm

3329999: Friction and Wear Performance of Novel Hybrid Base Fluids with Phosphorous Containing Additives

Sergei Glavatskih, Yiyuan Tian, KTH Royal Institute of Technology, Stockholm, Sweden, Thomas Norrby, Nynas AB, Nynashamn, Sweden

As a part of a visionary project aiming at increasingly sustainable base oil and lubricant product, four novel hybrid base fluids, composed of Naphthenic base oils and bio-based fluids, were created. By adding anti-wear additives to hybrid fluids, model lubricants based were formulated. Their friction and wear performance in steel-steel sliding contacts was investigated utilizing a pin-on-disc tribometer. The worn surfaces were examined by SEM and EDX, to elucidate the extent and nature of the tribofilm formation. In this study, we compare a traditional anti-wear additive (ZDDP) as a reference with two different oil-soluble phosphonium ionic liquid additives. We can observe different tribofilm forming kinetics and composition, wear scar development and friction behavior. The results indicate that the structure of the phosphorous containing anion imparts a large impact on the tribofilm formation, and the development of the wear scar.

2:30 - 3 pm

3282109: Anti-Wear Performance and Lubrication Mechanism of New TiO_2 Particle Based Lubricant Additives

Fabrice Dassenoy, Sophie Pavan, Jules Galipaud, LTDS - Ecole Centrale of Lyon, Ecully, France, Istvan Jenei, Stockholm University, Stockholm, Sweden, Stephan Wieber, Michael Hagemann, EVONIK, Darmstadt, Germany

There has been growing interest in nanoparticles for tribological applications over the past 20 years. Studies have shown their remarkable lubricating properties, namely friction-reduction and anti-wear, especially when used as lubricant additives. TiO_2 nanoparticles present several advantages. In addition to be easy to produce and to have low preparation cost, they provide good anti-wear properties to the lubricant in some conditions where the performance of other additives are sometimes limited. In this work, the tribological performance of new TiO_2 particle based lubricant additives are presented. The tribofilms generated during the friction tests were mainly characterized using X-Ray Photoelectron Spectroscopy (XPS) and Transmission Electron Microscopy (TEM) combined with analytical methods. The way the TiO_2 nanoparticles additives behave and offer surface protection against boundary contact will thus be discussed.

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

4 - 5 pm

3339340: Invited Talk: Tribocatalytic Formation of Carbon Films & Tribochemistry of Graphene/Graphite and MoDTC

M. Clelia Righi, University of Modena and Reggio Emilia, Modena, Italy

Graphene and other carbon nanostructures provide remarkable friction and wear performances, but need a continuous replenishment. By ab initio MD simulations we demonstrate that the dissociative extraction of graphene is possible from tribocatalysof methane molecules confined at sliding Ni interfaces.[1] We apply Quantum Mechanics/Molecular Mechanics (QM/MM) simulations to describe the tribochemistry of graphene interacting with water [2] and to describe the dissociation of MoDTC on clean and S and O passivated iron surfaces. [3]

[1] Giovanni Ramirez, et al In-Operando Conversion of Methane into Graphene and Other Carbon

Nanostructures on Catalytically Active Sliding Surfaces, submitted (2019). [2] P. Restucci et al, Real-time monitoring of graphene edges passivation by water: Insights into the lubricity of graphitic materials, Carbon 156, 93 (2020). [3] S. Peters et al Characterization of Molybdenum Dithiocarbamates by First-Principles Calculations, Phys. Chem. A 123, 7007 (2019).

5 - 5:30 pm
3283545: MoDTC Tribofilm Growth from Low Viscosity Fully Formulated Engine Oils
Gerda Vaitkunaite, Cayetano Espejo, Chun Wang, Anne Neville, Ardian Morina, University of Leeds, Leeds, Yorkshire, United Kingdom, Benoit Thiebaut, Catherine Charrin, TOTAL, Solaize, France

The future of engine oils is moving towards lower viscosity oils, enabling a reduction of energy losses in engine components but also increasing the boundary lubrication occurrence. This study focuses on the friction performance of low viscosity fully formulated oils containing MoDTC friction modifier at different concentrations. There is a knowledge gap considering oil friction behavior and formed tribofilm quality [1,2]. Tribological tests are run in a boundary lubrication regime using a ball-on-disk tribometer and rheological properties of the oils are modified by changing the base oil and the polymeric viscosity modifier. Raman Spectroscopy is used to analyze tribofilm spatial distribution on the contact surface. A correlation between MoDTC concentration in the oil and the duration of the stabilization time before the friction reduction has been observed. This performance is linked to the physical and chemical properties of MoS_2 tribofilm formed on the contact surface.

2K Michigan 1

Engine and Drive Train Special Session on Electric Vehicles II

Session Chair: Hamed Ghaednia, Gehring Group, Farmington Hills, MI
Session Vice Chair: Babak Lotfi, ExxonMobil, Baytown, TX

1:30 - 2 pm
3343494: Hybrid/Electric Powertrain Components & Tribology
Raj Chandramohanan, Tyler Garrard, BorgWarner Inc., Arden, NC

It is clear that the future of transportation will include more electric content. There are multiple factors leading to this conclusion including, lowering or eliminating direct GHG emissions, better transient response and future emissions regulations. BorgWarner Turbo, Emissions & Thermal Systems has electrified and hybrid products which include a motor and/or a generator including the Organic Rankine Cycle expander/generator/pump for passenger car and commercial vehicle markets. Each technology is unique in how it interfaces with the combustion engine in saving/recuperating energy. This paper will cover the fundamentals of how these products function and the distinct challenges they pose for lubrication and tribology.

2 - 2:30 pm
3322965: Dielectric Fluids for Use in Hybrid and Electric Vehicles
Gareth Moody, Croda, New Castle, DE

With new driveline configurations comes new challenges for lubrication. Many different configurations have been conceived which use different methods of cooling and lubrication. Gear lubrication needs to ensure high efficiency and low wear. Clutch lubrication requires smooth transitions with high durability of the fluid. These conditions could be controlled by base fluid or additive technology. This talk will discuss the excellent thermal properties of esters and how they could be used to both cool and lubricate. It is also possible that they could be used to cool sensitive components such as battery packs, regulating temperature and allowing better efficiency.

2:30 - 3 pm
3328322: Ultra-Low Viscosity Synthetic Fluids for Electric Vehicles (EVs)
Babak Lotfi, ExxonMobil Chemical Company, Houston, TX

Government regulations have been pushing automotive industries to lower CO_2 emission, which shifted many original equipment manufacturers (OEMs) toward electric vehicles (EV) design. New hardware design along with interest for using lower viscosity fluid for improving energy efficiency demands for EV/driveline fluid development with superior properties for electric vehicles (EV). Base oil plays a critical role in lubricant properties. In this work synthetic base oils have been studied and compared with mineral base oils. Tribological properties, energy efficiency, thermal management, etc. have been presented in this work. Results demonstrate an excellent performance and durability of synthetic molecules comparing to mineral base oils for developing EV fluids.

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

4 - 4:30 pm
3297982: Lubricant & Greases Solutions for the Whole Electrical Vehicle Drivetrain Including the Thermal Management of Batteries
Torsten Murr, Shell Global Solutions Germany, Hamburg, Germany

In 2019 more than 1.0 mio pure electrical vehicles has been produced, including hybrid vehicles the total production of electrical units is above 5 mio. In addition to the typical PasCar appl, electrical systems are being designed for LD-, HD Truck and Off Hway equipment. Even the highest electrical grade of PTs demands lubes solutions; for red.gears and e-axle systems dedicated trans fluids, for bearings dedicated greases and for battery cooling dedicated liquids with fluid volume from 0.5 to 4.0 l.In red. gear appl. the fluid does not get in contact with the electr propolsion system & only need to fulfill traditional hardware requirements. The wet E-Motor design, needs to consider chem & electromagnetic interactions of the fluid and the hardware components. For the new fluids new test method and screening tests need standardized, i.e Dielectric Breakdown, resitivity. In the area of Thermal management alternative fluids need to be qualified for immersed cooling with test methods describing power density & heat conductivity.

4:30 - 5 pm
3284626: Effects of Lubricant Additives on Copper in Soaking Test
Xinggao Fang, Don Pheneger, Afton Chemical Company, Richmond, VA

Copper materials are widely used in automotive transmissions. Transmission fluids are required to protect these materials for extended time. This study will focus on the effects of common additives on copper in an extended soaking test. End of test (EOT) fluids are analyzed for leached copper and changes

in chemistry. EOT coupons are analyzed with energy-dispersive X-ray spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS) to uncover underlying mechanisms. The learnings are then applied to formulate additive packages that provide superior copper protection.

2L Michigan 2

Contact Mechanics II

Session Chair: Alexander McGhee, University of Florida, Gainesville, FL
Session Vice Chair: Noel Brunetiere, Institut Pprime, Futuroscope Chasseneuil Cedex, France

1:30 - 2 pm
3325660: Effects of Surface Roughness and Viscoelastic Properties on the Friction from the Sliding Contact between Elastomer and a Dissimilar Hard Surface: A Numerical Investigation
Huan Zhang, Daniel Mosher, United Technologies Research Center, East Hartford, CT

For many engineering applications, it is critical to quantify the effects of viscoelastic properties and surface roughness on the friction resulting from the sliding contact between an elastomer block and a dissimilar hard surface. In this paper, a finite element (FE) model is developed to simulate such a contact by eliminating corner effects often encountered in previous numerical analysis and adopting proper contact formulation. A parametric study is conducted with the model to predict the steady-state sliding friction for a range of roughness wavelength and amplitude of the hard surface and varying viscoelastic property parameters of the elastomer. The dependence of friction on the sliding velocity is also quantified for various combinations of surface roughness and material viscoelasticity. In addition, a comparison is made between the model prediction and ring-on-disc test results for the model validation.

2 - 2:30 pm
3325986: Elastic Rough Surface Contact and Root Mean Square Slope
Robert Jackson, Yang Xu, Swarna Saha, Kyle Schulze, Auburn University, Auburn, AL

This study investigates the predictions of the real contact area for perfectly elastic rough surfaces using a boundary element method (BEM). Sample surface measurements are used in the BEM to predict the real contact area as a function of load. The surfaces are normalized by the root mean square slope to test if this normalization will collapse the predictions onto one curve. If so, this would confirm that the real contact area is directly proportional to the root mean square slope and the applied load. However, the predictions of the BEM do not follow this trend and deviate from each other significantly. The structure of the surfaces are further evaluated to illuminate why this property is seen in some types of surfaces and not others.

2:30 - 3 pm
3325269: The Contact Mechanics Challenge for Predicting Indentation Hardness
Matthew Brake, Rice University, Houston, TX, George Pharr IV, Texas A&M University, College Station, TX, Rosa Maria Espinosa Marzal, University of Illinois Urbana-Champaign, Urbana, IL, Philip Egberts, University of Calgary, Alberta, Canada

Following the success of the contact mechanics challenge organized by Muser, a new challenge has been organized in honor of STLE's 75th anniversary. While Muser's challenge focused on the real contact area and forces between two rough surfaces, this new challenge focuses on the fundamental relation between measurements of hardness at different scales and geometries. The first part, which will be open for the next year, is to predict the properties measured by an indentation test at the meso-scale with experimental data from a test conducted at the nano-scale using a geometrically similar indenter. The second part, which will be opened after the conclusion of the first, focuses on predicting the properties measured by an indenter at the same scale but a different geometry than data is provided for. Lastly, a third part will combine both geometry and scale dependency. This presentation will kick-off the challenge, as well as to release the experimental data provided with the challenge.

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

4 - 4:30 pm
3325628: Effects of Lubrication on Normal Elastic-Plastic Contact
Senyo Ahadzie, Rice University, Houston, TX

Lubricants have been studied often in terms of their frictional properties, but significant effort should still be devoted to determining their behavior in normal impact. The present work investigates the effect of different types of lubrication and varied thicknesses on impact-characterizing quantities. Collisions of a rigid sphere on an elastic-plastic flat were recorded with a high-speed camera and analyzed with MATLAB® and digital image correlation to calculate a coefficient of restitution. Optical profilometry was used to measure the amount of resultant plastic deformation. Preliminary results indicate that for nominally flat geometries and low impact velocities (<5 m/s), the critical thickness after which lubricant behavior is significant is relatively thin; furthermore, lubricant viscosity becomes increasingly important with rising applied thickness due to dissipation from inertia and adhesion.

4:30 - 5 pm
3313360: Influences of Adsorbed Water on the Interfacial Adhesion in the Early Stage of Sliding
Zaid Subhi, Malaysia-Japan International Institute of Technology, Kuala Lumpur, Kuala Lumpur, Malaysia

Surfaces are covered by adsorbed water layer due to ambient humidity. In the tribology of micro contacts, frictional and adhesive properties are sensitive to the adsorbed water because surface phenomena become more dominant than volumetric phenomena and therefore the influences of adsorbed water on adhesion become dominant. This study aimed to explore the mechanism of humidity changes to influence the adhesion by the observation of the tribological behaviour during the very early stage of sliding. In this study, a unidirectional ball-on-ball configuration tribo-contact simulator (T-CS) along with atmospheric humidity controller, were used to simulate the micro-sliding between two asperities. Results have suggested that the medium rate of relative humidity can be a critical condition for the tribo-contact due to the effect of liquid assisted adhesion. This critical condition is perhaps caused by the negative Laplace pressure of the meniscus bridge formed between the adsorbed water layer

5 - 5:30 pm
3288287: An Investigation on Oblique Gravitational Wave Trapping Using Poroflexible Geometry in Stratified Sea with Varying Base Topography
Nagmani Prasad, Indian Institute of Technology, Dhanbad, Jharkhand, India

In two layer fluid, a trapping problem of oblique wave by poroflexible structure in the presence of varying bottom is considered. The topography of the bottom is a union of two constant water depths and a varying water depth, intending to take form as step-type geometry. The surface piercing poroelastic structure is situated at wind side of constant water depth with a rigid backwall. Method of matched eigenfunction and modified mild-slope equation (MSE) is applied to get the solution of the problem. The application of continuity condition and mass flux at the interface would convert the present BVP into a system of equations. Different physical characteristics such as the Deflection of poroflexible wall, wave load on rigid backwall and optimum distances for least force on backwall are plotted.

5:30 - 6 pm
3309555: Contact Deformation and Stress Field of Materials Containing Debonded Inhomogeneities Under Cyclic Loading
Donglong Li, Northwestern University, Evanston, IL

An inhomogeneity may partially debond from the matrix material, resulting in the formation of void tips, which are sites of stress and strains concentrations. The numerical equivalent inclusion method (EIM) is employed to analyze this type of problem, especially the stress and strain fields at the vicinities of the core-matrix interface and void tips. A group of simulation results are obtained to quantify the influences of inhomogeneities, their material properties, geometry, location, and orientation on deformation transmission across the core-matrix interface. A set of plots are developed to view stress and strain concentrations around void tips at different orientations, and to explore the fatigue life of materials influenced by void tips under cyclic loading.

6 - 6:30 pm - **Contact Mechanics Business Meeting**

2M Michigan 3

Nanotribology II

Session Chair: Filippo Mangolini, University of Texas at Austin, Austin, TX
Session Vice Chair: Prathima Nalam, University at Buffalo, Buffalo, NY

1:30 - 2:30 pm
3289517: Invited Talk: Functionalizing Hydrogels with Polymer Brushes to Produce Lubricious Surfaces
Nicholas Spencer, ETH Zurich, Zurich, Switzerland

Our everyday lives involve the articulation of many joints in our bodies, and for the most part, these vital components last for many decades without the need for repair. Great progress has been made in the

replacement of load-bearing joints by engineering materials, but ultimately better solutions would be the replacement of diseased and worn sliding components with artificial materials with very similar properties to the natural cartilage. We are working on the early stages of this approach, using what is known about the behavior and properties of living cartilage and attempting to imitate it by constructing systems consisting of hydrogels covered by polymer brushes. The knowledge gained from these efforts will hopefully lead eventually to novel implant materials, but in the meantime it will help us to test current theories of joint function, and to develop lubricious polymeric systems that could have applications in other biomedical systems.

2:30 - 3 pm
3333229: Mechanochemical Decomposition of Phosphate Esters Confined and Sheared Between Iron Oxide Surfaces
James Ewen, Carlos Ayestaran Latorre, Daniele Dini, Imperial College London, London, United Kingdom

Molecular simulations provide a valuable tool to investigate the nanoscale behavior of lubricant additives. Relatively minor changes to their molecular structure can have a considerable impact on their macroscopic tribological performance. In this study, we compare the reactivity of phosphate esters with different alkyl and aryl groups confined and sheared between iron oxide surfaces. We employ ReaxFF simulations and first principles molecular dynamics simulations to study the additive decomposition mechanisms which initiate tribofilm formation. We show substantial differences between the additive structures which could provide design rules for new, more effective formulations.

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

4 - 4:30 pm
3320006: Effect of Macromolecular Architecture on Dynamic Crosslinked Self-Healing Polymers
Zhijiang Ye, Qinghua Fang, Ballal Ahammed, Borui Zhang, Mehdi Zanjani, Dominik Konkolewicz, Miami University, Oxford, OH

Dynamically crosslinked polymers and their composites have tremendous potential in the development of the next round of advanced materials for aerospace, sensing and tribological applications. However, it is still lack of understanding how the configurational arrangement and the nano/microstructure of these systems affect the performance and the mechanical, tribological and thermal properties. Here, we report a combined computational and experimental study of the mechanical, tribological, and thermal properties of self-healing polymer composites with different macromolecular architecture: Interpenetrating Networks (IPNs) and Single Networks (SNs) and with/without carbon nanotube reinforcement. We perform Molecular Dynamics simulations to evaluate mechanical and thermal properties of various systems. In comparison with experimental measurements, we evaluate and discuss the configurational details and structural impact on the mechanical, tribological and thermal performance.

4:30 - 5 pm
3337880: Ab-Initio and Molecular Dynamics Simulations to Study Surfactants Interactions with Engineering Surfaces
Carlos Ayestaran Latorre, James Ewen, Daniele Dini, Imperial College London, London, United Kingdom, Chiara Gattinoni, ETH Zurich, Zurich, Switzerland

Understanding the behaviour of surfactant molecules on iron oxide and coated surfaces is important for many industrial applications. Molecular dynamics (MD) simulations of such systems have been limited by the absence of a force-field (FF) which accurately describes the molecule-surface interactions. In this study, interaction energies from density functional theory (DFT) calculations are used to study detailed interactions between surfactants and iron oxide and functionalised surfaces, also in the presence of water molecules. We start by showing how optimised FF obtained from the DFT data achieve excellent agreement with the interaction energies obtained from DFT calculations for a wide range of surface coverages and molecular conformations near to and adsorbed on e.g. α-Fe2O3(0001). We then look at how hydroxilated surfaces behave and look at the effect of functionalisation in terms of improved chemisorption of surfactant molecules on different surfaces.

5 - 5:30 pm
3318070: High Temperature Nanomechanical and Nanotribological Behavior of Nitrogen-Doped Carbon Overcoats Films
Ahmad Shakil, Andreas Polycarpou, Texas A&M University, College Station, TX

The high-temperature tribological properties of ultra-thin nitrogen-doped carbon overcoat (NCOC) as a protective film for the magnetic disks are investigated. The NCOC with three different thicknesses (2.5, 3.5 and 4.5 nm) are examined in terms of both chemical and mechanical properties at different temperatures. The chemical structure changes are traced by XPS, revealing that the configurations of both carbon and nitrogen elements change partially from sp^3- to sp^2-hybridizations with exposing N-COC samples to high temperature. The friction coefficient, wear rate and deformation of the NCOC films are measured by the nano-scratch/wear tests. The tests verify the operating temperature and thickness dependences of the tribological behavior of the NCOC films. Besides, the NCOC samples show the average wear depth significantly less than that of COC (or DLC) counterpart after heat treatment procedure, offering a more durable film for high temperature applications.

5:30 - 6 pm
3285152: Effect of Chain Weight on Transfer-Film Formation Due to Friction between PTFE and Si3N4
Huijie Tang, Le Gu, Harbin Institute of Technology, Harbin, Heilongjiang, China

Polytetrafluoroethylene (PTFE) is widely used as a great self-lubricating bearing retainer material. The ceramic roller strikes the PTFE retainer in the working process, which lead to forming a thin PTFE transfer film in the ceramic roller surface to protect the roller from wearing. Extensive experiments has been done to study the tribology properties of PTFE transfer film, however, the forming mechanisms of PTFE transfer film still need to be investigated . In this study, we established PTFE-Si3N4 frictional model to simulate the film formation using molecular dynamics (MD) to directly compare effects of different chain weights of PTFE and the coupling effects of the fragments and rough contact area on transfer film properties. It is found that the contribution of chain weights and rough contact area to transfer film forming cannot be neglected on the nanoscale.

Tuesday, May 5, 2020

3A — Columbus AB

Commercial Marketing Forum III

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8 - 8:30 am - Open Slot

8:30 - 9 am - **Biosynthetic Technologies**

9 - 9:30 am - **The Lubrizol Corporation**

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

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

10:30 - 11 am - **Croda, Inc**

11 - 11:30 am - **Evonik Oil Additives, USA**

11:30 am - 12 pm - **King Industries**

3B — Columbus CD

Metalworking Fluids III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3303669: Foam Control & Formulation Techniques to Minimize Foam in Water Dilutable MWFs
Michael Miller, Univar Solutions, Houston, TX

With the demand for higher productivity; speeds and feeds are increasing in MWF applications. This necessitates fluids with excellent foam control. This presentation will address various methods of foam testing and their applicability, how to test for defoamer stability, selection of defoamers, but more importantly, how to select raw materials when formulating water dilutable metalworking coolants to reduce foam (what to include and why and what to exclude/limit and why). The talk will also discuss the causes of foaming and how to address them. Anyone looking for tools to address foam issues and improve fluid performance will find this program helpful.

8:30 - 9 am
3286360: Non-Ionic Performance Surfactants on High Performance Metal Cleaners
Eduardo Lima, Dow Brazil, Jundiai, São Paulo, Brazil

Historically foam generation represents a common problem faced on all water-diluted metalworking fluids classes, as so on performance cleaners, during metal processing and pressured cleaning process, one which can restrict their use on case of non-totally balanced formulations. The use of appropriate and designed surfactant creates a rational solution to mitigate foam problems and bring the real possibility to develop enhanced formulations and reach demanded properties. This study presents results on low foam surfactant on typical cleaners formulation, exploring more from a property methodology that makes possible evaluate a several amount different formulations, especially in a comparative base to proposed a superior solution.

9 - 9:30 am
3313898: Metalworking Fluids and Chloride Corrosion on Aluminum Alloys
Alan Cross, John Burke, Quaker Houghton, 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 aluminum alloys. The corrosion is manifested in the form oxidation and pitting. This paper will demonstrate the effects of increasing corrosion effects on aluminum 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 am
3324594: Reserving Metalworking Formulation Space for the Impossibilities
Nicole Clarkson, Clayton Cooper, Soraya Kraszczyk, ANGUS Chemical Company, Buffalo Grove, IL

Through the years, society has come to develop certain understandings. Gravity is one example - what goes up, must come down. However, in 1903 the Wright Brothers developed a way to defy gravity and now modern transportation includes flight. Another example is that fire requires fuel, oxygen and heat. Unless, of course, we're referencing pyrophoric metals which react spontaneously in air. While flight doesn't make gravity less relevant and pyrophoricity certainly doesn't mean we've eliminated the risk of forest fires, these impossibilities do challenge our understandings. They create perspective and give reason to question the status quo. This presentation focuses on a similar goal. To create a different perspective. In this analysis, we focus on reserve alkalinity and its necessity, or potential replacement, by impossibilities. Impossibilities that allow your metalworking formulation to maintain performance criteria, such as pH stability and microbial control, without excess buffering.

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

10:30 - 11 am
3325105: Beating the Odds – How to Consistently Build Successful Products
Emil Schnellbacher, Chemico Systems, Chesterfield, MI

It is said certain composers and writers have a method to produce multiple successful products over a period of time. Do similar method exist which companies can use to produce winning new products? Over the past 25 years, the Product Development Management Association (PDMA) conducted a series of innovation surveys identifying over 50 new product development (NPD) best practices contributing to NPD success. With so many best practices, how do companies incorporate these best practices into practice? This paper discusses using best practices and levels of innovation for developing industrial metalworking fluids. Using various stakeholder's viewpoints, a unified strategy can be developed assisting adoption of ideas. From this research, a framework is introduced to measure and build upon the unique strengths of each company in improving NPD success.

11 - 11:30 am
3314190: Concentration and Stability Profiles of Copper-Infused Wire Drawing Fluids
Matt Vanden Eynden, Formulaction, Inc., Worthington, OH, Christelle Tisserand, Yoann lefeuvre, Pascal Bru, Gerard Meunier, Formulaction, Toulouse, France

Lubricants that are involved in various types of metalworking or manufacturing environments will eventually undergo particle concentration changes after time and use in machinery. The oil and lubricant components of such emulsions need to be replenished periodically throughout a process. Having quick and quantitative access to this concentration profile information would be critical for operators to adjust their formulations without losing valuable time and efficiency during this process. We will show how Multiple Light Scattering can be used to quantify physical destabilization phenomena such as particle size and concentration changes without the need for sample preparation or dilution. This technique allows for facile modification of the mixtures if concentrations change or if impurities incorporate themselves into the formulations. This gives operators essential information into the integrity of their dispersions without the need for excessive or objective testing procedures.

11:30 am - 12 pm
3283029: Surface Behavior and Lubricative Properties of Hydroxyproline Rich, Natural Proteins in Metal Working Fluids.
Eric Yezdimer, Gelita USA, Sergeant Bluff, IA, Matthias Reihmann, Gelita AG, Eberbach, Germany

This work investigates the surface behavior of proteins and their application as additives in water-based metal working fluids (MWF). Quartz crystal microbalance analysis and contact angle measurements have found that dilute solutions of hydroxyproline rich proteins form a net hydrophilic, dynamic equilibrium layer several nanometers thick on different surfaces. These layers expel oil from surfaces, producing cleaner workpieces and machines. Cross cylinder abrasion and tapping-torque experiments have found these layers are also capable of imparting both improved heat transfer and lubricative properties to the parent aqueous fluid. Improvements in lubrication are also seen when these proteins are added to semi-synthetic formulations. The collected data supports a complex interplay between hydrophobic and hydrophilic forces on both the short- and long-time scales. The results of CNC machine trials using MWFs containing hydroxyproline rich proteins will also be reviewed.

Rolling Element Bearings III

Session Chair: Daniel Merk, Schaeffler Technologies, Schweinfurt, Bavaria, Germany
Session Vice Chair: Bryan Allison, SKF Aeroengine, Clymer, NY

8 - 8:30 am
3282380: Numerical Modeling of Three-Dimensional Crack Propagation under Rolling Contact Fatigue
Florian Meray, Daniel Nelias, Anthony Gravouil, Thibaut Chaise, Univ Lyon, INSA-Lyon, Villeurbanne, France, Bruno Descharrieres, Airbus Helicopters, Marignane, France

In Rolling Contact Fatigue (RCF), the complex repeated passages of rolling elements on contact surface generally lead to surface or subsurface cracks initiation [1]. These cracks can propagate and cause the bearing or integrate race failure. To improve the safety of these components, understanding the RCF cracks growth behavior is a crucial issue, especially for aerospace industry. The present work is focused on the 3D modeling of surface/subsurface initiated crack propagation under RCF. Therefore, a local/glocal coupling procedure is proposed: a SAM (Semi-Analytical Method, [2]) global model is employed to resolve the contact problem and a X-FEM (eXtended-Finite Element Method, [3]) local model is used to simulate the crack propagation in the zone of interest. This coupling strategy provides the advantage to model in a fast, robust and precise way the behavior of crack under rolling and sliding contact. Several examples will be exposed and highlight the potential of this development.

8:30 - 9 am
3309993: Evolution of Short Surface Cracks under Rolling Contact: 3D Crack Morphology and Influence of Material Composition
Chiara Bertuccioli, Finn Giuliani, Amir Kadiric, Imperial College London, London, United Kingdom

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

9 - 9:30 am
3278313: Propagation of Rolling Contact Fatigue Cracks in Ball Bearing
Kenji Matsumoto, Honda R&D Co.,Ltd., Haga-gun, Japan, Naoaki Yoshida, Kyushu University, Kasuga, Fukuoka, Japan, Akira Sasaki, Maintek, Yokohama, Kanagawa, Japan

We believe that it is important to elucidate wear mechanisms of rolling contact surfaces in order to predict the life of a ball bearing. Therefore, we focus on the inner race wear of the bearing and conduct

a detailed investigation. Results of cross-sectional TEM observation revealed that there are three typical patterns beneath the rolling surface. Based on that fact, we hypothesized that wear debris formed in the following process. (1) The crystal grains underneath the rolling surface become smaller and a fine crystal layer is formed. Then, cracks occur in the layer and scaly wear debris is formed. (2) Precipitates just under the rolling surface prevent wear, but when the limit is reached, cracks occur along the precipitates and large wear debris is formed. (3) Precipitates and grains just below the rolling surface are crushed finely, causing plastic flow. Then cracks propagate along the interface between the precipitates and grains, and wear debris is formed.

9:30 - 10 am

3323724: Investigation into the Propagation of Surface Cracks under Rolling Contact Using Experimental and Numerical Methods

Bjoern Kunzelmann, Amir Kadiric, Imperial College London, London, United Kingdom, Guillermo Morales-Espejel, SKF Research and Technology Development, Houten, Netherlands

This study investigates the propagation of surface cracks in rolling-sliding contacts of hard steels. The work combines experimental measurements of crack propagation, performed previously on a triple-disc fatigue rig, with numerical simulations of stress fields experienced by such cracks under different contact conditions. A three-dimensional FE model with a specific mesh considers the actual cracks observed in the experiments to predict the associated stress intensity factors and thus explain observed crack growth rates. The model uses a specific mesh implementation which enables it to resolve displacements and stresses near the crack front during contact over-rolling. The model simulates a Hertzian pressure distribution passing over the surface crack and includes the effects of crack face contact and friction as well as surface traction. The influence of a range of parameters, including the size of contact and the depth of maximum shear stress, is studied.

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

10:30 - 11 am

3283782: Investigation of Formation Mechanisms of Dark Etching Regions and White Etching Bands in SAE 52100 Steel Bearings

Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, United Kingdom, Bernd Vierneusel, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

Subsurface microstructural alterations such as dark etching regions (DER) and white etching bands (WEBs) manifest in steel bearings due to rolling contact fatigue. It is reported that alterations initiate as DER followed by WEBs which form at an inclined angle of 30° (LABs) first then at 80° to the surface in the rolling direction. While a number of hypotheses have been presented in literature suggesting formation mechanisms of these features, there is a lack of sufficient experimental evidence in confirming them. The transition from DER to LAB and to HAB is yet to be fully understood. This study focuses on finding formation mechanisms of DER, LAB and HABs through detailed analysis of these features at different stages of the bearing life, including elemental redistribution, dislocation density, mechanical properties and their micro and nano-structures. This study also aims to establish the links between these microstructural changes and final bearing failures.

11 - 11:30 am
3284271: Formation of White Etching Areas/Cracks on a Four-Disk Rig - Investigating Microstructural Changes
Adrian Mikitisin, Central Facility for Electron Microscopy, Aachen, Germany, Florian Steinweg, Institute for Materials Applications in Mechanical Engineering, Aachen, Germany

Microstructural changes in bearing elements made from SAE 52100 can result in early lifetime failure in various fields of applications. The microstructure alteration associated with the premature failure is widely known as White Etching Areas (WEA). The difference in microstructure of martensite matrix and WEA leads to cracks at the interface. These cracks are known as White Etching Cracks (WEC), which ultimately leads to failure. Even though WEC failures can be achieved on various benchtop tests, the phase transformation mechanisms during the formation of WEA's are under constant debate. Besides it is well known, that additional loadings such as hydrogen and electrical current amplify the formation of WEA. This work therefore focuses on the investigation of these microstructural changes during the formation of WEA. Testing was conducted on a four-wheel test rig using rollers made from the steel SAE 52100. A detailed microstructure analysis using SEM, EBSD and TEM was carried out.

11:30 am - 12 pm
3285641: Fracture-Mechanical Evaluation of Inclusions – Comparison with Test Results and Other Approaches
Joerg Binderszewsky, Wolfram Kruhoeffer, Toni Blass, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany

Fracture mechanics are one option for an analytical evaluation of non-metallic inclusions (NMIs) in bearing steel. An analytical fracture-mechanical approach considering the orthogonal shear stress, size and shape of the inclusions, and the short-crack behavior has been compared with different test results and other simulation methods as well as the recommendations of international standards. The influence of diffusible hydrogen on the material characteristics can be discussed by means of published test results and can support the understanding of the premature failure mode white etching crack (WEC).

3D — Columbus G

Biotribology III

Session Chair: Dipankar Choudhury, University of Arkansas, Fayetteville, AR
Session Vice Chair: Jack Famiglietti, University of Florida, Gainesville, FL

8 - 8:30 am
3280258: Tribological Effect of Nanodiamonds as Potential Lubricant for Artificial Joints
Asghar Shirani, Diana Berman, University of North Texas, Little Elm, TX

Hip implants are mostly made from titanium-based alloys. However, the wear of materials during the operation inside the human body is a key source of implant failure and adverse health effects. We offer a new vision on the lubrication of titanium components. Addition of less than 0.2 wt.% of nanodiamonds (NDs) to simulated body fluid promotes a dramatic reduction in friction and wear behavior of titanium-

based alloy. Adding NDs reduces friction up to 3 times and two order of magnitude in wear volume. Interestingly, the required NDs to improve the frictional behavior of Ti substrate directly depends on the concentration of NDs and applied pressure. Having minimalistic wear requires a higher concentration of NDs. Analysis of the wear track formed during sliding shows the formation of a carbon-rich tribolayer which improves tribological properties of the surfaces. Our results suggest that the carbon layer is formed from the nanodiamonds embedding in the top layer of titanium.

8:30 - 9 am
3324250: Novel Bio-Tribometer Exposing Macrophages to Freshly Generated In-Situ CoCrMo-Debris
Simona Radice, Kathrin Ebinger, Lauryn Samelko, Pourzal Robin, Nadim Hallab, Markus Wimmer, Rush University Medical Center, Chicago, IL

Mechanisms triggering body reactions to tribocorrosion debris from CoCrMo-implants in total hip replacements are not completely understood. This work aims to investigate differences in macrophage cell response to freshly generated in-situ debris, and stable debris, previously generated in the same biotribometer. The measured outcomes were cell viability and pro-inflammatory cytokine secretion of THP-1 differentiated macrophages. Cells challenged with fresh debris showed higher cell viability compared to cells challenged with stable debris; at the same time, fresh debris caused an increase of pro-inflammatory cytokines, not observed with stable debris. The increase in inflammatory reaction in response to fresh debris compared to time stabilized debris suggests the action of metastable short-lived species. Past studies may thus have underestimated the biologic reactivity of implant debris in-vivo and further investigations are indicated.

9 - 9:30 am
3316419: Fretting-Corrosion Induced Hydrogen Permetiation in Biomedical Ti-Alloys
Micheal Bryant, University of Leeds, Leeds, United Kingdom

The aim of this study was to analyse the effect of tribological and electrochemical mechanisms on hydrogen permeation of Ti biomedical alloys. A novel detection cell based on the Devanathan-Stachurski cell (DS cell) was designed to investigate hydrogen permeation in fretting-corrosion contacts. The cell was incorporated into a bespoke fretting-tribometer facilitating measurement of hydrogen permeation via potentiostatic electrochemical techniques. Hydrogen permeation was seen to be dependent on the amplitude of fretting displacement and slip regime. The results from this study show that during fretting-corrosion H_2 permeation occurs and is increased. This is dependent on the nature of the tribological contact and nature of the lubricating environment. The addition of an oxidiser was seen to affect the synergies between static permeation and fretting-induced permeation.

9:30 - 10 am - **Invited Talk**

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

10:30 - 11 am
3284242: A Biomaterial for Cartilage Replacement - A Tribological Study
Rahul Ribeiro, Arun B.P., Alliance University, Bengaluru, Karnataka, India

In order to overcome the drawbacks of current materials used in total joint replacements, and mimic natural cartilage, hydrogel composite materials were investigated. Inter penetrating networks of Poly Hydroxyethyl Methacrylate and Poly Acrylamide were synthesized with nano clay particles as

reinforcement. Tribological and compression tests were carried out. Four lubricants-simulated body fluid (SBF), and SBF with 0.1, 0.2, 0.3 mg/ml of Hyaluronic acid (HA) were incorporated in the tribological tests. The counter material was a stainless steel pin. It was found that the nanoclay particles significantly improved the strength of the composite. Increasing the HA concentration led to an increase in viscosity of the lubricant and a corresponding increase in the coefficient of friction. An increase in crosslink density also led to an increase in the coefficient of friction. The addition of nano clay did not significantly affect the frictional force.

11 - 11:30 am
3286662: Sniffing Wear Patterns: Acoustic Emission Signals as a Diagnostic Tool for Joint Wear
Khadijat Olorunlambe, Hua Zhe, Duncan Shepherd, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

Acoustic Emission (AE) testing detects the onset and progression of mechanical flaws. AE as a diagnostic tool is gaining traction for providing a tribological assessment of human joints and orthopaedic implants. Recent developments show that there is potential for using AE as a tool for diagnosing joint pathologies such as osteoarthritis and implant failure but to realise AE full potential, the analysis of the signal must differentiate between wear mechanisms. A challenging problem! This study uses supervised learning to classify AE signals from adhesive and abrasive wear processes under controlled joint conditions. AE features found to be significant based on k-means clustering analysis were fed into the Back Propagation (BP) neural network optimised by the Beetle Antennae Search (BAS) algorithm, achieving a classification accuracy of 80%. An exciting development for the clustering and supervised classification of AE signals as a bio-tribological diagnostic tool.

3F Columbus IJ

Lubrication Fundamentals III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3321496: Macroscale Superlubricity Enabled by Hydrated Multivalent Ions
Tianyi Han, Zhang Chenhui, Jianbin Luo, Tsinghua University, Beijing, China

In this work, we evaluated the lubrication and adsorption properties of multivalent ions between Si_3N_4 and sapphire surfaces. We found that the divalent and trivalent ions exhibit extremely low friction coefficients of 0.005–0.006 and 0.002–0.004 respectively under high contact pressures above 0.25 GPa, and three trivalent ions (Al^{3+}, Cr^{3+}, Ce^{3+}) can achieve superlubricity at quite low sliding speeds (3 mm/s), which is a significant breakthrough for superlubricity under boundary lubrication. Moreover, through zeta potential analyses, we revealed that divalent ions can reduce surface potential and lower surface charge density even further (compared with monovalent ions), and trivalent ions can neutralize the negatively charged ceramic surfaces and even lead to charge inversion due to the excess adsorption of the cations, which ensures strong adsorption of hydrated multivalent ions on friction surfaces, thus generating strong hydration repulsion.

8:30 - 9 am

3277410: The Effect of Magnetic Field on the Hydration Revealed by THz Spectroscopy and MDs

Yanqi Gu, Tianbao Ma, Jianbin Luo, State Key Laboratory of Tribology Tsinghua Universtiy, Beijing, China

Hydration lubrication for superlubricity with hydration shells surrounding ions has been studied years, but the influence of magnetic field on hydration is not well understood. Here the influence of an external magnetic field on the sub-picosecond network dynamics of solution is investigated by terahertz time-domain spectroscopy. We found experimentally by testing the variation of water clusters that the magnetic field enhances the number of water molecules involved in hydration and the radius of dynamic hydration layer in salt solutions. However, with the increasing concentration, there is a downward in the hydration enhancement per mole. Besides, the MDs reveals that external magnetic field mainly affects the second hydration layer and the stability of water molecules network in hydration layer is enhanced with external magnetic field.

9 - 9:30 am

3302240: Three-Way Compatibility among Ionic Liquids, MoDTC, and PIBSI Dispersant

Weimin Li, Lanzhou Institute of Chemical Physics, Lanzhou, Gansu, China, Chanaka Kumara, Huimin Luo, Harry Meyer, Xin He, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, Dien Ngo, Seong Kim, Pennsylvania State University, University Park, PA

Here we present compatibilities among three oil-soluble ILs, a MoDTC, and a PIBSI dispersant in a PAO base oil under boundary lubrication of a steel-iron sliding contact. Synergistic or antagonistic effects were observed depending on the IL's chemistry. Two ILs caused precipitation when blended together MoDTC and PIBSI into the oil, due to reactions between the IL and PIBSI to reduce PIBSI's availability for suspending MoDTC. The IL consumption and MoDTC precipitation led to detrimental impact on the friction and wear behavior. In contrast, a remarkable synergistic effect was achieved when using the third IL, MoDTC, and PIBSI together, yielding a sustainable, ultra-low friction coefficient. No IL-PIBSI reaction was detected in this case. A three-stage tribochemical process is proposed to explain how this IL and MoDTC work together to form a chemically-reacted, wear-protective tribofilm and a physically-adsorbed, friction-reducing film on top of it.

9:30 - 10 am

3284970: Tribo-Induced Interfacial Nanostructures Assisting Robust Superlubricity in Amorphous Carbon Films: From Mechanisms to Tailoring Strategies

Xinchun Chen, Tsinghua University, Beijing, China

The unique lubricity nature of amorphous carbon films, namely the capacity to achieve superlow friction and near-zero wear, has endowed the research community with the most promising pathways to combat friction and wear. As a universal phenomenon, tribo-induced formation of a nanostructured tribolayer during the atomic-scale rubbing processes is crucial in establishing a near-frictionless lubrication state for these films. The structural diversity and its self-adapted capability of amorphous carbon provide the greatest potentials to tailor the sliding interfaces for the realization of a robust superlubrity in each specific environment. The mechanisms of occurrence and existence of robust superlubricity are clarified from multi-coupling conditions. These critical understandings are of importance in designing more durable carbon-based lubricants, and also of guidance significance for developing other superlubricious materials.

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

10:30 - 11 am
3337896: Viscosity-Temperature Equations for Petroleum-Based Lubricating Oils
Jack Zakarian, JAZTech Consulting, LLC, Orinda, CA, Shaun Flannigan, Ashlie Martini, University of California Merced, Merced, CA

The viscosity of a lubricant changes dramatically with temperature and it is very important to accurately predict this behavior in engineering calculations. A number of equations that describe the viscosity-temperature dependence of lubricant hydrocarbons have been reported over the years. In this work, we review the applicability of the most commonly-used equations. We take advantage of a large dataset of pure hydrocarbons that were synthetized and characterized as part of the American Petroleum Institute's Project 42. We also compare the equations to datasets for actual lubricants, i.e, mixtures of pure hydrocarbons containing chemical additives. In addition, we examine the possibility of using existing and new equations as alternatives to the Viscosity Index method.

11 - 11:30 am
3293046: The Molecular Origins of Viscosity in the Ester Lubricants
Thomas Theyson, TensTech Inc., Matthews, NC

The author has, over the last 30+ years, accumulated a large data base covering the viscosity of low to intermediate molecular weight, liquid ester lubricants. The presentation will cover the normal rheological behavior associated with these materials along with what appears to be unexplained rheological phenomena: inflection points in viscosity-molecular weight curves and viscosity outliers (products with viscosities that are >10-fold higher than that expected based on their molecular weight). The literature provides little guidance on either of these issues and where it is discussed, it general reverts to correlative properties, rather than fundamental molecular interactions. The presentation will conclude with possible explanations for these phenomena and a review how work in this area is supporting the development of several new classes of high molecular weight, low viscosity ester lubricants.

11:30 am - 12 pm
3299774: Shear-Thinning and Rheological Transition in Lubricants Sheared at High Strain Rates
Vikram Jadhao, Indiana University, Bloomington, IN

Ongoing debate divides tribologists over the use of an appropriate rheological model to describe shear-thinning in machine lubricants at high rates common in elastohydrodynamic lubrication (EHL). This talk presents a computational study of the rheological properties of a model EHL lubricant, squalane, using simulations and machine learning (ML). The viscosity results from simulations are consistent with the experimental data for a broad range of equilibrium and nonequilibrium conditions. At low Newtonian viscosity, shear-thinning is described by power-law models. As Newtonian viscosity rises above ~1 Pa-s, shear-thinning is consistent with the Eyring model. To probe the molecular mechanisms underlying this rheological transition, ML is used to reduce the high-dimensional particle trajectory space and identify features that best classify molecular order. Results show that shear-thinning is dominated by saturated molecular order in squalane under the high-viscosity regime common in EHL.

Materials Tribology I - Solid Lubricants for Extreme Applications

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Session Chair: TBD
Session Vice Chair: TBD

8 - 9 am - **Invited Talk: Lubrication by Carbon - Surface Aromatization a General Route for Achieving Superlubricity**
Maria-Isabel De Barros Bouchet, École Centrale de Lyon

9 - 9:30 am
3286767: Tribological Performance of PS400 Coating from Cryogenic to Elevated Temperatures for Space Application
Kian Bashandeh, Vasilis Tsigki, Texas A&M University, College Station, TX, Pixiang Lan, Jacob Meyer, ATSP Innovations, Champaign, IL, Andreas Polycarpou, Texas A&M University, College Station, TX

Instruments for space exploration undergo extreme conditions, such as temperatures ranging from -220C on Europa to 485C on Venus. These extreme temperatures make traditional lubricants infeasible, compelling use of dry sliding components. These extreme temperatures with dry sliding make the tribology significantly challenging. In this study, we used tribo-pairs of advanced high-temperature bearing materials in the form of coatings on Titanium. Specifically, PS400 composite material (which was developed by scientists NASA's Glenn Research Center for applications up to 927C) sliding against different high-temperature materials, including BAM (9Al0.75Mg0.75B14) that are suitable for Venusian surface conditions. The experiments were performed at various temperatures from -196C to 600C in N2 and CO2 gas environments. This study will be invaluable in qualifying tribological materials for mechanical devices for use in planetary exploration and other applications at high temperatures.

9:30 - 10 am
3320312: Tribological Properties of Duplex PEO/Chameleon Coating on Aluminum Alloys
Asghar Shirani, Samir Aouadi, Andery Voevodin, Diana Berman, University of North Texas, Little Elm, TX, Aleksey Yerokhin, University of Manchester, Manchester, United Kingdom, Jon-Erik Mogonye, U.S. Army Research Laboratory, Adelphi, MD, Andras Korenyi-Both, Tribologix Inc., Golden, CO

In this study, a duplex composite coating was deposited on AA 6082 aluminum alloys. The coatings consisted of hard plasma electrolytic oxidation (PEO) matrix which is highly porous to provide space for burnishing a ternary soft lubricous material. The porous PEO coating has x um pores. These pores were filled by a combination of Sb2O3, MoS2, Graphite, and BN. These materials due to low shear and high-temperature stability provide low friction regime and the hard PEO matrix supports the integrity of the whole coating. The tribological behavior of the duplex system was analyzed by carrying out pin-on-disk and reciprocating wear tests in humid air within 25-300C. A low coefficient of friction was kept for all test conditions, proposing the self-adaptive property of the selected solid lubricant mixture. High-temperature pin-on-disk tests were conducted at 300 °C with an in situ Raman tribometer rig to analyze real-time phase changes in the wear track.

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

10:30 - 11 am
3286873: Aging Gracefully: Storage Effects on the Run-In of MoS_2-Based Solid Lubricants
Michael Dugger, Brendan Nation, Morgan Jones, Nicolas Argibay, John Curry, Michael Chandross, Sandia National Laboratories, Albuquerque, NM

Some aerospace applications require that precision mechanical mechanisms be stored for an extended duration before operation. At present, designers must anticipate increased friction on previously run-in surfaces during long periods of dormant storage, and include the additional energy required for startup. The need to accommodate elevated startup friction therefore drives over conservative designs and energy storage approaches. Sputter-deposited composite MoS2 films have been developed over several decades to improve tribological performance in non-inert atmospheres and to reduce wear rate. These tailored structures and compositions also affect friction evolution during aging and run-in. The composition and structure of several MoS2-based solid lubricants have been examined in the context of their long-term aging and run-in behavior. Mechanisms responsible for elevated startup friction will be discussed, and the results of recent efforts to minimize run-in will be presented.

11 - 11:30 am
3309532: Tribochemistry and Performance of Nanoparticle Additives in Spacecraft Lubricants
Andrew Clough, Edith Leung, Jeffrey Lince, The Aerospace Corporation, El Segundo, CA

While the tribochemical properties of metal disulfides have been well-studied as both bonded lubricant films and oil additives, little is known about the tribological behavior of molybdenum trisulfide (MoS_3) nanoparticles when used as additives in lubricants suitable for spacecraft applications. We have studied the friction and tribochemistry of several additives, including MoS_3 nanoparticles, dispersed in a commercially available multi-alkylated cyclopentane (MAC) oil and observed their tribological performance. Surprisingly, using MoS_3 nanoparticles as a lubricant additive outperforms the neat MAC oil and rivals the performance of molybdenum disulfide nanoparticle formulations. This is the first time that MoS_3 nanoparticles have been used as an additive in a typical spacecraft liquid lubricant and demonstrates their potential use as a lower cost alternative to MoS_2 formulations.

11:30 am - 12 pm
3339073: Effect of Stoichiometry and Oxygen on Crystallization of MoS_2 from Atomic and Molecular Precursors
Rimei Chen, Ashlie Martini, University of California-Merced, Merced, CA, Arben Jusufi, Andrew Konicek, Chris Kliewer, Aditya Jaishankar, Alan Schilowitz, ExxonMobil Research and Engineering Company, Annandale, NJ

Molybdenum disulfide (MoS_2) can be produced from chemical precursors used in gas engine lubricants, such as molybdenum dithiocarbamate (MoDTC), to reduce friction and wear in high pressure contacts during operation. However, it is not known whether such additives react to form MoS_2 through independent mechanisms or initially decompose and then recombine by similar mechanisms to form MoS_2. To explore this, we study the impact of stoichiometry (i.e., the concentration of molybdenum, sulfur, and oxygen) on MoS_2 formation in terms of degree of crystallinity, size, and edge chemistry and compare to the results from MoDTC precursors. Reactive molecular dynamics simulations of the crystallization process are complemented by experiments in which MoDTC is thermally decomposed to MoS_2 followed by quantification of crystal size with a transmission electron microscope (TEM). Results

provide mechanistic and kinetic information about the reactions leading to MoS_2 formation from lubricant additives.

3H Randolph 1

Grease III

Session Chair: Gareth Fish, The Lubrizol Corp.,Wickliffe, OH
Session Vice Chair: Cindy Liu, Kluber Lubrication NA LP, Londonderry, NH

8 - 8:30 am
3308619: A New Methodology to Characterize Constant Velocity Joint Greases
Valentin Ripard, Fabrice Ville, Jérôme Cavoret, LaMCoS - INSA Lyon, Villeurbanne, France, Pierre Charles, Groupe PSA, Velizy-Villacoublay, France

Nowadays transverse transmission is articulated by two mechanisms called constant velocity joints (CVJs). CVJ allows the suspension to move freely. CVJ functional analysis makes possible to identify important mechanical losses. The lubrication used in CVJ is grease. Previous works provide some data on tripod CVJ contact. The aim of this study is to reproduce tripod constant velocity joint kinematics on a dedicated tribometer which be presented. This tribometer which has been patented in 2019 is able to characterize the grease with 2 mains functions: A wear function using interferometry with a glass disc to visualize the lubricant distribution inside the contact. A friction mode which can provide a friction coefficient for this special contact in order to calculate shudders on drive shaft and optimize the friction coefficient for the application as a function of grease composition.To finish, first results on the rig will be compare to previous methodology used.

8:30 - 9 am
3284263: Corelating the Adhesion and Tackiness of Greases to Their Frictional Performance
Emmanuel Georgiou, Dirk Drees, Falex Tribology NV, Rotselaar, Belgium

The performance of greases in the field has been observed to strongly dependent on their interaction properties like adherence onto the surface of the component and their ability to form threads (tackiness). Recently a new method was developed by Falex to measure with precision the adhesion and tackiness of greases, based on repeated indentation and retraction measurements. However, until now the link between these intrinsic grease characteristics and their frictional performance has not yet been fully understood. For this reason, this work focuses in investigating the effect of adhesion and tackiness on the friction of greases. This is achieved by analyzing formulated greases with a defined adhesion and tackiness (as measured by indentation – retraction) and comparing them with Four-ball wear ASTM D4172, Block-on-Ring ASTM D3704, Mini-Traction (MTM) and TE-77 tests, which are frequently used test methods for evaluating the friction of greases.

9 - 9:30 am
3324539: Review of Custom SRV Tribological Test Fixturing to Simulate Bearing Test Rig Conditions
Rob Mulkern, Nye Lubricants, Fairhaven, MA

Tribology plays a large role when considering the use of a lubricant. Often, application demands expand well-beyond typical ASTM methods. Familiar and widely-accepted test methods like 4-Ball Wear and Timken OK Load are often chosen to evaluate a lubricant's performance. These tests, among others, are useful in many applications, but it is also very important to carefully consider the actual operating conditions. Bearing test rigs, more specifically the R0F, can offer a close representation of real world bearing applications. This testing is critical for bearing applications but can be costly in terms of time and money. The SRV's rolling/sliding adapter can be utilized to recreate the contact pressures seen in a bearing in order to act as a screening tool, thus minimizing these costs. A study was done to determine the rolling/sliding adapter's ability to successfully recreate the bearing life performance.

9:30 - 10 am
3322529: On the Modeling of Lubricating Grease Thickener Deformation
Lars Westerberg, Naser Hamedi, Luleå University of Technology, Luleå, Sweden

An understanding of the deformation of lubricating grease thickener structure is important in order to be able to fully disclose the flow behavior from very low- to very high shear rates. In this study, a first step has been taken through a flexible fibre model which has been implemented in the open source CFD code OpenFOAM. The three-dimensional Navier-Stokes equations which describe the fluid motion are employed while the fibrous phase of the fluid is modeled as chains of fiber segments interacting with the fluid through viscous- and drag forces. The aim of this study is to investigate the fibre dynamics against several orbit classes - i.e. rigid, springy, flexible and complex rotation of the fibres enabling the model to have all degrees of freedom: translation, rotation, bending, and twisting.

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

10:30 - 11 am
3340628: The Effect of Heavy Viscosity Base Oils on Grease Performance Properties
Edward Casserly, Ergon, Jackson, MS

Naphthenic base oils provide solvency and viscosity to many lubricant applications. Previous work has demonstrated that the higher solvency naphthenics, 750 SUS, have improved soap yields over paraffinic base oils in standard grease formulations, potentially lowering the overall cost of the formulation. However, the effect of very high viscosity base oils on the performance properties of industrial NLGI 2 greases has not been examined. A high viscosity bright stock, 5500 SUS at 100°F or 44 cSt at 100°C, was used to blend ISO 460 base oils and formulate NLGI 2 greases. The blends used lower viscosity naphthenics and Group II paraffinic base oils. The relative soap yields and lubricant functional properties were determined and related to base oil chemistry, e.g., base oil component viscosities, naphthenic/paraffinic content, and solvency parameters such as aniline point.

Tribochemistry III - Tribofilm Growth - Modeling & Characterization

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3338744: First-Principles Insights into the Mechanism of Metal-Polymer Contact Electrification for Triboelectric Nanogenerator
Alessandra Ciniero, Imperial College London, London, United Kingdom

In response to the global energy crisis an energy harvester namedtriboelectric nanogenerator (TENG) which is based on the contact electrification has been designed. The considerable output generated by TENG can be used to power microelectronic devices and sensors.
One of the major research directions of TENG is improving the amount of charge transfer during contact electrification by means of surface micro/nano structures or materials modification. However, the mechanism of charge transfer in contact electrification has not been well studied yet and the surface micro/nano structures design and materials modification are still lack of theoretical basis. In this work we report the use of first-principles calculations based on the quantum mechanics method as powerful tool to study the microcosmic electron transfer behaviors. The typical material pair Cu-PTFE of TENG is taken as the example to study the mechanism of metal-polymer contact electrification. Funding from Marie-Curie,EPSRC and TTRF

8:30 - 9 am
3325336: Relating Tribofilm Formation and Performance to the Adsorption Strength of Surface-Active Precursors
Arman Mohammad Khan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL, Hongxing Wu, Xi'an Jiaotong University, Xian, China

Mechanochemical reactions provide a unique approach for in situ synthesis of carbon tribofilms that can improve friction and wear performances of a tribological interface. In this work, we have studied how the formation of tribofilms can be related to the surface adsorption strength of three additives in PAO4 as base oil, viz., cyclopropanecarboxylic acid (CPCa), cyclopropanemethanol (CPMA), and 1-cyclopropylethanol (CPEA) as characterized by two different surface-active groups –COOH and –OH. Tribo-testing results reveal that addition of 2.5 wt% CPCa to PAO4 gives the lowest friction and wear volume. FTIR and Raman analyses demonstrate substantial tribofilm formation only in the case of CPCa. The thermogravimetric analysis and MD simulations indicate the stronger adsorption of CPCa on the iron oxide surface than that of CPMA and CPEA. Study reveals that stronger binding of an additive is highly critical for efficient formation of tribofilms under typical tribo-testing conditions.

9 - 9:30 am

3325221: Comparing the Composition and Evolution of Macro- and Nano-Scale Phosphorus Antiwear Tribofilms with ToF-SIMS

Kerry Cogen, Ryan Rieth, Infineum USA L.P., Linden, NJ, Matthias Lorenz, Alison Pawlicki, Nikolay Borodinov, Olga Ovchinnikova, Oak Ridge National Laboratory, Oak Ridge, TN

In vehicle transmissions, antiwear tribofilms form from lubricating fluids on rolling/sliding contacting surfaces and serve to control friction and protect surfaces from wear and fatigue. Understanding the mechanism of antiwear film formation and how to tune surface chemistry to control functionality is essential for development of next generation transmission fluids. Here we use both macro-scale generation of tribofilms by block-on-ring testing and nano-scale AFM single-asperity experiments for tribofilm preparation, and analyze the chemical composition of these films by depth profiling Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). We compare macro-scale films prepared from different phosphorus-containing lubricants with variable contact time between contacting metal surfaces to study changes in chemical composition of the films formed during their initial formation and evolution. This approach will provide better understanding of the mechanism of early film formation.

9:30 - 10 am

3325301: Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM

Kerry Cogen, Ryan Rieth, Hitesh Thaker, Infineum USA L.P., Linden, NJ, Alison Pawlicki, Nikolay Borodinov, Olga Ovchinnikova, Oak Ridge National Laboratory, Oak Ridge, TN

In vehicle transmissions, antiwear tribofilms form from lubricating fluids on rolling / sliding contacting surfaces and serve to control friction and protect surfaces from wear and fatigue. Understanding the mechanism of antiwear film formation and how to tune surface chemistry to control functionality is essential for development of next generation transmission fluids. Here, we developed a unique multimodal AFM methodology to understand initial film formation from different phosphorus-containing lubricants in-situ. We combined Friction Force Microscopy (FFM) to capture the spatial details of friction over the surface as the tribofilm forms and evolves and Nano Infrared Spectroscopy AFM (NanoIR-AFM) to understand the chemistry of the film. We demonstrate the formation of antiwear tribofilms on steel surfaces, the effect of lubricant formulation on how these films evolve in-situ, and the differences in chemistry between these films.

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

10:30 - 11 am

3286546: Fundamentals of Tribochemistry – Model Study with Tribopolymerization of Adsorbate Molecules

Seong Kim, Xin He, Pennsylvania State University, State College, PA

Unlike typical chemical reactions which are initiated by electronic excitation or transition within or among reactant molecules under the influence of heat, light, or electrical bias, tribochemical reactions are initiated by interfacial shear imposed onto the molecules by the solid surface. How could the mechanical energy of solid surfaces be channeled into reaction coordinates of molecules adsorbed and sheared at the sliding interface. We have addressed this question through carefully designed experiments and collaborations with computational groups. This talk will focus on the effects of chemical structures of the adsorbed molecules that are being sheared at the interface as well as the

roles of surface chemistry of solid substrates and surrounding gas environments.

11 - 11:30 am
3285552: Tribochemical Process on Silicon Surface: Fundamental Understanding and Application to Nanofabrication
Linmao Qian, Lei Chen, Chen Xiao, Southwest Jiaotong University, Chengdu, Sichuan, China, Seong Kim, Pennsylvania State University, State College, PA

Ultra-precision of nanomanufacturing process down to the atomic level is of paramount importance for new development of nanoelectronics with unique functionalities. Here, we demonstrate a mask-less and chemical-free nanolithography process for regio-specific removal of atomic layers on silicon surface via shear-induced mechanochemical reactions with water molecules. Since the chemical reactions involve only the topmost atomic layer exposed at the interface, the crystalline lattice beneath the processed area remains intact, which keeps perfect crystalline order without subsurface damage. Molecular dynamics simulations were used to explain the atom-by-atom removal process. Based on the parametric thresholds needed for single atomic layer removal, the critical energy barrier for water-assisted mechanochemical dissociation of Si-Si bonds is determined. The mechanochemical nanolithography method demonstrated here could be extended to nanofabrication of other crystalline materials.

11:30 am - 12 pm
3313186: Molecular Simulation Approach to Attack Friction Fade Out Phenomena
Hitoshi Washizu, Hirotoshi Akiyama, Riio Nakae, University of Hyogo, Kobe, Japan

Friction Fade-out (FFO) is the phenomena that the friction coefficient is reduced to the friction-tester noise level as low as 10^{-4} order when diamond-like carbon (DLC) film was slid by ZrO_2 pin under H_2 gas environment. Whereas the process is complicated, the formation of the polymer transfer film on ZrO_2 surface is required to make low friction. Using the molecular dynmics simulation with chemical reaction, we show our results for the very first formation process of polymerization of the transfer film. Under the confiment between ZrO_2 and DLC, ethanol molecules polymerized together by two chemical reaction.

3J — Randolph 3

Condition Monitoring I

Session Chair: Jatin Mehta, Fluitec International, Bayonne, NJ
Session Vice Chair: Kemberlee Snelling, Trico Corp, Davison, MI

Session Starts at 8:30 am

8:30 - 9 am
3285675: The Increased Acid Number Question – Does it or Doesn't it Cause Corrosion?
Michael D. Holloway, 5th Order Industry, Highland Village, TX

The ASTM D 664 method Acid Number of Petroleum Products by Potentiometric Titration, states that 'no general relationship between bearing corrosion and acid number is known'. Many practitioners of oil analysis and maintenance will agree that the generation of acid is a common occurrence with lubricants that are thermally and/or chemically stressed, and that strong acids that develop will corrode metal yet according to ASTM, there has not been empirical evidence the support those claims or refute the statement by ASTM until now. This paper explores the relationship between the presence of strong acids as they develop in used oil and the influence of, if any on corrosion occurrence.

9 - 9:30 am
3285444: Introduction of Online Oil Condition Monitoring System for Hydraulic Excavator
Hideki Akita, Hitachi Construction Machinery Co., Ltd , Tsuchiura, Ibaraki, Japan

In recent years, as the performance of machinery improves, the customer's interest of construction machines has shifted to the reduction of the life cycle cost and the improvement of the operation rate. To cope with this, construction machine manufacturers are providing information using ICT (Information and Communication Technology). Among them, Hitachi Construction Machinery(HCM) has a service solution utilizing ICT, from 2013. Once the customer has completed the procedure with the dealer, the report is sent by e-mail on a monthly basis, so logging into the website and information manipulation are not required anymore. In October 2017, HCM started a solution package oil monitoring system in Europe, Australia and Japan, that notifies rapid change when oil change is detected automatically. We are going to introduce a part of the system and service flow.

9:30 - 10 am
3284840: The Analysis of Wear and Wear Products from Gearboxes Utilization of Statistical Analysis
Surapol Raadnui, KMUTNB, Bangkok, Bang-Sue, Thailand

The gearbox is an important machinery component in any industry. Any defect in gears could lead to machine downtime resulting in a loss of production. Among gearbox condition monitoring techniques i.e. vibration, acoustic and noise monitoring, solid debris analysis is considered as one of an effective approach due to its capability of being able to reveal particular wear conditions of gearboxes through the analysis of suspended solid particles in the used oil samples. This was the motivation to study the effect of different gear and seal wear failure modes. In this particular paper, a series of investigations of seal and gear wear were systematically undertaken utilization of design of experiments in a laboratory-controlled conditions with the express aim of developing a generic type of worn products for diagnostic purpose.

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

10:30 - 11 am
3317073: High Throughput Particle Count and Elemental Analysis of In-Service Oils in One Run
Autumn Wassmuth, PerkinElmer, New Haven, CT

Particle counting is becoming a more routine tool for lubricant condition monitoring and maintenance programs to better identify particles of certain sizes and concentrations that can contribute to machine failure. In-service oils and other lubricants are monitored for particle size similarly to how they are monitored for elemental concentration. An increase in the ISO code (ISO 4406) for particle count or concentration of key wear metals indicates when maintenance is required. This presentation discusses the hyphenation of an in-line particle counter to the ICP sampling system between the autosampler and

the ICP nebulizer. The approach brings several benefits to particle counting. By doing the measurements on diluted lubricants, the ICP analysis is not impacted. Also, high sample throughput for particle counting is achieved at 45 seconds, sample to sample, analysis time, using less than one mL of undiluted sample overall.

11 - 11:30 am
3285697: Strange Influences on Oil Analysis Results
Michael D. Holloway, 5th Order Industry, Highland Village, TX

Oil analysis is a powerful tool for understanding the condition of used oil, wear debris generation, as well as the generation of internal contaminants and the presence of external contaminates. But every so often strange if not bizarre results will perplex even the most seasoned diagnostician. This session explores the strange, rare, and even unexplainable results from oil analysis results that influenced equipment reliability as well as explained such topics as the influence. This session explores the influence that processes, products, applications have on in-service lubricants and can send a diagnosis in a direction that may not produce an accurate assessment. This session also provides a process by which one can ascertain the data and with applying the right questions, these influences can be used as explanations for the seemingly random or unknown results.

3K Michigan 1

Engine and Drive Train I

Session Chair: Behzad Mahmoudi, Chevron Oronite LLC, Richmond, CA
Session Vice Chair: Abhishek Kar, Shell Global Solutions US Inc, Houston, TX

8 - 8:30 am
3274941: Emission and Vehicle Performance Evaluation of Aged Gasoline Particle Filter via Accelerated Ash and Soot Loading
Weizi Li, Xiaojun Wu, Shell (Shanghai) Technology Limited., Shanghai, China, Yansong Lin, Jinchong Pan, Suzhou Automotive Research Institute, Tsinghua University, Suzhou, China, Chen Yang, Haijun Yang, Geely Powertrain Research Institute, Ningbo, China

To meet recent legislation requirement, gasoline particle filter (GPF) is becoming popular to reduce particle number emission. Ash from engine oil could be loaded on GPF during driving and could potentially impact vehicle performance in long term. In this study, accelerated ash and soot loading methodology through lubricant and fuel mixed combustion for 200k km mileage equivalent is utilized and 3 engine oils with different ash level or detergent elements were chosen for testing, afterwards WLTC emission, real driving emission, back pressure and engine performance are all measured with loaded GPF. Preliminary data shows ash could help particle reduction but has negative impact on other emissions, no significant differences are found between high ash (1.2%) oil and middle ash (0.8%) oil, metal elements in detergent give little change, and fuel consumption is not strongly correlated with ash content. Besides, soot regeneration and vehicle acceleration are under investigation now.

8:30 - 9 am

3318940: Facile Mimicking of Internal Engine Oil Viscosity at Real Temperature and Shear by Way of a Microfluidic Rheometer

Matt Vanden Eynden, Formulaction, Inc., Worthington, OH, Patrycja Adamska, Thanina Amiar, Hubert Ranchon, Pascal Bru, Gerard Meunier, Formulaction, Toulouse, France

The high temperature and shear conditions present in combustion and other types of engines are of importance to mimic in order to predict the performance of engine oils and lubricants. Shear-thinning profiles of oils at these conditions are often extrapolated or estimated when devices of lower acquisition parameters are used while large volumes and longer times are needed with devices operating at higher temperature and shear ranges. A novel microfluidic rheometer can fulfill the purpose of mimicking the internal temperature and shear of an engine to provide resolved viscosity profiles of lubricant formulations in a matter of minutes with only several milliliters of sample. This technology eliminates the need for calibration or geometry setup and viscosity is monitored in real-time by visual flow acquisition methods, allowing for high throughput screening in a fraction of time of normal methods.

9 - 9:30 am

3294373: Effects of Powertrain Formulations in Taxi Cab Severe Field Service

JoRuetta Ellington, Evonik Industries, Horsham, PA

There are many inherent challenges in taxi cab applications operating in the extreme desert heat such as stop-and-go driving, 24-hour service, and continuous idling which place severe demands on lubricants. A series of API SN 0W-20 engine oils and MERCON® LV level automatic transmission fluids were evaluated in a Las Vegas taxi cab fleet to study the durability of two different classes of VI Improvers in the powertrain. These fluids were examined in turbocharged engines with six-speed automatic transmissions operating under severe service conditions. The 100K mile field trial, using vehicles equipped with 2.0L Eco-boost engines, was run to demonstrate that novel VII technology will do no harm to the vehicle while protecting the powertrain from sludge, varnish, and oxidation. Additionally, the fluids maintained viscosity and low temperature performance. This follow-up paper will present the remaining powertrain fluid performance results from the end of test along with teardown analysis.

9:30 - 10 am

3284520: Friction and Wear of Thermal Spray Coatings for Cylinder Bores

Arup Gangopadhyay, Larry Elie, Robert Zdrodowski, Zhiqiang Liu, Urban Morawitz, Joachim Patschull, Cliff Maki, Ford Motor Company, Novi, MI, Hamed Ghaednia, Gehring Group, Farmington Hills, MI

Thermal spray coating on cylinder bores of automotive engines offer lightweight and heat transfer improvement because of the elimination of cast iron liners in an aluminum engine block. The processes for deposition of such coatings include plasma transferred wire arc (PTWA), electric wire arc, twin wire arc, atmospheric plasma etc. The coatings are ferrous based and contain 1-2 % pores. This paper will describe the development of high porosity (1-16%) PTWA coatings, and characterization of thermal and mechanical properties. In addition, friction characteristics were evaluated using laboratory bench tests, motored unpressurized cranktrain tests, and single and multi-cylinder engines. Significant friction benefits were observed in all tests. The wear performance of PTWA coating also evaluated in a motored unpressurized multi-cylinder cranktrain tests in contact with rings with different coatings using radiotracer method. The performance found to be comparable to cast iron liner material.

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

10:30 - 11 am

3285656: Development of a Fired-Engine Test Cycle to Evaluate the Effect of Engine Oil Formulation on Emulsion Formation

Dan Engstrom, Southwest Research Institute, San Antonio, TX

With the increased number of hybrid vehicles in the market, there is an increased concern regarding the formation of water-in-oil and fuel-in-oil emulsions due to the absence of sustained engine operation. In hybrid or plug-in hybrids, the electric drive system provides much of the power needed for low speed commuting cycles and does not allow the oil to heat up as it would in a conventional IC engine-powered vehicle. The suggested solution when emulsions form is to drive the hybrid vehicle on the highway to heat the oil to operating temperature to burn off the water and fuel in the oil. Due to a desire to better understand this phenomena and evaluate the performance of different oil formulations, a two-stage test development was selected. The study described outlines the first stage of development with a modified Sequence VH stand demonstrating the repeatable formation of emulsions with a baseline oil and studying the effects of engine oil formulations on reducing such emulsion.

11 - 11:30 am

3286684: Component Wear in Diesel Engine High Pressure Fuel Pumps Operating with Heavy Fuel

Nikhil Murthy, Stephen Berkebile, Blake Johnson, CCDC Army Research Laboratory, Aberdeen Proving Ground, MD, Caleb Matzke, University of North Dakota, Grand Forks, ND

Many diesel engines rely on high pressure fuel pumps as a major component of the fuel delivery system to supply fuel to the rail and injectors, however the pumps contain multiple sliding interfaces that are prone to damage. We examined the components within several pumps which operated with a heavy fuel (F-24). Of the pumps evaluated, one of the pumps was a pristine unused pump, two were operated without failure for 1100 and 1800 hours and two more were operated for 500 and 1200 hours until failure resulting in a decrease in output flow. The component surfaces were analyzed using photography, bright-field imaging, scanning light interferometry and scanning electron microscopy with energy dispersive spectroscopy. In the used pumps wear was observed to change the profile of surfaces in the cam-ring, bucket, and plungers. Coating delamination was also visible. In the failed pumps, non-oxidative scuffing of the surfaces was observed and hypothesized to have resulted in the reduced flow.

11:30 am - 12 pm

3283984: Influence of Fluids on the Operational Efficiency of Transmissions and Drivetrain Components

Dean Tomazic, FEV North America Inc., Auburn Hills, MI

The use of innovative drivetrain technologies including conventional and electrified propulsion systems is expected to play an increasingly important role in helping OEMs meet fleet CO_2 reduction targets for 2025 and beyond. This presentation will showcase a systematic process aimed at understanding the overall energy flow in a vehicle over the course of a representative fuel economy drive cycle. Examples from testing of a hybrid vehicle will be utilized to describe the losses in various portions of the drivetrain. The influence of various sub-systems on the transmission efficiency will be highlighted. The importance of transmission fluids on the efficiency of both conventional and electrified drivetrains will be discussed. Industry trends aimed at minimizing the losses related to hydraulics and drivetrain fluids will be shared and aspects of improved hydraulics and low-viscosity fluids will be illustrated using examples from case studies on transmissions and drivetrain components.

Contact Mechanics III

Session Chair: Kylie Van Meter, University of Florida, Spring Hill, FL
Session Vice Chair: Bo Tan, University of Kentucky, Lexington, KY

8 - 8:30 am
3278124: Computational Contact Modeling of Lithium Metal and Solid Electrolyte Interfaces
Xin Zhang, Q. Jane Wang, Northwestern University, Evanston, IL, Stephen Harris, Lawrence Berkeley National Lab, Berkeley, CA

The lithium metal and solid electrolyte (SE) would greatly increase the energy density of rechargeable Li batteries. However, poor Li-SE interfacial contact, and hence high interface resistance, affects Li ion transport, which confines the battery performance. This presentation reports a semi-analytical 3D time-spatial multi-scale contact model, aiming at 1) quantify the Li-SE interaction, 2) analyze the contact stress, and 3) simulate the Li metal surface evolution during charging/discharging processes. This model considers the elasto-perfectly-plastic deformation of the Li-metal, its creep, its surface roughness and variation due to Li plating/stripping. The proposed model is implemented to analyze a typical Li-SE interface for the understanding of the influences of surface roughness, stack pressure, and current density on true charging/discharging areas, subjected to Li creeping and plating/stripping processes.

8:30 - 9 am
3283853: Comparison of Scale in Indentation Experiments
John Despard, Matthew Brake, Rice University, Houston, TX

Instrumented indentation is an attractive method for the characterization of materials. It allows for bulk material testing and the probing of individual constituents in heterogenous samples. Instrumented nanoindentation, for example, is widely utilized for evaluating thin coatings. However, recent work on hard gold, electroless nickel, and thermally sprayed iron coatings has confirmed shortcomings in the nanoindentation method. Namely, defining surface features such as target surface roughness and porosity limit the usefulness of the method when evaluating in-situ coatings of 0.5 to 180 µm thickness. In response, a new mesoscale indenter (indentation depth < 90µm and contact force < 3000N) has been developed in the Tribomechadynamics Lab at Rice University. A comparison of nanoindentation and new mesoscale indenter data is presented. Additionally, the influence of indenter geometry with the new mesoscale test rig is reviewed.

9 - 9:30 am
3315526: A Benchmark Study of Conformal Contact
Jiahui Hou, Pu LI, JiangLin Li, Xiaoqing Jin, Chongqing University, Chongqing , China, Leon M. Keer, Northwestern University, Evanston, IL

Rolling element bearings are one of the essential components in machinery. A basic component in bearing designs is to determine the interactions between the ball and raceway, which may have a significant impact on the service life of the rotating elements. An accurate theoretical analysis of the ball-raceway contact is usually not a trivial task, since this involves conformal contact and would result

in appreciable errors when solved by the well-known Hertz theory. This study provides benchmarks on the validity of the classical Hertz contact theory for a general conformal contact. Both two-dimensional and three-dimensional formulae are investigated and compared with the finite element computations. As a particular application, the present non-Hertzian contact analyses are performed for exploring the characteristics of the ball-raceway contact in bearings.

9:30 - 10 am
3314982: The Origin of the Friction Coefficient for Randomly Rough Surfaces in Elastic Contact
Feng-Chun Hsia, Cyrian Leriche, Steve Franklin, Bart Weber, Advanced Research Center for Nanolithography (ARCNL), Amsterdam, Netherlands, Daniel Bonn, University of Amsterdam, Amsterdam, Netherlands

The origin of the friction coefficient (CoF) remains elusive. In adhesion friction, surface topography is one of the main parameters controlling friction. The surface topography at the contact interface can be deformed purely elastically if the local contact pressure does not exceed the flow strengths of the contacting materials. In fact, in the elastic regime, the contact pressures are determined by the local surface topography: sharper roughness peaks lead to a smaller real area of contact, resulting in higher local pressures. Here, we mechanically manipulate the surface topography of SiN balls and subsequently slide these balls against smooth sapphire flats. We show that the CoF can be tuned through control of the surface topography, and we analyze the real area of contact using in-situ fluorescence visualization and contact calculations. Our results indicate that, while the average normal stress at the interface strongly depends on the topography, the average shear stress does not.

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

10:30 - 11 am
3322337: Transient Thermomechanical Analysis of Asperity Sliding Contact Considering the Effect of Temperature and Strain Rate on Material Properties
Bin Zhao, Hanzhang Xu, Xiqun Lu, Zhigang Liu, Tongyang Li, Harbin Engineering University, Harbin, China

A transient thermomechanical sliding contact model of an elastic-plastic asperity based on Johnson-Cook model is established to predict the contact temperature and coefficient of friction. The model is different from the previous model by considering the coupling effects of temperature and strain rate on material properties during sliding contact. The SnSbCu alloy is focused in this work as it is the common journal bearing material, and its material property is obtained from the split Hopkinson pressure bar experiment. The influence of overlap, relative speed, elastic modulus, plastic deformation parameters and ultimate shear strength on tangential, normal force, energy loss, coefficient of friction and maximum temperature are studied. The results suggest that yield strength, overlap and relative speed are positively related to maximum temperature. A small friction coefficient can be obtained when the relative speed, overlap and elastic modulus are large and yield strength is small.

11 - 11:30 am
3317854: High-Temperature Nanomechanical Behavior of Inconel 617 Surface Oxides
Sepehr Salari, Ali Beheshti, George Mason University, Fairfax, VA, Md Saifur Rahman, Andreas Polycarpou, Texas A&M University, College Station, TX

Inconel 617 is a principal candidate for helium gas-cooled very-high-temperature reactors. This study investigates the nanomechanical and nanotribological properties of the oxide of the topmost layer of

Inconel 617 using experimental hot nanoindentation and finite element analysis. Comprehensive understanding of mechanical properties especially the time-dependent creep properties of these oxide layers provides useful data to understand and predict Inconel 617 oxide long-term wear, contact, and frictional properties. Finite element analysis is used to extract the mechanical properties such as yield strength, strain hardening and creep parameters of the oxide layer. While Young's modulus of the oxide is found to be close to the bulk of Inconel 617 for temperatures ranging from 25 °C up to 600 °C, the yield strength and hardness increase significantly after aging. Based on the experiments and FEA results till 600 °C, creep deformation is dominated by diffusion through the boundaries.

11:30 am - 12 pm
3323585: High-Temperature Contact Creep and Friction of Inconel 617 Surface Oxides
Sepehr Salari, Lamar University, Fairfax, VA, Md Saifur Rahman, Andreas Polycarpou, Texas A&M University, Fairfax, VA, Ali Beheshti, George Mason University, Fairfax, VA

Inconel 617 is a principal candidate for helium gas-cooled very-high-temperature reactors with outlet temperatures of 700-950 °C. Surface friction, wear, and contact properties of the contacting pairs degrade at high temperatures impacting the performance and controlling of moving parts. This study investigates the influence of high temperature creep on friction and evolution of contact area for Inconel 617 at high temperatures up to 600 °C using finite element analysis. The mechanical properties of the oxide are utilized to study friction temperature and dwell time on contact area and friction coefficient variation creep for a spherical asperity. Using a machine learning approach, friction coefficient sensitivity on load, temperature, and holding time is measured and consequently, a nonlinear empirical model at asperity level is obtained. This model for one asperity is expanded to a population of asperities using Greenwood based statistical models for rough surface contacts.

3M — Michigan 3

Lubrication Fundamentals Special Session I: Four Decades of Patri-Cheng Average Flow Model and Future Challenges in Tribology (Invited Talks Only)

Session Chair: TBD
Session Vice Chair: TBD

As the lubrication science deepens in understanding and widens in its application to novel fields, time has come to review progress made in the past 40 years and discuss current challenges and future needs. This symposium brings together researchers in the field of lubrication to share their accomplishments in research and present their visions for future research and development.

4A — Columbus AB

Commercial Marketing Forum IV

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

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

4 - 4:30 pm - **The Lubrizol Corporation**

4:30 - 5 pm - **BASF Corporation**

5 - 5:30 pm - **Eastman Chemical Company**

4B Columbus CD

Metalworking Fluids IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3324812: Cross-Functional Benefits of Metalworking Fluid Additives
Co-Presenters: Nicole Clarkson, ANGUS Chemical Company, Buffalo Grove, IL and Michael Stapels, Kao Chemicals GmbH, Emmerich am Rhein, Germany
Co-Authors: Clayton Cooper, Soraya Kraszczyk, ANGUS Chemical Company, Buffalo Grove, IL, Sabine Wohlfahrt, Lea Tekath, Kao Chemicals GmbH, Emmerich am Rhein, Germany

Faced with an ever-shrinking toolbox of available chemistries, creativity in formulation and raw material selection is essential for today's metalworking fluid manufacturers. While alternative chemistries are available to help meet performance criteria, it is key to understand the potential benefits of these chemistries when used in combination with certain other formulation components to create unique opportunities. This presentation explores utilizing the modern metalworking toolbox to achieve different formulary and performance benefits in finished metalworking fluid formulations. Through outlining characteristics such as emulsion stability, foaming, corrosion, fluid longevity and more, formulators can generate solutions based on their needs. This helps remove prevalent roadblocks for formulators by meeting performance expectations through different avenues. It also creates opportunities to not only rival, but also surpass, previous performance to meet today's metalworking needs.

2:30 - 3 pm
3297106: Investigation of O/W Emulsion in Rolling of Strips
Behnam Hajshirmohammadi, Louisiana State University, Baton Rouge, LA

Oil in water emulsions are widly used in metal forming processes. Cold rolling is one application this lubricant. The oil properties and the oil content of emulsion has major impact on many properties of the propduct of this process. A model is presented for studying the surface properties with the application of interstand tension between the roling stands.

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

4 - 4:30 pm

3303685: Measuring Tapping Performance Parameters - Using Tapping Torque to Evaluate Coolants and Coolant Additives

Michael Miller, Univar Solutions, Houston, TX

Many additives contribute to lubricity in a metalworking fluids. In this work a tapping torque tester is used to evaluate the performance of a series of different chemistries and how they compare utilizing various metal substrates. The talk will also cover the methodology and data evaluation techniques for using the Microtap to screen and bench test fluids and the pitfalls to avoid. Anyone looking for tools to evaluate MWFS and MWF additives, address lubricity, and improve fluid performance will find this program helpful.

4:30 - 5 pm

3319978: Correlation of Cutting Fluid Lubricity to Tool Life in Hard Metal Machining with An Improved Tapping Torque Test Method

Chandra Khadilkar, Brian Mattes, Z. Tahir, Master Fluid Solutions, Perrysburg, OH

Metalworking cutting fluids are used to provide lubricity and cooling at the tool / material interface to increase tool life, improve surface finish and increase material removal rates resulting in improved productivity. Tool wear during machining depends on multiple factors including metallurgy, tool design & coating and machining conditions. Currently, there is no established method to validate lubricity on hard metal such as aerospace alloys such as Ti6Al4V, Inconel 718. A validated test method to measure lubricity is a prerequisite for development of high lubricity products for hard metals. Tapping torque test is commonly used to assess cutting fluid lubricity during the product formulation stage where average lower torque value is associated with the better lubricity. We have developed an improved tapping torque test for hard metal machining and used this method to validate increased tool life during end milling and high speed face milling operations.

5 - 5:30 pm

3310322: The Performance of Environmentally Friendly Metalworking Fluids in Drilling on Titanium Alloy

Junhui Ma, Javad Mohammadi, Olufisayo Gali, Reza Riahi, University of Windsor, Windsor, Ontario, Canada, Yan Zhou, Houghton International, Oak Ridge, TN, Jeff Larsh, Kris Januszkiewicz, Yixing Zhao, Quaker Houghton, Philadelphia, PA

The application of metalworking fluids (MWF) to the machining of titanium alloy has received increasing interest due to the severe tribological conditions occurring during this process. However, environmental concerns surrounding the disposal of metalworking fluids has led to the development of environmentally friendly metalworking fluids and additives. This study is carried out to investigate the effect of the variation of cutting speeds and feed rates at a constant metal removal rate on the performance of two environmentally friendly metalworking fluids. The average torque value and the tool wear have been measured to compare the performance of the metalworking fluids. The specific cutting energy (SCE) was also calculated. The optimum drilling conditions were noted for each MWF and the influence of the environmentally friendly additive on the performance of the MWF was observed.

5:30 - 6 pm - **Metalworking Fluids Business Meeting**

Rolling Element Bearings IV

Session Chair: Bryan Allison, SKF Aeroengine, Clymer, NY
Session Vice Chair: Behrooz Jalalahmadi, Sentient Science Corp., Charlotte, NC

2 - 2:30 pm
3329361: Experimental and Numerical Assessment of Power Loss in Aero-Engine Cylindrical Roller Bearings: M50 versus Hybrid Bearings
Rami Kerrouche, Azzedine Dadouche, Mahmoud Mamou, National Research Council Canada, Ottawa, Ontario, Canada, Salah Boukraa, University of Saad Dahlab, Blida, Algeria

Rolling-element bearings operate in the EHL regime where only a thin layer of lubricant is needed in the contact area. However, under high speeds and heavy loads; a significant amount of heat is generated due to friction. Therefore, fresh oil must to be constantly pumped into the contact to address the cooling needs and maintain acceptable operating temperatures. Another approach to lower heat generation is the use of hybrid bearings. The main objective of this study is to assess heat generation and determine temperature distribution within typical aero-engine cylindrical roller bearings operating at various speeds and radial loads. The experiments were carried out on two distinct CRBs: M50 and hybrid bearings. The latter features silicon nitride rollers (Si_3N_4) and M50 rings. A comparison of friction torque, power loss and temperature is presented and discussed in this paper. Numerical results based on thermal network approach are also presented and compared to the experimental data.

2:30 - 3 pm
3285428: Enhancement of Kinematic Hypothesis in Quasi-Static Models for Angular Contact Ball Bearings
Pradeep Gupta, PKG Inc, Clifton Park, NY

The commonly used quasi-static models for angular contact bearings are enhanced by coupling the contact mechanics and bearing kinematic analysis with frictional behavior in ball to race contacts. The points of pure rolling in the contacts, which constitute the primary inputs in the kinematic equations, are determined by minimizing the frictional dissipations based on elastohydrodynamic traction models. Such an intricate coupling between contact mechanics, bearing kinematics and lubricant behavior provides significant enhancement of simple quasi-static model for greatly improved prediction of heat generation in ball bearing contacts. The prediction so obtained is in close agreement with that obtained by truly dynamic analysis based on integration of classical differential equations of motion of bearing elements.

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

4 - 4:30 pm
3283250: Bearing Performance Analysis using an Advanced Dynamic Bearing Model
Young Kang, Matthew Wilmer, The Timken Company, North Canton, OH

In some bearing applications, rolling element bearings experience highly dynamic operating conditions created by the surrounding systems. Dynamic bearing analysis is of importance because highly accelerated bearing component motion can lead to the severe damage to the components, especially cages. To evaluate the bearing component performance and optimize the designs under the extreme transient operating conditions, it is necessary to investigate the motion and contact forces of bearing components using a three dimensional, six degree of freedom dynamic bearing model. The dynamic bearing model for this investigation was tested under various operating conditions. The calculated bearing performance results correlated well with the experimental results. This model provides an understanding of roller bearing fundamentals and guidelines for design and optimal operating conditions.

4:30 - 5 pm
3285157: Investigation of Cage Instability Mechanism with Considering Cage Design
Yuanqing Liu, Wenzhong Wang, Beijing Institute of Technology, Beijing, China

The dynamic behaviors under high-speed conditions significantly influence the performance and stability of rolling bearing. In this paper, a sophisticated dynamic model is established for angular contact ball bearing, which considers the interaction between rolling elements and raceways, cage and lubricant, and a stable and robust solution approach is developed. The effects of different cage structure on vibration, power losses and impact force are investigated. The results are verified with the experimental measurements, and the simulation results show that the guide clearance, pocket clearance and shape significantly affect the dynamic characteristics of rolling bearing. The instability mechanism of cage is explored and the strategy for optimally determining the structure of the cage is further proposed.

5 - 5:30 pm
3311744: Experimental and Numerical Investigation of Spherical Rolling Element Bearing Performance under Different Combinations of Radial and Axial Loads, Speed and Lubrication
Nikhil Londhe, John Rhodes, Caleb Chovan, Shawn Froelich, The Timken Company, Canton, OH

Rolling element bearings used in mechanical power transmissions systems experience range of different application-specific loading conditions. For reliable bearing performance prediction, common practice is to use quasi-static equilibrium solution methods. Conventional numerical solution methods such as Newton-Raphson approach can be challenging to achieve three-dimensional equilibrium solution of rolling elements with multiple roller-raceway and roller-cage contacts. This work proposes novel artificial intelligence based solution method which guarantees roller equilibrium solution for all the possible bearing operating conditions. Model prediction for torque and roller skew angle for spherical rolling element bearings are compared with experimental measurements. Data shows excellent agreement between model predictions and experimental measurements for different combinations of radial and axial loads, speed and lubrication.

5:30 - 6 pm
3282859: Investigation on the Mixed Lubrication Performance of a Coated Angular Contact Ball Bearing
Jiqiang Wu, Liqin Wang, Tingjian Wang, Harbin Institute of Technology, Harbin, China

A mixed elastohydrodynamic lubrication (EHL) model for a coated angular contact ball bearing is developed by combing the influence coefficients (ICs) with a mixed EHL model. The ICs are obtained from frequency response functions with the DC-FFT method. The proposed model is validated by

comparisons to the available published data and finite element method results. Effects of surface roughness, coating thickness, and boundary friction coefficient on the mixed EHL performance of bearing are discussed. Obtained results show that the increasing surface roughness causes bad lubrication state and increases the risk of coating failures. Coating thickness has limited influences on film thickness ratio and friction, while has significant influences on maximum surface tensile stress and interfacial shear stress. A low friction properties self-lubricated coating can effectively improve the bearing tribological performance, especially in the bad lubrication state with severe asperity contacts.

6 - 6:30 pm – Rolling Element Bearing Business Meeting

4D Columbus G

Biotribology IV

Session Chair: Angela Pitenis, University of California, Santa Barbara, CA
Session Vice Chair: Gagan Srivastava, Dow Chemical Company, Jackson, TX

2 - 2:30 pm
3325108: Biotribological Investigation of Cartilage Inspired Textured Ti-6Al-4V and PEEK Interface
Dipankar Choudhury, Evelyn Smith, Josh Goss, Min Zou, University of Arkansas, Fayetteville, AR

Star-, square-, triangular- and circular-shaped micro dimple arrays were fabricated on Ti-6Al-4V ELI substrates inspired by the porous cartilage topography. Biotribological experiments were conducted on the textured samples against polyether ether ketone (PEEK) pins under in-vitro conditions. It was found that the star-, square- and triangular-shaped micro dimple arrays reduced the coefficient of friction by 8% and eliminated the squeaking noise significantly compared to the non-dimpled sample. Notably, the star-shaped micro dimple arrays yielded a substantial wear reduction in both the Ti-6Al-4V discs and the PEEK pins. Microscopic images revealed a large amount of metallic debris transferred from the non-dimpled Ti-6Al-4V discs and embedded on the counterface pins, which is a potential risk for human body. On the other hand, only minor scratch marks were identified in the star-shaped micro dimple Ti-6Al-4V substrates and the accompanying pins after 30,000 rubbing cycles.

2:30 - 3 pm
3313747: A New Laser Textured Structure to Improve Tribocorrosion Behavior of Ti-6Al-4V ELI for Orthopedic Applications
Yidong Xu, Jiahui Qi, Mingwen Bai, Jiawei Xi, Nutter John, Mark Rainforth, University of Sheffield, Sheffield, United Kingdom
In this work, we designed a new texturing structure in Ti64 ELI based on selective laser melting (SLM). It introduced a combination of ridges and valleys that not only created space for wear debris storage, but also strengthened the surface through the formation of nanoscale acicular α’ martensite inside molten pool. In-situ micro pillar test indicated the treated surface presented 60% higher strength than the primary equiaxed structure. Tribocorrosion tests under open circuit potential (OCP) in Simulated body fluid (25%vol. bovine serum albumin solution, BSA) also showed the specific wear rate of treated specimen was dramatically improved by several orders and there was stable recovery during rubbing. TEM samples of SLM specimen from worn surface suggested that structural evolution of subsurface

presented a more uniform equiaxed nano-crystalline layer, which is responsible for the superior tribocorrosion properties.

3 - 4 pm - **Break**

4 - 4:30 pm
3276530: Experimental Biotribological Testing of Hydrogels and Articular Cartilage for Medical Engineering Applications
Florian Rummel, Anton Paar Germany GmbH, Ostfildern, Germany, Dominique Felk, Tübingen University, Tübingen, Germany, Kartik Pondicherry, Anton Paar GmbH, Graz, Austria

The complex nature of biological tribosystems requires test scenarios as close as possible to the real life conditions. The current work presents a methodology for the characterization of frictional behavior of porcine articular cartilage and polyvinyl alcohol (PVA) hydrogels, with the latter as a possible replacement material for cartilage. Extended Stribeck curve measurements and reciprocating sliding tests over a broad range of sliding speeds are carried out to measure the friction in static and dynamic friction regimes. PVA hydrogels are obtained by freeze-thaw (FT) technique (5 cycles from -20 °C to 8 °C), combined with in situ optical observation. Viscoelastic properties of the PVA hydrogel are also characterized. Special adapters are used to accommodate the soft cartilage and PVA specimen. Results from comparative tribological measurements with real cartilage and PVA are shown. The role of interacting fluids, sliding direction and limitations of the method are discussed.

4:30 - 5 pm
3285465: Comparison of the Biotribological Behaviors of an Artificial Cervical Disc with the Articulation of TC4-XPE and CoCrMo-XPE
Song Wang, Research Institute of Tsinghua University, Shenzhen, Guangdong, China

The in vitro wear behaviors of an artificial cervical disc were assessed with different material pairs using a wear simulator under 8 MC testing intervals for the articulation of TC4-XPE and CoCrMo-XPE. The surface damage pattern of the upper end plate is mainly scratches with the wear mechanism of abrasive wear for the two pairs. The major damage characteristics of the Polyethylene nucleus pulposus in TC4-XPE pair are scratch and plastic fatigue deformation with the wear mechanism of abrasive wear and adhesion wear. However, they are mainly scratches and grooves with the wear mechanism of abrasive wear in CoCrMo-XPE pair. The morphology shapes of the wear debris for the two pairs are mainly bulk, accompanied by flocculent, ribbon, lath and fracture. However, TC4-XPE also produces a large number of agglomerated debris. The particle size of TC4-XPE pair is 14.47μm while it is 31.50μm for CoCrMo-XPE pair, which reveals a difference in particle size distribution between the two pairs.

5 - 5:30 pm
3325261: Wear of Antibacterial Coatings on CoCrMo under Butterfly Motion and Dynamic Loads in a Biotribometer
Angela Maria Tortora, Deepak Halenahally Veeregowda, Ducom Instruments Europe B.V, Groningen, Netherlands

Conventional tribometers with an unidirection motion and fixed load are not suitable to investigate wear behavior of implant materials. We have designed a biotribometer that is compatible with physiological dynamic loads (250 to 400 N) and multi-direction motion (butterfly stroke), to investigate the wear behavior of antibacterial coatings on CoCrMo. The counter body was an UHMWPE pin and the

lubricant used was calf serum at 37 deg C. Friction and wear behavior of these coatings were monitored for 10^6 cycles. In general, the deformation and wear rate of UHWMPE was in the same order as that of clinical reports on UHMWPE cup penetration and wear rate. Results showed the differences between coating A and B. Coating A had increased the wear rate of UHMWPE by a factor of three compared with coating B. Furthermore, the post-test wear images showed severe scratches on the coating A compared to coating B. This study shows that biotribometer can mimic the wear behavior of implant materials.

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

4E **Columbus H**

Surface Engineering I - Additive Manufacturing

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3282152: Effect of Test Temperature on Tribological Behavior of Additively Manufactured Stellite 21 Coating on 350 Maraging Steel
Sougata Roy, Niyanth Sridharan, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, Hamed Ghaednia, Gehring Group, Farmington Hills, MI, Arup Gangopadhyay, Ford Motor Company, Novi, MI

Current study was directed to characterize a Co-based Stellite 21 coating fabricated by laser melting and study its tribological behavior at different temperatures, 23, 150, and 300^o C. Detailed microstructure study on the 3D printed samples was conducted using EBSD, XRD, SEM and EDS techniques. Friction and wear results of Stellite coated surfaces were compared against the substrate material 350 maraging steel. The Stellite coating showed significantly lowered friction than the maraging steel at all test temperatures. While the Stellite's wear loss was higher than the steel in general, it retained wear resistance better at elevated temperatures. At a higher temperature, more material transfer from the coated surface to the counterface was observed. XRD based observation revealed FCC to HCP phase transformation due to heat treatment and during reciprocating wear tests which can be considered as the key factor in retaining the wear resistance at elevated temperatures.

2:30 - 3 pm
3287053: Surface Energy and Wetting Behavior of Additive Manufactured Inconel 718 Alloy for Efficient Tribological System
Arpith Siddaiah, Pankaj Kumar, Manoranjan Misra, Pradeep Menezes, University of Nevada-Reno, Reno, NV

Additive manufacturing (AM) metallic materials are gaining significant attention due to the additive layer technology that can enable advanced lean manufacturing. Complex 3D Inconel alloy components are one such materials being developed for jet engines and aerospace applications that are manufactured using Laser powder bed fusion (LPBF) process. The advancement of the manufacturing technology has left new research gaps such as the understanding of tribological and tribocorrosive properties of the additive manufactured Inconel 718 alloys. Additionally, there is a need to understand

the surface energy behavior of these surfaces that can provide insights into the corrosion inhibition properties based on their interfacial surface energies when interacting with various harsh working environments. The present study aims to understand the tribology, tribocorrosion, and surface energy behavior of Inconel 718 alloys that are manufactured though LPBF additive manufacturing process.

3 - 4 pm – Exhibitor Appreciation Break

4 - 4:30 pm
3316642: Tribology of Surfaces with 3D Textures Fabricated via Two Photon Lithography: A Multi-Scale In-Situ Study
Mahyar Afshar Mohajer, Min Zou, University of Arkansas, Fayetteville, AR

Reducing real area of contact via surface texturing is an effective way to decrease adhesion and friction between two surfaces in dry rubbing conditions. Enabled by a high-resolution additive manufacturing technique known as Two Photon Lithography (TPL), surface textures were fabricated with precise shape, position, and sub-micron dimension control. This allows a systematic study of textures with truly 3D structures (cones) versus equivalent 2.5D structures (rods and cylinders). An in-situ multi-scale tribological study of the textures was carried out using a digital microscope with a tribometer at the macro-scale and an in-situ SEM picoindenter at the micro-scale. Cone textures not only had the lowest friction due to the lowest area of contact at the tip but also had the best durability provided by a large base. In-situ observations provided valuable insights at different scales such as the relationship between structure deformation and friction at micro-scale.

4:30 - 5 pm
3322986: Characterization and Performance of a PTFE-Based Ice-Phobic Coating
Robert Fleming, Arkansas State University, Jonesboro, AR, Giselle Toledo, German Perez Bakovic, Sam Beckford, SurfTec, Fayetteville, AR

In this study, the mechanical and chemical properties of a novel polytetrafluoroethylene (PTFE)-based ice-phobic coating for metal surfaces are characterized. The coating is composed of a PTFE layer composited with metal and ceramic nanoparticles, along with a biomimetic adhesion layer, to form a superhydrophobic surface with a topography that mimics the surface of certain frost-resistant plants. The results show that the coating both reduces the adhesive strength of accumulated ice by adhesion reduction factor of 3.3, and also prevents the nucleation of ice for surfaces with tilt angles as low as 2.8°. The coating also exhibits robust durability due to the adhesion layer, in contrast to the high wear-rates typically observed in PTFE-based materials. As a result, the coating is potentially well-suited for a variety of tribological and industrial applications, such as aircraft skin, wind turbine rotor blades, power lines, and heat exchangers.

5 - 5:30 pm
3285432: Post-Additive Manufacturing Surface Modification Technology for Controlling Microstructure and Tribological Properties of Metallic Alloys
Auezhan Amanov, Young-Sik Pyun, Sun Moon University, Asan, Republic of Korea

This paper presents the microstructural evolution and tribological properties of metallic alloys prepared by addtive manufacturing (AM). Metallic alloys were subjected to ultrasonic nanocrystal surface modification (UNSM) technology at room and high temperatures. Experimental results revealed that the UNSM technology was able to reduce the surface roughness of the as-printed state, where the surface

hardness and surface roughness were increased with increasing the temperature of UNSM technology. Moreover, the friction coefficient of the UNSM-treated metallic alloys was found to be lower, while the wear resistance was found to be higher in comparison with the as-printed alloys throughout the temperature, which are mainly attributed to the reduction in surface roughness and elimination of pores from the surface, and also due to the increase in hardness and also yield strength.

4F Columbus IJ

Lubrication Fundamentals IV

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3321896: Soot Composition and Its Impact on Wear
Nicole Doerr, Serhiy Budnyk, Adam Agocs, Marcella Frauscher, AC2T Research GmbH, Wiener Neustadt, Austria

Soot is known as major cause of increased engine wear. However, little is reported about the chemical composition of soot particles. Soot samples were gained from engine oils in passenger cars, an engine test rig, a stationary gas engine and compared with carbon black, a soot substitute used in some tribological studies and test methods. Soot particles were then characterized by transmission electron microscopy together with electron energy loss spectroscopy, among others. The elemental distribution of elements such as phosphorus and zinc was determined. Selected soot samples were re-dispersed in engine oil for triboexperiments using a SRV® tribometer with a reciprocating ball-on-disk contact configuration. Tribological evaluation based on friction and wear was compared with soot composition.

2:30 - 3 pm
3325719: A System Engineering Approach to Reduce Soot Wear
Deepak Halenahally Veeregowda, Angela Maria Tortora, Ducom Instruments Europe B.V, Groningen, Netherlands

Engine oil lubricants contaminated with carbonaceous matter like soot has increased friction and wear of engine components. Over a decade of research has helped us to identify the soot wear mechanism, the solutions to soot wear problem must be developed, however. In this study, we have proposed a solution using W-DLC coated steel balls and organic friction modifier (GMO) in the lubricants. Tests conducted in four ball tester (FBT-3) showed that GMO and W-DLC decreased the wear scar diameter and friction heat compared to lubricants without GMO and steel without W-DLC. Overall, a system like GMO based lubricant and W-DLC on steel, helps in retention of protective surface film and resist abrasive nature of soot due to increase in surface hardness.

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

4 - 4:30 pm

3291404: A New Approach to Optimize the One-Dimensional Lubricated Contact

Mhammed El Gadari, Ensam Meknes, Meknes, Morocco, Mohamed Hajjam, Pprime Institute, Poitiers, France

Since the 1960s all studies have assumed that a given film thickness h(x), i.e., the clearance geometry, provides the pressure p(x) throughout the lubricated contact by resolving the Reynolds equation. However, it is relevant to study how far is it correct to have only, one, clearance geometry for a given hydrodynamic pressure? Thus, this paper describes "a new method to generate an infinite number of the film thickness profile" that gives the same hydrodynamic pressure, by combining the direct and inverse theory. The proposed approach gives all film thickness solutions by keeping the gap inlet, and maintaining the same flow rate with a slight friction effect variation for each solution.

4:30 - 5 pm

3284937: Investigation of the Lubricant Oil Flow Pattern around Rolling Point Contacts

Hongbai Chen, Wenzhong Wang, He Liang, Beijing Institute of Technology, Beijing, China

It is widely known that the transport and distribution of lubricant oil are crucial to the oil supply to contact spots and the lubrication performance in ball bearings. In this work, the flow pattern of lubricant oil around the rolling point-contact is observed and measured in ball-on-disc experiments. Typical flow regimes and flow patterns are summarized by analyzing the oil volume distribution and the flow field. Furthermore, two-phase flow Computational Fluid Dynamics (CFD) model are established to conduct the simulation of oil flow around the contact area, which provides detailed information of the formation and transition of the flow patterns. The influences of velocity, air-oil surface tension and initial oil distribution are explored. This work will contribute to the revelation of the replenishment mechanism of lubricant oil and starvation in rolling bearings.

5 - 5:30 pm

3281895: Achieving Liquid Superlubricity under Boundary Lubrication Conditions

Qiang Ma, Arman Mohammad Khan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL

Literature studies indicate that in order to achieve liquid superlubricity (i.e., coefficient of friction < 0.01) without the benefit of a full hydrodynamic fluid film, one has to satisfy at least two conditions: passivation of the contact surfaces and formation of low-shear-strength films that can withstand high contact stresses. Our research builds on this knowledge by exploring the concept of using two surface-active, fully mixable chemicals in combination to provide liquid superlubricity, one being robust enough for load bearing while the other to provide low shear strength. The surface-active nature of these chemicals allows them to readily adsorb on and passivate surfaces. Under boundary lubrication conditions, we observed these mixtures giving rise to friction coefficients of less than 0.01, some right from the start and all within less than five minutes. These observations suggest a new strategy to achieving liquid superlubricity in engineering applications.

5:30 - 6 pm

3273970: Influence of Surface Thermal Properties on EHL Friction

Wassim Habchi, Lebanese American University, Byblos, Lebanon, Scott Bair, Georgia Institute of Technology, Atlanta, GA

This work investigates the influence of surface thermal properties on EHL friction. A TEHL finite element model is employed to investigate two distinct cases: case-hardened steel surfaces and coated surfaces with a coating of lower thermal inertia than the substrate. In the first case, it is shown that within TEHL simulations, the usually employed erroneously high thermal conductivity of non-hardened steel leads to an overestimation of friction in the thermoviscous regime. In the second case, it is shown that the lower thermal inertia of the coating leads to reduced friction in the same regime. Both cases are linked, since it is found that the reduced friction is a result of the insulating characteristics of the solid surfaces, which lead to increased film temperatures and thus reduced lubricant viscosity and frictional dissipation. In addition, in both cases, film thickness is little affected since the film temperature rise is confined to the central part of the contact.

4G Columbus KL

Materials Tribology II - Protective Thin Films & Coatings

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3286724: Polymer Coatings as "Pre-Deposited Transfer Layers" for Extreme Temperature Applications
Pixiang Lan, Jacob Meyer, ATSP Innovations, Champaign, IL, Vasilis Tsigkis, Kian Bashandeh, Andreas Polycarpou, Texas A&M University, College Station, TX

We use a tribo-pair of advanced polymer bearing coatings sliding with each other for wide temperature range (cryogenic to 400C) application: the coatings are based on aromatic thermosetting copolyesters (ATSP), which has demonstrated excellent tribological performance in a wide temperature range with tribo-pairs of steel vs. ATSP based polymer coatings in previous studies. In the current study, the concept of polymer coating sliding on polymer coating is arising from the beneficial effects of the “transfer layer”, which can efficiently reduce friction. In other words, one of the polymer coatings will work as a “pre-deposited transfer layer” that is permanently attached to the counter steel surface from the beginning of the tests, and thus this “transfer layer” can reduce the friction from the very beginning to the end of the tests.

2:30 - 3 pm
3317704: Effect of Cosmic Radiation on the Micro/Nanomechanical and Morphological Properties of Selected Hard and Soft Coatings
Andreas Polycarpou, Vasilis Tsigki, Kian Bashandeh, Texas A&M University, College Station, TX, Pixiang Lan, Jacob Meyer, ATSP Innovations, Champaign, IL

Components of space instruments will go through high cosmic radiation with long duration of missions in space exploration. Such long radiation will impose degradation. Since tribological performance under dry sliding is mainly determined by mechanical properties of bearing materials’ surfaces, it is necessary to use micro/nanoindentation to measure such properties in top layers to access degradation. In this study, advanced high-temperature bearing materials, namely ATSP-based polymer coatings, PS400 coating and ceramic composites such as BAM, were exposed to proton radiation, alpha ray, and in

combination with equivalent of 10-year radiation. Micro/nanoindentation was used to measure properties of these bearing materials from 23-300C for ATSP coatings, and 23-600C for PS400 and BAM. SEM and 3D laser microscopy were used to study morphological changes. Such measurements provide valuable insights on material changes under radiation and help to explain macro tribological response.

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

4 - 4:30 pm
3284210: Carbon Nanotube Forest as a Protective Coating for Tribological Application
Chanaka Kumara, Michael Lance, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Vertically aligned carbon nanotube (CNTs) forests were grown on stainless steel as a protective coating by catalyst-free chemical vapor deposition (CVD). The protective coating (composed of 30 µm tall and 60 nm diameter CNTs) changed the steel surface from hydrophilic to superhydrophoibic with a static contact angle of 160 ^{o} and at the sametime improved the oil wettability with static contact angle of 4.6^{o}. Tribological tests were conducted on a CNT-coated disk sliding against an M2 steel plate under an oil-starved condition. The CNT-coating demonstrated anti-scuffing properties and an ultra-low friction coefficient of 0.02, which is 80% friction reduction compared with the bare steel disk. Electron microscopy and Raman spectroscopy analysis confirmed the deposition of graphitic carbon layers on both contact surfaces, leading to ultra-low friction.

4:30 - 5 pm
3325457: Ultralow Wear Plasma Enhanced Atomic Layer Deposited Nitrides: Exploring Processing, Structure, Properties and Mechanisms
Tomas Babuska, Jewel Haik, Istiaque Chowdhury, Nicholas Strandwitz, Brandon Krick, Lehigh University, Bethlehem, PA, Mark Sowa, Veeco CNT, Waltham, MA, Alexander Kozen, University of Maryland, College Park, MD, Guosong Zeng, Lawerence Berkeley National Laboratory, Berkeley, CA, Kylie Van Meter, University of Florida, Spring Hill, FL

Recently, plasma enhanced atomic layer deposited (PEALD) multi-metal nitrides have shown superb tribological performance that have been shown to be highly influenced by the underlying substrate. PEALD nitrides are widely used on silicon MEMS/NEMS. ALD TiVN deposited on silicon has shown in some instances to reach ultralow wear rates similar to diamond like carbon (~7x10-9 mm3/Nm) while being electrically conductive. While being extremely wear resistant, lack of an oxide adhesion layer causes films to delaminate frequently. The addition of thermally grown silicon oxide and ALD alumina adhesion layers has been shown to significantly increase the adhesion strength of TiVN films to the substrate though wear rates increase which appears counterintuitive. Growth of epitaxial PEALD nitride films on c-plane sapphire has shown well adhered low wear films comparable to films grown on silicon. This indicates a change of film morphology that is dependent on the material-substrate interface.

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

Grease IV

Session Chair: Scott Crawford, Primrose Oil Co., Dallas, TX
Session Vice Chair: TBD

2 - 2:30 pm
3286489: Fully Customizable Calcium Sulfonate Greases for Optimum Performances
Guillaume Notheaux, SEQENS, Porcheville, France

Benefits of OverBased Calcium Sulfonate (OBCaS) greases are well known in the industry and their manufacturing well established. However, as conventional process involves converting an amorphous OBCaS precursor into calcite form thickener, the final grease composition cannot be fully customized due to carry-over base oil from precursor. 20-50% of this (base) oil in the precursor, which still remains in the grease. SEQENS avoids this by synthesizing OBCaS thickener under calcite form directly. This so-called “1-step process” provides flexibility in choosing base fluid. Selecting 100% of the oil part contained in the final grease during the process, enables us to offer for example: -New non-labelled, biodegradable OBCaS greases -Solutions to replace completely Group I oils in the final grease -A better behavior at cold temperature. Through technical examples, we will showcase special applicative developments we made with this 1-step process to address demand for top-notch performances.

2:30 - 3 pm
3321671: A New Preformed Polyurea Thickener for Grease
Zhe Jia, John Cuthbert, Kevin Capaldo, Bruce Hook, Andrew Larson, Dow Chemical, Freeport, TX

In this work, we develop a series of pre-formed polyurea thickeners produced through Dow proprietary process technology. This novel process can safely and reliably produce high quality polyureas in a continuous fashion. The resulting product is a finely powdered thickener agent with carefully designed chemical structure, which can be fed directly to a standard grease kettle for mixing with lubricating base stock and additive package. The resulted greases exhibit superior thickening efficiency and shear stability at elevated temperatures and shearing conditions. This preformed thickener provides a safe, easy and cost-effective way for making polyurea greases versus the conventional in-situ polyurea grease production process which involves the handling and storage of toxic raw materials.

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

4 - 4:30 pm
3332057: Novel Additive for Water Elimination in Bearing Greases
Germán Prieto, Walter Tuckart, Camila Müller, Consejo Nacional de Investigaciones Científicas y Técnicas, Bahía Blanca, Buenos Aires, Argentina, Bruno Pilotti, Andrés Ciolino, Planta Piloto de Química / UNS-CONICET, Bahía Blanca, Buenos Aires, Argentina

Water is one of the most deleterious contaminants for a lubricating system, promoting lubricant degradation and the corrosion of mechanical components. Our research group developed a novel additive for water elimination in lubricating systems that tackles this issue by a chemical route. This

additive has been added to the base oil of two commercially available bearing greases that were contaminated with different amounts of distilled water. The greases were applied to ball bearings that were tested in a disc-on-disc tribometer, rotating at 350 rpm and 1000 N of applied normal load. Both the frictional torque and vibrations were continually measured and the tests were run until spalling was detected. In addition, some tests were interrupted at fixed durations for evaluation of the racetracks for signs of corrosion or superficial damage by means of Raman spectroscopy and SEM-EDS analysis. In average, bearings with our additive shown a 425% extension in lifetime.

4:30 - 5 pm
3284306: The Impact of Viscosity of Naphthenic Oils on Different Type of Lubricating Greases
Mehdi Fathi-Najafi, Nynas AB, Nynäshamn, Sweden, Ameneh Schneider, Optimol Instruments Prueftechnik GmbH, Munich, Germany

Lubricating grease and lubricating oil behave differently in a tribological contact. Complexity in tribology of greases has been discussed through the last decades in which the effect of thickeners on the tribological performances has been the core of many publications. The aim of this study is to investigate step by step how the formulation of lithium and lithium complex greases for high load and low speed applications can be optimized by using Tribological tests. These kinds of greases are widely appreciated in the modern applications. Three straight cuts of hydrotreated naphthenic oils with various viscosities (150, 375 and 600 mm^2/s) and one additive package that consists of anti-oxidant, anti-wear and extreme pressure have been used. Besides the characterization of the greases according to the state of art, the tribological properties of all formulated greases were studies by using by both traditional tribometer (4-ball machine) and the new generation of tribometer such as SRV®5.

5 - 5:30 pm
3282417: The Effects of Addition of Zinc Stearate in Grease on the Tribological Properties of PA66-GF Composite in Contact with Carbon Steel
Takeshi Kunishima, Vincent Fridrici, Gaëtan Bouvard, Jean-Christophe Abry, Philippe Kapsa, LTDS Laboratoire de Tribologie et Dynamique des Systèmes, Lyon, France

Polyamide66 is widely used for sliding parts such as resin gear. Reinforcement fibers such as glass fibers are usually added to increase its strength and stiffness in order to satisfy the needs of downsizing and high power driving of the parts. Some parts are used under grease lubrication especially in much severer sliding conditions. However, the effects of grease and low friction additives have not been clarified yet. In this research, the temperature dependence of tribological behavior was investigated with adding zinc stearate as low friction agent in the grease. There were no effects of adding zinc stearate for tests at room temperature; however, at 80 degrees Celsius, there was a great effect of decreasing friction coefficient and improving the wear resistance of composite. The identifications of tribofilm on sliding surface were performed with SEM-EDX and XPS and the mechanisms of tribochemistry are discussed.

Tribochemistry IV - Perspectives & Applications

Session Chair: TBD
Session Vice Chair: TBD

2 - 2:30 pm
3324464: Tribochemistry – Past, Present, and Future
Stephen Hsu, George Washington University, Washington, DC

In the 1960s, ASME organized a multi-disciplinary study and it resulted in a publication entitled, "Boundary lubrication – An appraisal of world literature," published in Jan 1969. Experts from physics, chemistry, and engineering were assembled to analyze the lubrication puzzle. One of the big gaps identified was the lack of basic understanding of the chemistry as related to materials under sliding conditions. Empirical evidence seemed to suggest metals catalyzed lubrication when wear occurred. This was the beginning of Tribochemistry. Current emphasis on energy efficiency and eventually electrification creates revolutionary changes in engine design and new multilayer materials introduction at a rapid pace. Again, this creates lubrication challenges and new additive chemistry is needed again. Looking forward, electrochemistry and catalytic tribochemistry may be waiting. The talk will present highlights of key tribochemical advances and future technological challenges.

2:30 - 3 pm
3284999: Mechanochemical Wear of Silicate Glass: Beyond the Conventional Materials Removal
Hongtu He, Southwest University of Science and Technology, Mianyang, Sichuan, China, Seung Ho Hahn, Seong Kim, Pennsylvania State University, State College, PA

Understanding the friction and wear of oxide glass is of great importance for its manufacturing and operation processes. Previously, it was indicated that the friction and wear behavior of oxide glass was very sensitive to the presence of water, due to water induced mechanochemical reactions at glass interfaces can dramatically affect the wear behavior of oxide glass. However, when the wear track is formed by the water-induced mechanochemical process, the structure underneath the wear track may be affected by the shear stress along the sliding direction. With various experiments and Reax-FF MD simulations, it is indicated that when the glass surface are scratched with stainless steel ball in DI water, the subsurface densification underneath the wear track of glass can occur during the mechanochemical wear process. Therefore, not only mechanochemical wear induced material removal, the friction-induced subsurface deformation can also play important roles during the wear process of glass.

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

4 - 4:30 pm
3291335: Durable Lubricating Properties of Mussel-Inspired Polydopamine Nanoparticles as a Water-Based Additive
Guangyan Chen, Yongyong He, Jianbin Luo, State Key Laboratory of Tribology, Beijing, China, Jun Zhao, Beijing University of Chemical Technology, Beijing, China

Water lubrication has great application potential due to its advantages of cleanliness and low cost. Si_3N_4 has been widely used as the material of water-lubricated bearings because of its unique properties. However, due to the poor carrying capacity, water lubrication often causes severe wear of Si_3N_4. Lubricant additives can enhance the interface performance of Si_3N_4 under boundary lubrication. In this work, inspired by mussels, we prepared polydopamine (PDA) nanoparticles as lubricant additives. The results show that the coefficient of friction of PDA is reduced by more than 80% and 60% under an optimal concentration of 0.4 wt%, compared with that of pure water and graphene oxide. The lubrication mechanism is that the PDA nanoparticles have good film forming ability under water, and have a tribo-chemical effect with the friction pairs. Therefore, the PDA nanoparticles as lubricant additives show excellent tribological properties, and offer great potential for lubrication application.

4J Randolph 3

Condition Monitoring II

Session Chair: Daniel Walsh, Spectro Scientific, Chelmsford, MA
Session Vice Chair: Michael Plumley, U.S. Coast Guard Academy, New London, CT

2 - 2:30 pm
3271943: Determination of Total Oil Content in Metalworking Fluid Emulsions by a Fourier-Transform Infrared Method
Brittney Lagerman, BP Lubricants USA Inc, Naperville, IL

Determination of total oil content is a common concentration control used in condition monitoring of metalworking fluid emulsions. Traditionally, total oil content is determined with the use of hot concentrated acid to split the emulsion. The accuracy and precision of the traditional method is challenging. A Fourier-Transform Infrared (FTIR) test method was developed to quantify the total oil content of an emulsion without chemical addition. An emulsion is analyzed on a universal product curve to determine total oil content. Product-dependent factors applied to total oil content quantify the emulsion's concentration and oil contamination present. The developed FTIR method eliminates the risks associated with handling hot concentrated acid, eliminates the production of acid waste, reduces the total oil analysis to less than five minutes per sample and improves analysis precision to <5% relative standard deviation.

2:30 - 3 pm
3284704: Analysis of Metal Additives and Wear Metals in Lubricants by High-Resolution ICP-OES
Oliver Buettel, Siqi Sun, Analytik Jena US LLC, Upland, CA

The analysis of metals in lubricants typically serves two different purposes: Product specification monitoring as part of quality control, namely to ensure the correct contents of metal-based additives, as well as wear metals analysis for monitoring equipment conditions and early detection of failures. Metals can be present in lubricants over a wide concentration range, from traces, particularly in wear metals analysis, to percent-levels of certain additives. ICP-OES is particularly suited for this type of analysis. However, certain challenges exist to this technique, most of which are associated with analyzing organic solutions. These include plasma instabilities and carbon deposition, both of which affect precision and

long-term stability, and complex spectra from the organic solvent. This presentation discusses the challenges of lubricant analysis and points out how modern instrumentation helps overcome these challenges and produce accurate, reproducible results in the routine lab.

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

4 - 4:30 pm
3293271: Prevention of Electrostatic Charge Generation in Filtration of Low Conductive Oils by Surface Modification of Modern Filter Media
John Duchowski, Johannes Staudt, HYDAC FluidCareCenter®, Sulzbach, Saar, Germany, Stephan Leyer, University of Luxembourg, Luxembourg

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

4:30 - 5 pm
3295693: Isolation and Identification of Oxidation Products in Thermally Oxidized Group I, III, and IV Base Oils by Flow Modulated Two-Dimensional Gas Chromatography - Time of Flight Mass Spectrometry
Paul Harvath, Added Dimension Consulting, Lake Orion, MI, Christina Kelly, Joe Binkley, Lorne Fell, LECO Corporation, St. Joseph, MI, John Bucci, Bill VanBergen, Savant Group, Midland, MI

Three lubrication base oils (Group I, Group III, and Group IV) were each oxidized in the ASTM D2272 procedure (RPVOT) using a unique rotating pressure vessel with the ability to permit sampling the oil being tested during test. Samples taken at the start of a test, during the test, and at the end of a test were then analyzed by a flow-modulated, two-dimensional, gas chromatograph coupled to a time-of-flight mass spectrometer (GCxGC - TOFMS). This work shows the identification of low-level oxidation products (acids, ketones, and aldehydes), and links the timing of the oxidation product formation over the course of thermal oxidation treatment to base oil type. Thus, this experimental technique provides significantly more information than total acid number or infrared spectroscopy analysis, and demonstrates the sensitivity and robustness of flow modulation GCxGC – TOFMS for the analysis of lubricants and their responses to use.

5 - 5:30 pm
3310476: Fast and Reliable Quality Control of Fresh and In-Service Lubricants by FT-MidIR Spectrometry
Aaron Mendez, Ayalytical Instruments, Chicago, IL

Operations in the oil industry are negatively impacted by loss of efficiency of lubricating systems. Lubricants degrade overtime due to loss of viscosity, oxidation, nitration, sulfation, polar contamination

and water and soot formation. Additive depletion, lubricants properties and quality parameters can reliably and precisely be measured and displayed in real time. These evaluation tests can be easily determined with an unattended software-controlled procedure that utilizes FT IR absorption analysis and chemometric models based on customer-expandable libraries. This highly utilized technology provides trending and quantitative high-speed analysis, robust calibration, ease of use and low maintenance, offering potential for analytical developments such as Fuels and FAME contamination. Experimental results of real-world formulations properties such as TAN, TBN and viscosity are discussed and their comparison to classical methods D664, D4739 and D445 show excellent correlation.

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

4K Michigan 1

Engine and Drive Train II

Session Chair: Oluwaseyi Ogunsola, Shell Technology Center, Houston, TX
Session Vice Chair: Piotr Grzyska, Afton Chemical Corp., Richmond, VA

2 - 2:30 pm
3316461: A Study of Surface Acoustic Wave Sensors to Evaluate Fuel Dilution in Engine Oils
Seyed Mirmiran, FCA US LLC, Auburn Hills, MI, Lisa Williams, Randi Price, Spectro Scientific, Chelmsford, MA

This study will explore the process of fuel dilution mapping of a competitive engine followed by evaluation of fuel burn-off rate. By simulating engine-run conditions, fuel was infused into the oil and measured after varying durations of run-time. For each duration of the engine run, a small oil sample was taken and the fuel content, viscosity and water were evaluated. Approximately 250 oil samples were evaluated using varying methods of measurement, including % Volatility via a Muffle Furnace, Gas Chromatography and Surface Acoustic Wave (SAW) sensor technology. In the comparative analysis, SAW sensor methods have the capability to produce very reliable fuel dilution results, even when fuel concentrations are elevated. This paper will explore the varying forms of measuring fuel dilution/volatility in an engine oil and provide cost-effective solutions to gather reliable and repeatable data.

2:30 - 3 pm
3296296: Real Time Wear Mapping of a 2.0L Turbocharged Gasoline Direct Injection Engine – Part II
Peter Lee, Gregory Hansen, Carlos Sanchez, Craig Wileman, Cole Hudson, Southwest Research Institute, San Antonio, TX

A 2.0L turbocharged direct injection gasoline engine was disassembled, measured and parts irradiated to create measurable 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 work is continuation from that presented at the 2019 STLE conference.

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

4 - 4:30 pm
3323460: The Effect of Engine Oil and Lubrication System Design on Engine Friction as Demonstrated in a Motored Engine
William Anderson, Kongsheng Yang, Yun Zhang, Sha Yang, Afton Chemical, Richmond, VA, Yuelei Ding, PATAC, Shanghai, China

Motored engine friction testing is a well established methodology to demonstrate the effectiveness of lubricants to reduce the internal friction of an engine and provide fuel economy benefit. In general, the addition of friction modifiers and lower lubricant viscosity can improve motored engine friction. However, the relative effectiveness of the lubricants will depend on the design of the engine components and lubrication system. A systematic study of lubricant formulation effects in a turbocharged gasoline direct-injected (TGDi) engine has been performed to understand the overall effects of lubricant, engine and lubrication system design to lower internal engine friction. Results show that efficiency can be obtained when considering the full system.

4:30 - 5 pm
3286119: Development and Testing of a Low Viscosity, Fuel Efficient, Heavy-Duty Diesel Engine Oil for Severe Service
Allen Comfort, US Army Ground Vehicle Systems Center, Warren, MI, Steven Thrush, Oakland University, Rochester, MI

The U.S. Army has developed a low viscosity (0W-20), HDEO that could provide significant reductions in logistical burden. Advanced base oils/additives were leveraged to improve fuel efficiency, reduce oil change frequency, and minimize viscosity grades. The development program, from conception to bench/dynamometer testing, and finally field testing will be briefly reviewed. The presentation will then focus on results from a 400-hour NATO endurance test of a combat vehicle engine, tested at desert operating conditions. Oil samples were taken every 50 hours for analysis. Engine parameters such as fuel, air, oil, coolant and exhaust were instrumented to evaluate the engine's performance. Data collected was analyzed and compared to a previous test run using 15W-40. The data showed the engine performed well, without any modifications for the low viscosity oil. Used oil analysis, engine performance data, and results from the tear-down and inspection of the post-test engine will be reviewed.

5 - 5:30 pm
3269401: Efficiency and Friction Investigation on Drive Chains - Comparison between Two Different Tribological Test Rig Concepts
Dominik Meffert, Andre Becker, Bernd Sauer, Technische Universität Kaiserslautern, Kaiserslautern, Germany

Beside wear as lifetime-limiting criterion, the efficiency of chain drives gets in the focus of investigations. To achieve global emission goals the efficiency of vehicles is continuously improved. Also for high performance racing applications, the improvement of the transmission efficiency is a main key for competitiveness. At the MEGT at the Technische Universität Kaiserslautern, researches on drive chains for motorcycle transmissions and timing drives of combustion engines are done with regard to efficiency and wear of the entire drive trains. So a test rig, the chain joint tribometer, was built. That

enables to do wear and friction researches on all parts inside of a chain joint like pin and bush. This rig can represent free load curves, in particular the contact force and the relative motion of a real chain drive. Results of efficiency investigations on entire motorcycle chain drives are compared to friction measurements on the chain joint tribometer.

5:30 - 6 pm
3313981: Piston Ring on Liner Lubrication Monitoring in a Marine Diesel Engine using Ultrasound
Jack Rooke, Xiangwei Li, Rob Dwyer-Joyce, University of Sheffield, Sheffield, South Yorkshire, United Kingdom, Henry Brunskill, Peak to Peak Measurement Solutions Ltd, Sheffield, South Yorkshire, United Kingdom, Matthias Stark, WinGD, Winterthur, Switzerland

Marine diesel engines are designed based around high thermal efficiency, high fuel economy and durable performance although this leads to substantial emissions levels. One route to cut emissions is to reduce frictional losses, granting a higher operational efficiency. The interaction with the greatest frictional impact is the piston ring on cylinder liner contact.
Traditional measurements on liners required highly invasive instrumentation often requiring transducers to be mounted on the internal surface of the liner whereas with ultrasound, this oil film can be studied by instrumenting piezoelectric transducers to the outer surface of the liner. Through the variation in ultrasonic pulses detected by these transducers at a range of engine speeds and oil feed rate, parameters such as oil film thickness and ring scuffing can be quantified non-invasively. Optimisation of factors such as oil film thickness has the potential for significant reductions in emissions, wear and oil consumption.

6 - 6:30 pm
3326611: Tribological Aspects of Utilizing Wet Friction Materials in Wet Clutch Systems
Vladimir Klotchikhine, Greening Inc., Detroit, MI

Tribology of wet friction materials (WFM) covers many directions of tribology of sliding contact, and boundary/hydrodynamic regimes of lubrication. In automotive powertrain wet clutch systems (WCS), they interact with automatic transmission fluid and metal made counterface material under various contact pressures and elevated temperatures. WCS play important role on the WCS performance. WFM have different technological identity, appearance and texture, configuration and design. WFM are made as felt-like materials having many ingredients of various properties, or woven-fabric-like materials made of carbon based or other thermostable fibers, or multilayers compounds having deposited friction ingredients and making them look as sand-paper-like materials. Wet friction materials should provide steady and high friction during wet clutch engagements, opearte smoothly at shiftings, mitigate shudder phenomena, resist to fast degradation of working fluid, and reduce wear of contacting surfaces.

4L — Michigan 2

2D Materials - Materials Tribology and Nanotribology Joint Session I

Session Chair: Mohammad Vazirisereshk, University of California Merced, Merced, CA
Session Vice Chair: Nicholas Chan, University of Calgary, Calgary, New Brunswick, Canada

2 - 2:30 pm

3286531: Chemical and Physical Origins of Friction on Two-Dimensionally Flat Surface with Atomic Steps

Seong Kim, Zhe Chen, Pennsylvania State University, State College, PA, Ashlie Martini, Arash Khajeh, Mohammad R. Vaziriserehk, University of California Merced, Merced, CA

When two solid surfaces are in contact and shear each other, there is always a friction. Depending on the materials involved and the chemistry of surrounding environments, friction coefficient can be even larger than 1 or as small as <0.01. What governs such a large variance in friction coefficient? To better understand the origins of friction, we studied friction on a chemically and topographically well-defined interface – a graphite step edge – using atomic force microscopy and molecular dynamics simulations. We identified the separate contributions of physical and chemical processes to friction and showed that friction coefficient can be separated into two terms corresponding to these effects. We also found that the friction force measured with an AFM tip moving across an atomic step edge does not positively correlate with the adhesion force measured with the same tip at the same step edge. The findings provide deeper insights into the chemical and topographic origins of friction.

2:30 - 3 pm

3288831: Superlubricity of Black Phosphorus as Lubricant Additive

Hanjun Gong, Guoxin Xie, Shuai Wu, Tsinghua University, Beijing, China, Wei Wang, Xi'an University of Architecture and Technology, Xi'an, China, Ziyi Cui, Zhuzhou Electrical Locomotive Co., Zhuzhou, China

The development of new superlubricity materials will have positive impacts on energy-saving and emission reduction. Black phosphorus (BP) has recently received considerable attention. In this work, a relatively systematic work including the synthesis and characterization of BP nanomaterials, as well as their lubrication properties at different scales is introduced. The BP nanomaterials modified by sodium hydroxide as the lubricant additive in aqueous solutions could exhibit superlubricity behaviors. A lowest coefficient of friction (COF) of 0.0006 was achieved, and stable ultralow COFs could be kept in a wide range of contact pressures, sliding velocities and additive concentrations for a relatively long period. Besides, the anisotropic friction behaviors as well as the enhanced lubrication behavior of the degraded BP flakes in ambient conditions were discussed, to get deep insight into the underlying mechanism of the superlubricity behavior of BP nanomaterials at a fundamental level.

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

4 - 4:30 pm

3323166: In-Situ Reactive Formation of MoS_2 Tribofilms: Interaction with ZDDP and Dispersants

Manel Rodriguez Ripoll, Bernhard Kohlhauser, Sara Spiller, AC2T Research GmbH, Wiener Neustadt, Austria, Carmen Vladu, CEST GmbH, Wiener Neustadt, Austria

In the present work, we study the in-situ reactive formation of MoS_2 tribofilms in lubricated contacts. Instead of using Mo-containing friction modifiers or MoS_2 nanoparticles, we aim to generate MoS_2 in-situ via a tribochemical reaction between sulphur-containing extreme pressure (EP) lubricant additives and molybdenum-containing substrates. MoS_2 formation is verified using Raman spectroscopy and transmission electron microscopy (TEM). Under certain testing conditions, the in-situ tribochemical formation of MoS_2 is accompanied by the presence of oil-derived carbon tribofilms. In a second step, we address the synergies and antagonisms of the in-situ formed MoS_2 tribofilms with co-additives, such as ZDDP and succinimide dispersants. MoS_2 tribofilms can be tribochemically formed in conjunction with

ZDDP tribofilms, as evidenced using TEM. On contrary, the use of dispersants prevents MoS_2 tribofilm formation, analogous to observations done using MoS_2 nanoparticles as lubricant additives.

4:30 - 5 pm

3321456: Effect of Ni Dopant and Environment on Wear life of MoS_2 Dry Film Lubricant

Azhar Vellore, Sergio Romero Garcia, Ashlie Martini, University of California Merced, Merced, CA, Duval Johnson, Andrew Kennett, Matthew Heverly, NASA Jet Propulsion Laboratory (JPL), Pasadena, CA, Nicholas Walters, Lawrence Livermore National Laboratory, Livermore, CA

This work investigated the performance of two dry film lubricants using a ball-on-disk tribometer. The substrate material was 440C heat treated to a hardness of 45-50HRC with a surface roughness of 100-200 nm Ra. A 440C ball of hardness 60HRC was used as the counter-face material. The dry film lubricants were applied using a physical vapor deposition (PVD) process known as sputtering. One set of disks were sputtered with molybdenum disulphide (MoS_2) while the second set of disks were sputtered with a nickel doped (4-7%) MoS_2. The coating thickness in both cases was ~800 nm. The tests were conducted at peak Hertzian contact pressures varying between 300 MPa and 1.1 GPa while the sliding speeds were varied from 1 m/s to 0.1 m/s, and the tests were conducted in different atmospheric conditions. It was found that nickel improved the life of the dry film at low pressures but had little effect at high pressures.

5 - 5:30 pm

3279907: In-Plane Potential Gradient Induces Low Frictional Energy Dissipation during the Stick-Slip Sliding on the Surfaces of 2D Materials

Feng He, Xiao Yang, Guoxin Xie, Jianbin Luo, State Key Laboratory of Tribology,Tsinghua University, Beijing, China

Understanding the nanoscale friction properties of two-dimensional materials and further manipulating their friction behaviors are of great significance for the development of various micro/nano devices. Recent studies used an external out-of-plane electric field to control the interfacial friction. Nevertheless, friction increases in most cases. Here, an in-plane potential gradient has been applied for the investigation of the contribution of electric charges to friction on the surfaces of 2D materials. Experimental results show that the friction between an AFM tip and the flakes of 2D materials decreases with the application of the in-plane potential gradient, and the higher the potential gradient, the greater the friction decrease. By comparing the in-situ atomic-level stick-slip maps,it is proposed that the promoting of low friction dissipative motion during the stick-slip process owing to the presence of the potential gradient gives rise to the friction reduction.

5:30 - 6 pm

3281733: Tribo-Induced Interfacial Material Transfer of AFM Probe Assisting Superlubricity in WS_2/Graphene Heterojunction

Jisen Tian, Tsinghua University, Beijing, China

Robust superlubricity of 2D materials could be obtained by transferring graphene on the tip surface for the formation of interlayer friction of heterojunction, owing to the availability of stable interfacial incommensurate contact. Nevertheless, the material transfer mechanisms governing superlubricity via atomic force microscopy (AFM) probe are still hardly comprehended. In this work, we reported the superlubricous sliding on the WS_2/graphene heterojunction by graphene flake-transferred AFM tips to achieve a superlow friction coefficient (0.003) and a sliding velocity-independent superlubricity state. A more in-depth investigation on the frictional contact zones of probes was performed through high-

resolution transmission electron microscopy (HRTEM). The observations emphasize the universal prevailing of tribo-induced interfacial material transfer mechanism when AFM probes scanning on the surface of 2D materials.

4M **Michigan 3**

Lubrication Fundamentals Special Session: Four Decades of Patri-Cheng Average Flow Model and Future Challenges in Tribology (Invited Talks Only)

Session Chair: TBD
Session Vice Chair: TBD

As the lubrication science deepens in understanding and widens in its application to novel fields, time has come to review progress made in the past 40 years and discuss current challenges and future needs. This symposium brings together researchers in the field of lubrication to share their accomplishments in research and present their visions for future research and development.

Wednesday, May 6, 2020

5A — Columbus AB

Commercial Marketing Forum V

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8 - 8:30 am - Open Slot

8:30 - 9 am - Open Slot

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

9:30 - 10 am - **STLE Emerging Trends Report**

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

5B — Columbus CD

Environmentally Friendly Fluids I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30 am

8:30 - 9 am
3283665: EU Ecolabel for Lubricants – European Approach to Evaluate EALs
Salvatore Rea, Lanxess Corp, Perkasie, PA, Thomas Klein, Lanxess Deutschland GmbH, Mannheim, Germany

The EU Ecolabel is a voluntary scheme which covers several product groups, including lubricants. Criteria were developed to assess finished lubricants on the basis of components (base oils and additives). The criteria include environmental and health hazards, sustainability, packaging, technical performance and waste disposal. A compilation of assessed ingredients (the “Lubricant Substance Classification” or “LuSC” list) helps the formulator to develop finished lubricants which meet the criteria. The criteria restrict or limit substances and define a classification concerning persistency, bioaccumulation and aquatic toxicity and give rules how to deal with multiple additives with the same risk profile. The EU Ecolabel scheme is not only important for lubricant manufacturers that want to sell environmentally friendly lubricants in the EU. It also works as a guideline for the development of marine lubricants which meet the requirements of the US Vessel General Permit.

9 - 9:30 am
3285535: Experimental Comparison of EALs for Marine Vessel Stern Tubes
Sam Davison, University of Sheffield, Sheffield, South Yorkshire, United Kingdom

Each year 80 million litres of harmful oil leaks into the sea from marine vessel stern tubes during routine operations. The use of environmentally acceptable lubricants (EALs) in marine vessel stern tubes is a legal requirement in United States waters for ships over 79 feet. A rise in bearing failures since the adoption of EALs, has resulted in costly bearing repairs and downtime for ship operators. The performance of a selection of EALs, of varying cost, and a traditional mineral oil has been compared using a journal bearing test rig which was designed as a scale representation of a typical stern tube bearing. The lubricant films were characterised using friction, film thickness and temperature measurements, at controlled speeds and loads on the bearing that simulate real operating conditions. The methodology and results are presented to justify which EAL type is superior for this application.

9:30 - 10 am
3322919: EALs for Marine Vessel Stern Tubes – Not All Esters Are Equal
Kevin Duncan, Croda, Cowick, United Kingdom

In 2013 the US government passed the vessel general permit (VGP) legislation to control marine discharges. This covered stern tube lubricants of certain vessels and drove a change in the global market towards environmentally acceptable lubricants (EALs). Esters are ideal for use as EALs as they are: biodegradable, have minimum toxicity, and will not bioaccumulate. They had been used for numerous years in various applications under the Eco-Label system and were quickly adopted as the primary alternative to conventional stern tube lubricants based on mineral oils. 5 years on, and evidence of increased bearing wear during the first dry-dock evaluations has raised concerns about lubricant choice. This is highlighted in a resent DNV-GL publication. This talk will aim to differentiate between ester types and demonstrate the benefits of high performing esters to show that with careful selection it is possible to achieve the required environmental profile with superior lubricant performance.

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

10:30 - 11 am
3308645: Triblock Polyalkylene Glycols as Hydrolytic Stability Improvers for Esters
Martin Greaves, Dow Chemical, Horgen, Switzerland

Environmentally Acceptable Lubricants (EAL) are commonly used in equipment where there are concerns over leakage of the lubricant into the environment. The European Eco-label and the Vessel General Permit (VGP) in the USA, provide guidance on the many performance requirements of EALs. The most common chemistries used are natural and synthetic esters. Many of these offer excellent biodegradability profiles and some are derived from renewable feedstocks. In some environments esters are prone to hydrolysis. The inclusion of carefully designed polyalkylene glycols (PAG) with an ABA triblock structure consisting of blocks of polyoxyethylene (A) and polyoxypropylene (B) can improve the hydrolytic stability of natural and synthetic esters. These PAGs act as polymeric sponges for water and can significantly reduce the rate of hydrolysis. Moreover, many of these structures also offer high levels of biodegradability.

11 - 11:30 am
3285392: Group V Basestocks on the Rise – Unconventional Basestocks as One Lever for More Sustainable Lubrication
Frank Rittig, René Koschabek, Henrik Heinemann, Uwe Förster, Edith Tuznya, BASF SE, Ludwigshafen, Germany, Gene Zehler, BASF Corp, Cincinnati, OH

In the industrial gear oil market, the share of synthetic basestocks is growing. Today most formulations consist of group IV (PAO) basestocks. However, unconventional basestocks - group V basestocks, e.g. esters and polyalkylene glycols (PAGs) – grow even faster than PAOs. PAGs are known for their excellent performance with respect to cleanliness, anti-wear properties, and low coefficients of friction. But it is known that PAGs show limited compatibility with hydrocarbons. To address this, a new energy efficient basestock combining superior performance with excellent compatibility with hydrocarbons oils was developed. The paper will discuss the benefits of PAGs and the energy efficient basestock in industrial lubricant applications and demonstrate how both can contribute to potential reduction in friction and energy saving. The presentation will also provide more insights on the environmental footprint of these technologies and their impact along the entire life cycle of the lubricant.

11:30 am - 12 pm
3324278: Optimization of Bio-Derived Basefluid Properties to Improve Efficiency in Hydraulic Systems
M. Cinta Lorenzo Martin, Oyelayo Ajayi, George R Fenske, Argonne National Laboratory, Lemont, IL, Girma Biresaw, Grigor Bantchev, USDA-ARS-NCAUR-BOR, Peoria, IL

Demand for high efficiency environmentally friendly hydraulic fluids is increasing for a variety of applications, such as agricultural and marine applications. 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 ester from high oleic sunflower oil 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.

5C — Columbus EF

Rolling Element Bearings V

Session Chair: Vasilios Bakolas, Schaeffler Technologies AG & Co KG, Schweinfurt, Germany
Session Vice Chair: Trevor Slack, American Roller Bearing Company, Morganton, NC

8 - 8:30 am
3279481: Dynamics in Kinematics - Running Noise Calculation of Bearings in the Kinematic Regime
Hannes Grillenberger, Schaeffler Technologies AG & Co KG, Herzogenaurach, Bayern, Germany

Running noise is an important performance criterion of bearings. The main part of the running noise are variable compliance oscillations which are introduced in the bearing due to its varying stiffness as the rolling element set is rotating. As a continuously changing number of rolling elements supports the external load, the displacement of the bearing will change accordingly. A displacement of the bearing may also be excited by a deviation from the ideal shape. From a physical point of view there is not difference to the normal variable compliance except frequency and amplitude. In the kinematic assumption, this vibration may be simulated as a series of quasi-static load calculations. As this assumption is valid in many cases, running noise calculation may be performed very fast enabling holistic assessments of deviations not only in NVH but also life and friction. Besides a theoretical background, simulation examples and validation work will be part of the presentation.

8:30 - 9 am

3286527: A Strongly Coupled FDM – FEM Model for 2D Elastohydrodynamically Lubricated Contact

Wyatt Peterson, Thomas Russell, Farshid Sadeghi, Purdue University, Lafayette, IN, Michael Tekletsion Berhan, Ford Motor Company, Dearborn, MI

A partitioned strongly coupled fluid-solid model was developed to solve the 2D elastohydrodynamic (EHD) lubrication problem. The model passes information between a control volume finite difference discretized Reynolds equation and ABAQUS finite element (FE) software to solve for the fluid pressure and elastic deformation within heavily loaded lubricated contacts. Pressure and film thickness results obtained from the fluid-solid model were corroborated with open published results. Details of the model are presented focusing on the simultaneous solution of the Reynolds equation, load balance and the coupling of the solid ABAQUS FE with finite difference fluid (Reynolds) model. The coupled model provides the critical venue needed to investigate many important tribological phenomena such as plasticity, subsurface stress, damage, etc. The current model was used to investigate the effects of microstructure inhomogeneity, material fatigue damage and surface features on EHD lubricated contact.

9 - 9:30 am

3323754: Fatigue Spall Propagation of AISI 52100 and VIM-VAR M50 Angular-Contact Bearings

Jeremy Nickell, Lewis Rosado, Mathew Kirsch, AFRL/RQTM, Wright Patterson Air Force Base, OH

This study generated experimental data on the spall propagation process of ball bearings made of AISI 52100 and VIM-VAR M50. While there is prior work published on the rolling contact fatigue initiation of bearings, little has been published on spall propagation after initiation. Since spall growth can lead to catastrophic failure, understanding factors which influence accelerated growth rates is of high interest. This study presents the procedures and results from seeded-fault spall propagation experiments performed on 208-size (40 mm bore) ball bearings. Damage progression was monitored using accelerometers and an oil debris monitor (ODM). Both materials exhibit a rapid spall growth rate after an initial low-rate growth period as reported in previous studies. The time-to-critical growth rate was swiftest in AISI 52100 steel when compared to VIM-VAR M50, also similar to previously reported data. Microstructural analysis was conducted to infer subsurface crack propagation mechanisms.

9:30 - 10 am
3288261: Influence on Rolling Bearing Performance of Contact Temperature and Wear
Jonas Stahl, Lars-Erik Stacke, AB SKF, Goteborg, Sweden, Guillermo Morales-Espejel, SKF BV, Houten, Netherlands

The effects of kinematic sliding on rolling contact fatigue life have been discussed in many occasions. The effects of kinematic sliding of Hertzian contacts are studied from two different standpoints: (1) the combination of sliding speed and contact pressure giving rise to seizure, that is, high instantaneous contact temperatures leading to film collapse and adhesive wear, and (2) other possible effects of sliding in heavily loaded lubricated contacts, as the concurrent damage mechanism caused by wear and rolling contact fatigue. The bearing damage phenomena are studied in a multibody simulation software. This enables accurate input data to the physical contact models based on the operating conditions the bearings are exposed to. It regards both mechanical conditions, like contact pressures, and thermal conditions giving individual body and contact temperature variations. Simulations are compared with experimental data for cases where seizure and wear failures have been observed.

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

10:30 - 11 am
3286447: The Rating Life of Needle Roller Bearings in Universal Joints
Georg Breslau, Institute of Machine Elements and Machine Design (Technische Universitaet Dresden), Dresden, Germany

Almost 20 years ago, HOUPERT developed a calculation approach for oscillating bearing motion based on the LUNDBERG/PALMGREN model. It takes into account the reduced number of cycles on the inner ring within the load zone and an equivalent load for each position on the raceway. However, during an intensive and thorough revision of the HOUPERT model, an inconsistency was found which leads to an overestimation of the rating life for load distributions with $\varepsilon \leq 1$.This paper presents a corrected and extended model, which is applied using the example of the needle cup bearing on a universal joint. Different life modification factors apply to consider the oscillating motion of the outer and inner ring. For the special application in a universal joint, the determination of an equivalent load over the oscillation angle and the subsequent conversion into a life modification factor is described. The common life modification coefficient (a_{osz}) is related the nominal rating life.

11 - 11:30 am
3316320: Service Life in Rolling Element Bearings
Bruno Mevel, NTN-SNR, Annecy, France

This article is based on the fact that the rolling element bearing technology has reached a high level of reliability. In automotive, industry and aeronautics, the rolling element bearings last for a long time if the running conditions remain normal or standard. . The current model to calculate the rating life of bearing was built at a time where the fatigue of the material and the wear dominate the reliability. The steel used in rolling element bearing has reached a high level of cleanliness. This principal causes that less and less fatigue failure in bearing life is noticeable. When a phenomenon is diminishing, it implies that other failure modes are likely in rolling element bearings. Zaretski has published an interesting paper on this subject. In this paper, some analysis of bearing failure is reported, and the material fatigue life represents less than 10\% of the failures that were noticeable. In this paper, we will expose how this kind of results can be used in a modern manner

Fluid Film Bearings I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3286293: Drag Power Loss Correlations for Flooded Tilting Pad Journal Bearings – A Predictive Model and its Experimental Verification
Manish Thorat, Wei Li, Elliott Group, Jeannette, PA, Luis San Andres, Texas A&M University, College Station, TX, Hardik Jani, Honeywell, Mt. Laurel, NJ, Hussain Kaizar, Kelm Engineering, Friendswood, TX

This paper presents a prediction method to estimate power loss in a pressurized lubricant housing or flooded design Tilting Pad Journal Bearing (TPJB). A model sensitivity analysis quantifies the influence of bearing design geometry and operational parameters on the predicted power loss for a five pad TPJB. This predicted sensitivity is experimentally verified based on mechanical power loss measurements using an in-line torquemeter. The experimental data provides a mean to tune the model. For faster evaluation, a parametric model follows from the predictive model and its predictions are further compared to the test data while deviations are noted. The paper also provides a unique comparison of drag power loss estimates based on recorded flow rates and discharge oil temperature measurements, a common practice, against those derived directly from the torque meter. The estimates are (on average) 18 % lower, hence pointing to a flagrant limitation of the conventional practice.

8:30 - 9 am
3322397: Performance Evaluation of Different Configurations of Hydrostatic Grinding Spindles
Hua-Chih Huang, Wei-Yang Chen, National Kaohsiung University of Science and Technology, Kaohsiung City , Taiwan

This paper evaluates three configurations of hydrostatic spindles for grinding machines. Three configurations of hydrostatic spindles have different bearing arrangements, which are two hydrostatic journal bearings with hydrostatic thrust bearing in the rear side (type 1),two hydrostatic journal bearing with hydrostatic thrust bearing in between (type 2), and two hydrostatic conical bearings (type 3). These three hydrostatic spindles are designed at four fixed condition, which are the same bearing span, journal bearing diameter, housing diameter and housing length. Three hydroatatic spindles are evaluated under two performance indecies, namely, the overall thermal deformation at rotating speed of 1000 rpm, the total structural deformation of spindle nose under maximum cutting force. Ansys Fluent is used to analyze their perfromance. For these two performance indecies, hydrostatic spindle type 1 has the best performance, and and hydrostatic spindle type 3 has the worst performance.

9 - 9:30 am
3319883: Numerical and Experimental Analysis of Starvation for a Tilting Pad Journal Bearing
Scan DeCamillo, Kingsbury, Inc., Philadelphia, PA, Cori Watson-Kassa, University of Virginia, Charlottesville, VA

A series of journal bearing tests were conducted to acquire more detailed information on the behavior of individual pads in a tilting pad journal bearing and how the individual behavior may affect the performance and dynamic characteristics of the bearing. Unique information were acquired during the course of the tests. Two results are particularly interesting. First, the oil films tend to cavitate at the axial edges rather than starve the leading edge (a typical assumption in direct lube bearing code development). Second is a tendency for an increase in temperature towards the axial edge rather than the centerline of the pad surface. The results seemed contradictory until a recently published computational fluid dynamics (CFD) analysis of an elliptical bearing predicted similar behavior. The authors decided to collaborate on applying CFD multiphase fluid-structure interaction (FSI), conducted in ANSYS CFX, to the experimental results. Results are presented in this paper.

9:30 - 10 am
3286458: Computer Experimental Design for Tribological Optimization
Nenzi Wang, Yu-Wen Chen, Chang Gung University, Tao-Yuan, Taiwan

The objectives of this study are to develop an effective data sampling technique for selecting initial designs in an air bearing optimization study as well as to propose a stopping criterion for the design procedure. A multifactor externally pressurized air pad is used to illustrate the experimental design of the optimization analysis. The particle swarm optimization method is selected as the global search scheme for its easy implementation and high efficiency. The design goal is to optimize a weighted sum of several performance factors (dimensionless bearing stiffness, load capacity, and supply air consumption) of the bearing. It can be seen that a good sampling technique can speed up the search of the optimum solution and a properly selected stopping criterion can minimize the search effort without sacrifice the solution accuracy in tribological optimization.

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

10:30 - 11 am
3285921: Experimental Response of a Rotor Supported on Simple Rigid Surface Gas Bearings
Keun Ryu, Youngseok Song, Hanyang University, Seoul, Republic of Korea

Gas bearings in rotating machinery provide notable system level benefits, such as compact size, light weight, and extended speed limit and life cycle compared to rolling element bearings. The current work reports measurements of the rotordynamic response and drag torque for a small rigid rotor driven by a high speed automotive turbocharger up to 150 krpm. The test rig consists of a rotor, 7 mm in journal diameter, 13 mm in thrust runner diameter, 65 mm in overall length, and 26 g in mass, supported on simple and inexpensive gas journal and thrust bearings. The measurements show that the test rotor-gas bearing system is stable without noticeable subsynchronous instability. Rotordynamic predictions for imbalance response amplitudes and rigid-mode damped natural frequencies agree very well with the test data. The present experiments demonstrate reliability and rotordynamic characteristics of simple rigid surface gas bearings for compact high-speed rotating machinery.

11 - 11:30 am
3323521: On the Significance of Bearing Configurations and Imbalances on the Dynamics of Small Automotive Turbochargers: A Lesson from Comprehensive Experiments and Predictions
Keun Ryu, Kyuman Kim, Hanyang University, Seoul, Republic of Korea

Automotive turbochargers require low production cost, reliable, durable, and predictable bearing systems over a wide range of rotor speeds at extreme operating conditions. The recent trend in automotive industry demands more fuel-efficient and more compact turbocharger systems with improved transient response performance. The present work details progress on the measurements and predictions of rotor-bearing systems in small automotive turbochargers. Furthermore, the work focuses on the significance of bearing configurations and imbalances on the dynamics of turbochargers from extensive experiments and predictions. In the current study, the test turbochargers are supported by one of three bearing types: fully floating ring bearings, semi-floating ring bearings, or ball bearings. Predictions show the importance of the actual rotor imbalance distribution, bearing/damper clearance, and oil supply conditions in the design and understanding of dynamics of turbocharger rotor-bearing systems.

11:30 am - 12 pm
3326426: Experimental and Numerical Analysis of a Connecting Rod Bearing
Aurelian Fatu, Mihail Radoi, Yann Henry, Institut Pprime, Angouleme, France

Over the past 20 to 30 years, the development of new generations of internal combustion engines has led to numerous experimental and numerical studies focused on the analysis of engine journal bearings. Many of these bearings must support a dynamic load and operate under severe conditions in terms of load, temperature and rotational speed. As a result, it is often difficult to properly instrument the bearings and obtain actual measurements of lubrication parameters. This makes it difficult to compare numerical predictions with experimental measurements. This study presents experimental results obtained on a test bench designed to test real connecting rod bearings under conditions as close as possible to real lubrication conditions. The tests performed on the bench are then numerically reproduced using a TEHD software. Thus, experimental measurements in terms of temperature, leakage rate and power loss are compared with numerical predictions obtained using different modelling strategies.

5E — Columbus H

Tribology of Biomaterials - Biotribology and Materials Tribology Joint Session I

Session Chair: George Degen, University of California, Santa Barbara, Goleta, CA
Session Vice Chair: Kylie Van Meter, University of Florida, Spring Hill, FL

8 - 8:30 am
3324450: Mechanisms of Aqueous Gel Adhesion
George Degen, Allison Chau, Angela Pitenis, University of California, Santa Barbara, Goleta, CA

Adhesion of aqueous gels is important for many natural and synthetic systems. For example, adhesion involving mucous membranes (mucoadhesion) is relevant to biomedical application including drug delivery and medical implants. Hydrogels are convenient models for such biological surfaces, and adhesion and friction of hydrogels has been widely studied. However, molecular mechanisms of hydrogel adhesion are not fully understood. Recent studies show that hydrogel surfaces are fundamentally different from the bulk, and that surface layers may influence gel properties including

adhesion. Here, we present hydrogel adhesion measurements made using a surface forces apparatus (SFA) to assess the contributions of physical bonding, poroelasticity, and polymer chain interdigitation on adhesion in symmetric gemini (gel-gel) and asymmetric (gel-glass) configurations. The results yield a better understanding of rate-dependent gel adhesion and suggest new design rules for hydrogel materials.

8:30 - 9 am
3325549: Microstructural Contribution to Hydrogel Frictional Dissipation
Tooba Shoaib, Paige C. Prendergast, Justin Silberman, Rosa Espinosa-Marzal, University of Illinois at Urbana-Champaign, Urbana, IL

Hydrogels are often used as model systems to investigate some mechanisms underlying biolubrication. This work aims to understand the relation between hydrogels' lubrication mechanisms, frictional characteristics and their microstructure. To achieve this, the response to friction and compression of hydrogels with modulated microstructure has been studied over a wide range of loading conditions by combining atomic force microscopy and an extended surface forces apparatus. Based on the viscoelastic behavior of hydrogels, we model hydrogel friction as the combination of viscous dissipation and the energy dissipated through the rupture of the transient adhesive bridges across the interface, while accounting for hydrogel's time-dependent deformation. Our experimental studies provide insight into the influence of the microstructure on the various frictional dissipation mechanisms and pave ways for the design of hydrogels as replacement biomaterials.

9 - 9:30 am
3324847: Speed-Independent Friction with Yield Stress Gradients
Eric McGhee, W. Gregory Sawyer, University of Florida, Gainesville, FL

Aqueous lubrication of the eye-lid and the cornea during the blink yields an extraordinarily low, and nearly speed-independent, shear stress. This near constant shear stress is the opposite of most viscous fluid lubricated surfaces which transition through the various lubrication regimes - boundary, mixed, etc. A potential cause of this constant shear stress during sliding is if gel-forming mucins function as a yield stress fluid where their weakly bound crosslinks function as somewhat of a mechanical fuse. Concentration gradients of these mucins in the tear film can then form dynamic slip planes which respond to the shear stress produced in a blink. Here, we present a simple model for such a phenomenon and speculate as to the existence of an as yet unmeasured tear-film mucin concentration-gradient.

9:30 - 10 am
3325050: Fragile Objects and Interfaces
Angela Pitenis, George Degen, Allison Chau, University of California, Santa Barbara, Goleta, CA

Energy-dissipation mechanisms abound in nature. In natural sliding systems, interfaces are often characterized as "fragile" or "weak" yet they are uniquely capable of mitigating shear stresses, reducing contact pressures, and sustaining adequate lubrication over a wide range of engineeering-like challenges where engineered materials have failed. Efforts to characterize these natural interfaces have been limited by their high water content, low polymer concentration, high sample variability, low sample volume, and tendency to age and degrade. Model materials, such as high water content aqueous gels, offer highly tunable and controllable routes towards understanding complex interfacial phenomena and may serve to bridge microscale structure to macroscale properties, such as friction and adhesion.

Ongoing research is dedicated to fully vizualizing the hierarchical structures of these fragile objects and interfaces through advanced materials characterization techniques.

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

10:30 - 11 am
3315962: A Numerical Modeling Framework for Lubrication in Compliant Contacts
Abdullah Azam, Abdel Dorgham, Micheal Bryant, Mark Wilson, Nikil Kapur, Anne Neville, University of Leeds, Leeds, United Kingdom

The lubrication of compliant materials poses several challenges. The key issue is that most solvers are unable to handle the large deformation and achieving convergence becomes very difficult. An efficient numerical procedure is proposed to solve the compliant contact lubrication problems using the conventional Boussinesq integral based formulations for deformation. An implicit scheme is utilized to ensure stable numerical solutions. The model produced stable and accurate output for a range of materials with varying elastic moduli at loads ranging from mN to N and pressures ranging from kPa to Pa. The predictions from the current method show very good qualitative and quantitative agreement against published experimental and numerical results. The proposed numerical framework can be easily automated using advanced CFD solvers in commercial packages.

11 - 11:30 am
3324615: Impact of Metal Release on Chondrocytes Due to Biotribocorrosion in CoCrMo Sliding Against Articular Cartilage
Manel Rodriguez Ripoll, Bojana Simlinger, Friedrich Franek, AC2T Research GmbH, Wiener Neustadt, Austria, Christoph Bauer, Christoph Stotter, Thomas Klestil, Stefan Nehrer, Danube University Krems, Faculty of Health and Medicine, Krems, Austria

Partial knee replacement and hemiarthroplasty are some orthopedic procedures resulting in a metal on cartilage interface. Our aim is to assess the role of biotribocorrosion on the metal-cartilage interface with an emphasis on metal release during sliding contact. Bovine osteochondral samples were investigated under reciprocating sliding against CoCrMo using an electrochemical cell 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 leads to Co release. Mass spectrometry analyses revealed that Co was bound in form of organometallic complexes with amino acids. The cytotoxicity of the released metal was assess using human articular chondrocyte 2D cultures. The results show a decrease in metabolic activity and expression of chondrocyte-specific genes by metal ions, which also caused a release of proinflammatory cytokines.

11:30 am - 12 pm
3324098: Mechanical and Biological Responses of Cartilage to Tribological Challenge- a 3-Factor Central Composite Design Analysis
Catherine Yuh, Benjamin Witt, Spencer Fullam, Susanna Chubinskaya, Markus Wimmer, Rush University, Chicago, IL, Suzanne Maher, Hospital for Special Surgery, New York City, NY

Knee articular cartilage experiences mechanical stresses from loading and sliding during joint articulation. We assessed the effects of kinematic/kinetic variables that drive changes in cartilage stiffness, cell viability, and tissue damage. Combinations of load, sliding speed (SS), and migrating contact frequency (MCF), determined using a CCD, were applied to each explant with a biotribometer.

Microindentation was performed within the contact/non-contact regions of the explant, before/after biotribometer testing. Explants were partitioned to perform cell viability assay, histology, and RT-qPCR. Overall, tissue stiffness increased following biotribometer testing. Load, all interaction terms, and $(SS)^2$ showed significant effects on tissue stiffening. Cell viability was significantly affected by load and $(MCF)^2$. Histologically, the tissue showed minimal damage. RT-qPCR may suggest downstream effects that are currently being evaluated. Thus, factors act on both the tissue and cell level.

5F Columbus IJ

Lubrication Fundamentals V

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3283757: Sliding Tribological Performance of the Proppant in Shale Rock Fractures Under Water-Based Fracturing Fluid
Huijie Zhang, Shuhai Liu, Huaping Xiao, China University of Petroleum-Beijing, Beijing, China

The tribological properties of proppant particle sliding on shale rock determine the shale gas production. This work focuses on investigating the impacts of sliding speed on the coefficient of friction (COF) and wear of the silica ball-shale rock contact, which was lubricated by water or different types of polyacrylamide (PAM) aqueous or brine solution. Experimental results show that both boundary and mixed lubrication occur under specific speed and load. COF and wear depth of shale rock under water are higher than those under PAM solution due to superior lubrication of PAM. COF and wear of shale rock under PAM brine solution are more serious, attributed to the corrosion of shale rock and adverse effect on lubrication of PAM by brine.

8:30 - 9 am
3323479: Rheology and Wear Reduction Characteristics of Base Oils in Pure Sliding Point Contacts
Sipho Masilela, Philip de Vaal, University of Pretoria, Pretoria, Gauteng, South Africa

Gas to liquid technology (GTL) produces a low cost base oil which promises to achieve a balance between superior lubrication and low environmental impact. Furthermore, the drive towards the use of low viscosity base oils for reduced friction has become apparent. It has, therefor, become of utmost interest to determine and characterize the lubricating characteristics of the GTL base oil. This work demonstrates the lubricating characteristics of a GTL base oil, in comparison with conventional base oils comprising of a solvent refined mineral oil (GI) and a synthetic (oligomerized) polyalphaolefin base oil (PAO). Viscosities range from 4 to 8 cSt at 100 ^{o}C. The comparative analysis was done using composition, rheology, coefficient of friction, wear mechanisms and the wear volume generated using an SRV4$^{®}$ tribometer with a ball-on-flat configuration under a constant speed of 0.2 m.s^{-1}, load of 150 N and temperatures 40 – 120 ^{o}C.

9 - 9:30 am

3323514: The Effect of Temperature on the Friction and Wear Behavior of Fuel Oils under Oxygen and Nitrogen (Inert) Atmosphere

Trinity Thobejane, Philip de Vaal, University of Pretoria, Pretoria, Gauteng, South Africa

Fuel oils are passed through pumps, filters, nozzles and other equipment before they reach the burner section. Currently, several users of fuel oils are experiencing problems such as blockages in the fuel oil filters and injector nozzles, increased wear and failures of pumps. In an attempt to understand the role of oxygen as a contributing cause of the problems experienced with fuel oils at different temperatures, lubricity tests were performed with a selection of fuel oil samples on the HFRR lubricity test rig following method ISO 12156-1. Two atmospheres (i.e. oxygen and nitrogen (inert) were used). Three unique fuel oil samples were selected. These fuel oils were a light cycle oil (LFO), a medium wax-blend oil (MFO) and a crude-derived heavy fuel oil (HFO). Results for the LFO-, MFO- and HFO-samples showed that temperature and atmospheric conditions contributed to the friction and wear behaviour, but that composition of each of these fuel oils played a more significant role.

9:30 - 10 am

3324555: Steady State Friction of Metals: Progress in Prediction

Stephen Hsu, George Washington University, Washington, DC

Friction is a transient phenomenon; its instantaneous magnitude depends on many parameters: surface roughness, load, speed (vibration), alignment, duty cycle, and material properties, etc. It is also intertwined with wear, as a part of the energy dissipation process. Today, engineering friction emerges as the key issue in improve energy efficiency and reduce carbon emission. Yet today, we still do not have a good way to predict friction. If we define steady state friction as the net resistance to motion of one surface over another, under lubricated conditions, what are the main causes of friction going beyond the intrinsic sliding friction without penetration? Plowing would be the main cause for high friction. This presentation will summarize our current understanding and describe our attempt towards a predictive process.

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

10:30 - 11 am

3323522: Thermo-Kinetic Behavior and Lubricity of Molecularly Thin Lubricant in Head-Disk Interface

Changdong Yeo, Shahriar Rahman, Jingan Song, Texas Tech University, Lubbock, TX

Hard disk drive (HDD) is required to have smaller head-media-spacing (HMS) for higher data capacity and to operate at elevated temperature especially under heat-assisted-magnetic-recording (HAMR) technology. With these trends of HDD technology, the design of molecularly thin lubricant in head-disk-interface (HDI) is of great importance to satisfy the reliability. In this study, we investigate the thermo-kinetic material behaviors and lubricity of three different lubricant designs, i.e., Z-Tetraol, D4OH, and ZTMD, through molecular dynamics (MD) simulations. Under the controlled sliding speed and temperature, the lubricant transfer (or lubricant pick-up) and frictional force are quantitatively measured with respect to the lubricant film thickness, whose results are compared among the three lubricant designs. The research outcome would provide more physical insight into the tribological behaviors of lubricants in HDI, which accordingly can deliver its key design rules for future HDDs.

11 - 11:30 am
3325184: Development of Lubricity Test Methods to Investigate Aging of Lubricants
Deepak Halenahally Veeregowda, Fabio Alemanno, Giulia Chiarioni, Ducom Instruments Europe B.V, Groningen, Netherlands

Field tests used to determine the aging of lubricants is expensive. Furthermore, it offers limited information on friction behavior of lubricants. Here, we have accelerated the aging of lubricants in the lab by using KRL shear stability tester, that is equipped with friction, temperature and load sensors. Aging of lubricants was confirmed by determining the deterioration of anti-wear additives (four ball tester, FBT-3), shear stability of polymers (viscometer) and specific functional groups in the lubricants (IR spectroscopy). Results indicated that the friction was sensitive to changes in lubricant temperature. Friction decreased due to increase in lubricant temperature, this was attributed to shear thinning. Lubricants with mineral base oil showed a significant viscosity loss compared to synthetic base oil, also confimed by IR spectroscopy. Furthermore, lubricants with synthetic base oil showed significant deterioration of antiwear additives compared to mineral base oil.

11:30 am - 12 pm
3323616: Using Bespoke Friction Rigs to Develop the Next Generation of Slideway Technologies
Ralph Lumby, Afton Chemical Ltd, Bracknell, United Kingdom

Slideway/guideway fluids are designed to lower friction and avoid stick slip during the operation of manufacturing machines in order to achieve accurate positioning and movement of a tool relative to a work piece. Afton Chemical has developed a series of bespoke friction tests to facilitate the development of our new generation of slideway additive packages. Our Darmstadt rig, which has been developed from a slideway machine in a workshop, can be used to accurately compare the friction performance of different slideway fluids at a range of speeds. We have also designed and built our own stick slip rig which allows us to accurately compare the stick slip ratios of different slideway fluids. This presentation will explore Afton's slideway friction rig capability and how we've used it to design and develop our latest slideway technologies.

5G — Columbus KL

Materials Tribology III - Hard to Soft: Fluoropolymer Composites & Hydrogels

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Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3319935: A Comparative Study on the Structure- Process Relationship of PTFE- PEEK Composites
Kasey Campbell, Cooper Atkinson, Tomas Babuska, Brantley Balsamo, Christopher Junk, Brandon Krick, Lehigh University, Bethlehem, PA, Mark Sidebottom, Miami University, Oxford, OH

The tribological behavior of polytetrafluoroethylene (PTFE)- based composites has been studied extensively and shown that compositing PTFE with fillers such as alumina and polyether ether ketone (PEEK) can improve the composite's wear rate up to four orders of magnitude. This improvement is

attributed to tribochemical reactions facilitated by radical initiation that aid in the formation of coordinated complexes between the polymer/running film and steel countersample, which is dependent on sliding environment. Another critical parameter in understanding the ultralow wear of these systems is processing condition; however it has been understudied for PTFE- PEEK composites. These composites can yield wear results that differ by almost three orders of magnitude ($K \sim 10^{-6}$-10^{-9} mm^3/Nm). The processing-structure-property relationships will be examined to probe if structural manipulation via processing can explain the wear differences exhibited by these composites.

8:30 - 9 am
3289374: Maximizing the Impact of Nanofillers on PTFE Wear Resistance
Istiaque Alam, Aman Garodia, David Burris, University of Delaware, Newark, DE

Certain alumina filler reliably reduces wear of polytetrafluoroethylene (PTFE) by 99.9%. What makes these microscale aggregates of nanofillers unique is their ability to survive processing and subsequently disrupt sub-surface damage in the nanocomposite while promoting favorable tribochemical reactions after disbanding at the sliding interface. This strength, however, reveals a limitation: any particle performing two functions excels at neither. This paper uses a hybrid (PEEK microfiller + alumina nanofiller) approach to separate these functions and isolate the minimum effective dose of nanofillers. Outsourcing the function of mechanical reinforcement to the PEEK revealed that the optimal nanofiller content is at least 10X below the 2-15 wt% optima reported in virtually all other polymer nanocomposite wear studies; hybrid design appears necessary to extract the full benefit of nanofillers in this context.

9 - 9:30 am
3323503: Effect of Filler and Countersurface Mechanical Properties on Wear of Fluoropolymer Composites
Mark Sidebottom, Sifat Ullah, Miami University, Oxford, OH, Nathan Heckman, Brad Boyce, Sandia National Laboratory, Albuquerque, NM, Tomas Babuska, Brandon Krick, Lehigh University, Bethlehem, PA

Certain Fluoropolymer (PTFE, PFA) –alumina (Al_2O_3) particle composite materials have exhibited a 10,000x improvement in wear rate compared to unfilled fluoropolymers. Protective tribofilms that minimize damage to the fluoropolymer composite and counterface during sliding have been identified as key factor in promoting this improvement. In this work, the tribological properties of a wide range of PTFE composite materials were tested against countersurface materials with differing mechanical properties (i.e. hardness, modulus). Post experiment characterization techniques (IR spectroscopy, profilometry, nanoindentation) of the worn surface of the countersurface and worn fluoropolymer composite surface were made to understand the structure and composition the tribofilms. From these results, the effect of the mechanical properties of the filler and countersurface have on the formation of tribofilms and wear behavior of fluoropolymer composite systems may be determined.

9:30 - 10 am
3324515: Fluoropolymer Composites: Effect of Counterface and Filler Material Properties on Wear Performance
Sifat Ullah, Mark Sidebottom, Alex Rhodes, Jan Gabski, Miami University, Oxford, OH

Certain fluoropolymer composites exhibit 10-100x lower wear rates than other fluoropolymers composites. These composites are called ultralow wear composites. The mechanism for this ultralow wear has been studied over the past 15 years with certain combinations of fluoropolymer composites

and metal-countersurfaces. This ultralow wear mechanism has been attributed to/affected by particle properties (e.g. porosity, size, etc.), robust tribofilms, environment, and surface roughness. However, different testing pairs of fluoropolymer composites and metal countersurfaces may reveal different wear behavior. Therefore, combinations of different fluoropolymer matrices, filler particles and/or counter surface materials will be evaluated using linear reciprocating tribometers. Characterization methods (e.g. infrared spectroscopy, optical profiling, nano-indentation etc.) will be used to evaluate different properties of the tribofilms and constituent materials.

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

10:30 - 11 am
3323565: Hysteretic Lubrication of Polyacrylamide Hydrogels Caused by Transient Water Film Formation
Jiho Kim, Alison Dunn, University of Illinois at Urbana-Champaign, Urbana, IL

Hydrogels exhibit unique lubrication behaviors, including lubrication hysteresis found in tribo-rheometry measurements. In this study, we visualized the lubrication behavior of a hydrogel under continuous contact using Confocal Laser Scanning Microscopy (CLSM). We designed a sliding tester on a stage of an inverted microscope and conducted sliding experiments at different sliding speeds. After a sliding at higher speeds, greater amount of water penetration was captured and squeeze out flow occurred over time, which showed that the lubrication is speed-dependent as well as time-dependent. A hydrogel lubrication model that describes the hysteresis was previously developed using a complex fluid model which confirms the polymer/fluid interaction in the lubrication. The model was improved to incorporate the water penetration and squeeze behavior at the interface. This work demonstrates the buildup of a water film in a hydrogel interface similar to recent hypotheses of cartilage lubrication.

11 - 11:30 am
3322046: Compositional Dependence of Hydrogel Wear Mechanisms under Mild Abrasion
Shabnam Bonyadi, Alison Dunn, University of Illinois at Urbana-Champaign, Urbana, IL

Hydrogels are polymer networks that retain large volumes of water and develop a surface layer that has a lower polymer density than the bulk. In this work, a sandpaper covered probe attached to a microtribometer with a reciprocating stage was used to wear 7.5% polyacrylamide hydrogels, and the wear scars were analyzed after a predetermined number of passes by the probe. We evaluated the wear rates as a function of wear cycles, and found that the wear mechanism of hydrogels evolves with the wear depth despite consistent wear parameters. To more directly compare the effect of polymer density to wear behavior, polyacrylamide hydrogels with varying concentrations of polymer and crosslinker were worn using the same setup. We found that the degree of microplowing changed with the composition of the hydrogel. This work is the beginning of developing more accurate predictions of the wear behavior of biphasic materials.

11:30 am - 12 pm
3285834: Linking Energy Loss in Soft Adhesion to Surface Roughness
Tevis Jacobs, Abhijeet Gujrati, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Siddhesh Dalvi, Ali Dhinojwala, University of Akron, Akron, OH, Lars Pastewka, University of Freiburg, Freiburg, Germany

A mechanistic understanding of adhesion in soft materials is critical in transportation, biomaterials, and soft robotics. On rough surfaces, the apparent work of adhesion coming into contact is lower than the

intrinsic value for the materials, and there is adhesion hysteresis during separation. Still lacking is a quantitative experimentally validated link between adhesion and surface topography. Here, we used in situ measurements of contact size to investigate the adhesion behavior of soft elastic hemispheres on four different nanodiamond substrates with topography characterized down to the Ångström-scale. The results show that the reduction in apparent work of adhesion is equal to the energy required to achieve conformal contact. Further, the energy loss during contact is equal to the product of intrinsic work of adhesion and true contact area. These findings reveal the mechanism that links adhesion hysteresis to roughness, rather than viscoelastic dissipation.

5H Randolph 1

2D Materials - Materials Tribology and Nanotribology Joint Session II

Session Chair: Philip Egberts, University of Calgary, Calgary, Alberta, Canada
Session Vice Chair: Arnab Bhattacharjee, University of Delaware, Newark, DE

8 - 8:30 am
3286667: Hydrodynamic Slip and Frictional Characteristics of the Graphene-Liquid Interface
Rosa Espinosa-Marzal, Gus Greenwood, Jin Myung Kim, SungWoo Nam, University of Illinois at Urbana-Champaign, Urbana, IL

Macroscale fluid dynamics generally assumes a no-slip boundary condition for fluids experiencing a shear stress while in contact with a solid. In boundary lubrication, the fluid film thickness is reduced to a few nanometers. Here, the no slip assumption is often not valid and the fluid velocity at the interface is non-zero. The slip length depends on the wettability of the fluid on the solid. This work investigates the effects of graphene's substrate on the slip length of various liquids in contact with graphene to systematically measure dynamic forces. The results provide evidence that the slip length is tunable and related to the molecular mobility of liquids in contact with graphene. This is then compared to the frictional characteristics of the interface. The conclusions inferred from this study with regard to the tribological properties of this interface will help design systems for boundary lubrication that leverage the synergy between graphene and a fluid.

8:30 - 9 am
3320097: Novel Solid Lubricants for Use in Multifarious Environments at High Load and Sliding Speeds
Aditya Ayyagari, Kalyan Mutyala, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Existing solid lubricants such as MoS2 and Graphite lack the adaptability to dynamically changing atmospheres. This study, we present the results of novel 2D materials based solid lubricant that we have developed, which overcome this drawback. Solution processed 2D-Molybdenum disulfide and Graphene-oxide were sonixed and deposited on to stainless steel substrate using simple spray-coating process. The tribological performance of the coatings showed very low friction and wear at 0.03 (dry nitrogen); 0.05 (vacuum) and 0.08 (ambient air) at high contact pressures (~1GPa) and at high speed (0.5 m/s) in comparision to steel-on-steel tribopair (0.78-0.1). Raman spectroscopy and transmission electron microscopy of the tribolayers revealed highly aligned MoS2 packets sandwiched between graphene-oxide layers which may have helped in preventing oxidation of MoS2 and thus leading to the

excellent tribological performance in all environments.

9 - 9:30 am
3272845: Liquid Superlubricity Enabled with Two-Dimentional Nano-Additives
Hongdong Wang, Yuhong Liu, Tsinghua University, Beijing, China, Ali Erdemir, Argonne National Laboratory, Argonne, IL, Jianbin Luo, Tsinghua University, Beijing, China

In the process of exploring the water-based superlubricity system, it is found that ultralow friction coefficient (with a minimum value of 0.0023) of polyalkylene glycol (PAG) aqueous solution has been achieved in both droplet state (40 μL) and full immersion over a wide range of velocity and concentration (30–60 wt%). The layered structure and unique diversity of LDHs have endowed the LDH-based materials with excellent tribological properties in both oil- and water-based lubricant systems. Since LDH nanosheets are a kind of hydroxide material and possess the ultrathin longitudinal dimension compared to the thickness of lubricating film, a small amount of additives in PAG aqueous solution will enable the sliding solid surfaces to be flattened and polished during the running-in period. Thus, the initial stage of running-in period to achieve the superlubricity is greatly shortened, and the ultimate load-bearing capacity gets improved.

9:30 - 10 am
3285813: Shear Response of Graphene in N-Hexadecane
Behnoosh Sattari Baboukani, Prathima Nalam, University at Buffalo, Buffalo, NY, Zhijiang Ye, Miami University, Oxford, OH

Two-dimensional materials such as graphene are emerging as novel friction-reducing additives in transmission fluids to enhance the service life of sliding components. In this study, the dissipative mechanisms of a single-layer graphene sheet in presence of n-hexadecane ($C_{16}H_{32}$) is investigated using atomic force microscopy. We measured the interfacial friction of mechanically- exfoliated graphene on silica substrate as a function of immersion time (up to 80 hours) in a humidity-controlled, n-hexadecane solution. The impact of diffusion and intercalation of non-polar n-hexadecane molecules underneath the graphene on friction forces and adhesion is investigated. The observed non-monotonic changes with immersion time is the resultant of the conformational re-ordering of the oil molecules at the confinement, also leading to changes in pinning forces at the sliding contact.

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

10:30 - 11:30 am
Invited Talk
Jonathan Felts, Texas A&M University

11:30 am - 12 pm
3282823: Direct Visualization of Exciton Transport in Defective Few-Layer WS_2 by Ultrafast Microscopy
Huan Liu, Dameng Liu, Jianbin Luo, State Key Laboratory of Tribology, Tsinghua University, Beijing, China

Nanoscale energy transport in the form of excitons is at the core of two-dimensional transition metal dichalcogenides (TMDCs). Energy transport mainly includes exciton recombination, annihilation and diffusion. As defects usually limit the exciton dynamics in two-dimensional TMDCs, the interaction knowledge of defects and exciton dynamics is crucial for understanding frictional energy dissipation. We develop a direct visualization of defect-modulated exciton transport in few-layer WS_2 by ultrafast

transient absorption microscopy. Neutral excitons can be captured by defects to form bound excitons, leading to decreased exciton lifetime and diffusion coefficient. The exciton diffusion length of defective sample has a drastic reduction from 340.53 nm to 104.50 nm. These spatially and temporally resolved measurements reveal the interaction mechanism between defects and exciton diffusion dynamics in 2D TMDCs.

5I Randolph 2

Surface Engineering II - Surface Texture

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3281368: Tribology and Biomimetic Surface Application in Oil and Gas Field
Yanbao Guo, Zheng Zhang, Xuanli Zhou, Deguo Wang, China University of Petroleum, Beijing, China

Friction is widespread in almost every field in the oil and gas industry, and it is accompanied by huge energy losses and potential safety hazards. To deal with a series of questions in this regard, biomimetic surfaces have been developed over the past decades and successfully introduced into the related fields of oil and gas industry. This presentation will provide an overview of recent development of tribology and biomimetic surface application in the oil and gas field and summarize the direction of friction research in the oil and gas field in the near future. Overall, the combination of biomimetic surface engineering and tribology in the field of oil and gas can lead to a more efficient and green design and application that can help toward the realization of secure and sustainable energy future.

8:30 - 9 am
3287110: The Effect of the Surface Texturing Fabrication Technique on the Coefficient of Friction Under Dry Sliding Contact Condition
Ola Rashwan, Pennsylvania State University - Harrisburg, Middletown, PA, Vesselin Stoilov, University of Windsor, Windsor, Ontario, Canada

In this project, two fabrication techniques used for surface texturing of the tool steels are investigated: CuBr Laser ablation and photolithography with an isotropic ferric chloride etchant. The 5 µm deep-circular and hexagonal craters of sizes range between 5µm to 40 µm were tested under dry sliding contact condition using the micro scratch tester. Different scratch orientations were made to estimate the coefficient of friction. It is noted that the method of texturing affects the surface morphology, surface roughness, and consequently the coefficient of friction. Micro bulges resulted from the laser ablation process increased the average surface roughness, thus the coefficient of friction increased. Yet, when these bulges were removed a reduction of COF of 14% was realized. Also, the photolithography alters the surface morphology of the textured surface. It is recommended that laser ablation is more effective than photolithography since it does not alter the surface morphology.

9 - 9:30 am
3323364: Friction Characteristics of Arbitrary Biosurfaces
Shelby Maddox, Mahyar Afshar Mohajer, Min Zou, University of Arkansas, Fayetteville, AR

There are many different types of surfaces found in nature which can increase or reduce friction, such as the well-studied frog toe or lotus leaf. However, methods for replicating these surfaces on a large scale for use in industrial applications is needed in order to take advantage of this natural friction engineering. Most replication processes rely on molding which requires an input surface size comparable to the desired output surface. We present a novel approach of replicating large-scale biosurfaces using a combination of confocal laser scanning microscopy and 3D two-photon photolithography. Three different natural surfaces (banana skin, flower petal, and leaf surface) were replicated. An intermediary tiling process was used to cover a target area of arbitrary size independent of the input texture size. The frictional and wettability characteristics of the replicated surfaces are then examined.

9:30 - 10 am
3323495: Design Guide of Laser Surface Texturing for Reduction of Wear and Coefficient of Friction by Using Different Geometries on Tools for Manufacturing Applications
Demófilo Maldonado, Laura Pena-Paras, Natalia Rodriguez, Marcelo Posada, Universidad de Monterrey, San Pedro, Mexico

Laser surface texturing (LST) has been studied for several years. Researchers have worked with different application, geometries, pressure, and lubricants. Having positive results in enhancing the tribological properties focusing on COF and wear. Circles, triangles and lines are the micro cavities geometries with the most information and results. In this work a design guide for LST in metal mechanical process application is going to be presented, comparing the three geometries mention before, as well as square, crosshatch and “S” shape this last three being geometries with not enough study, therefore a new design was proposed for S shape. A T-05 conformal contact black-on-ring tribo tester was used for measuring COF and wear values according to ASTM G77 standard applying three different pressures with non-continuous revolutions and just one application of lubricant. Finally, a design guide for LST application in production tools based on contact pressure has been generated

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

10:30 - 11 am
3323715: Tribological Effects of Triangle-Shaped Surface Textures under Unidirectional Lubricated Sliding
Pawel Pawlus, Slawomir Wos, Waldemar Koszela, Andrzej Dzierwa, Rzeszow Univerity of Technology, Rzeszow, Poland

Surface texturing is a method of reducing friction of lubricated sliding pairs. The shapes of dimples had substantial impact on the tribological performance of sliding assemblies. Triangle-shaped textures are promising in lubricated unidirectional sliding. Tests were carried out using an Optimol SRV5 tester, equipped with a rotation module in unidirectional sliding in pin-on-disc configuration. Both counterparts were made from steel 42CrMo4. Before each test the same volume of a lubricant was supplied to the contact zone. Disc samples were textured by abrasive jet machining. The spiral pattern of triangular dimples was used. One side border perpendicular to the sliding direction first entered the contact area. Triangular oil pockets had various dimensions. Their angular position to the sliding direction varied. Tribological effects of surface textures were tested in various operating conditions (speed and load). In

most cases, surface texturing resulted in a reduction of friction.

11 - 11:30 am
3324246: Surface Texture Design Guideline and Testing
Stephen Hsu, Govindaiah Patakamuri, George Washington University, Washington, DC, Tim Cushing, GMC, Detroit, MI

Surface topography and discrete dimples can influence interfacial properties significantly in bench scale testing where most of the conditions are carefully controlled. As a result, literature is full of papers claiming significant benefits: control of friction, enhanced lubrication, heat transfer control, etc. Yet at the same time, few reports on actual applications have been reported, except for seals. We have conducted extensive bench scale testing and summarized the results into design guideline. We have also developed various bench and rig test methods in an attempt to simulate actual applications. This presentation describes our test results from bench tests, modeling, and engine tests. As the complexity increases, the magnitude of uncertainty increases and test precision decreases. We will report our test results on the effect of surface textures.

11:30 am - 12 pm
3284264: Effect of Film-Temperature Boundary Conditions on the Lubrication Performance of Micro-Dimpled Parallel Thrust Bearing
Tae-Jo Park, Gyeongsang National University, Jinju, Republic of Korea

Surface texturing has been recognized to be very efficient in improving the tribological performances of machine elements. In sliding bearings, the viscous shearing movement raises the oil temperature. The majority of theoretical studies on the textured surface has been limited to isothermal flow and was not considered the thermal effects. In this study, the effect of dimple depths and film-temperature boundary conditions on the thermohydrodynamic (THD) lubrication performances of textured parallel thrust bearing are investigated numerically. Using a computational fluid dynamics (CFD) code, FLUENT, the continuity equation, the Navier-Stokes equation and the energy equation, and the temperature-viscosity and temperature-density relations are analyzed. The pressure and oil temperature distributions are highly depend on the film-temperature boundary conditions, and thermal wedge effect plays a significant role in the lubrication performances.

5J Randolph 3

Condition Monitoring III

Session Chair: Kemberlee Snelling, Trico Corp, Davison, MI
Session Vice Chair: Daniel Walsh, Spectro Scientific, Chelmsford, MA

Session Starts at 8:30 am

8:30 - 9 am

3284243: Monitoring of Transmissions With Oil Immersed Discs in Heavy Duty Equipment: Ineffectiveness of Standard Oil Analysis & the Need for Specific Testing

Joseph Fotue, TOTAL Cameroon, Douala , Cameroon

A customer sometimes ago had a problem on the powershift transmission of his grader. The parking brake discs inside the component worn out rapidly because they were not completely disengaged while the machine was moving, and it was not noticed. This happened because the compressor responsible for disengaging the discs didn't supply the right air pressure. My astonishment was at its height when I realized that this customer was performing oil analysis and could not notice that something wrong was going on in his machine. Examining some reports, I could understand why it was not able to realize it: some keys parameters were missing on oil analyses report. This article aims at presenting critical oil testing requested for an efficient monitoring of transmissions with oil immersed discs.

9 - 9:30 am

3287103: Product Quality Maintenance & Reliability in the Lubricant Supply Chain

Michael Roe, MJR Lubricant Distribution Consulting & Auditing, Cypress, TX

This paper discusses Lubricant Product Quality & Reliability Maintenance issues in the Lubricant Supply Chain. Topics include Lubricant Products, Lubricant Supply Chain & Focus Areas, Supply Chain Issues & Resolutions, Supply Chain Tools, and Key Takeaways. There is a large variety and number of lubricants due to application-specific requirements. Lubricants themselves range from very simple to highly complex. Because of their physical and chemical nature, lubricants are easily commingled if not handled properly. The supply chain is also varied and complex, including not only lubricants but non-lubricant products, with multiple entities handling lubricants with different equipment types, processes, activities, quality approaches, and personnel training. Product quality and reliability maintenance is essential because it is directly related to lubricant performance in the application, and directly affects customer perception, reputation and brand image, and the bottom line.

9:30 - 10 am

3323493: Bearing Condition Monitoring with High-Frequency Impedance Analysis

Georg Martin, TU Darmstadt, Darmstadt, Germany

Condition monitoring of rolling bearings has been a research topic for decades, and vibration-based condition monitoring is nowadays widely used in industry applications. In spite of this, the accurate early diagnosis of bearing damage and the prediction of upcoming failures remains a challenge. This paper presents a new approach, the use of electrical bearing impedance for condition monitoring. The relationship between bearing impedance and operating conditions, such as bearing loads, has also been a research topic for some years. In this paper, we present an analysis of bearing impedance with very high time resolution. This can reveal processes in the EHD lubrication film that occur on a timescale of less than 10 microseconds. We show that progressing bearing damage leads to short increases of bearing capacitance compared to normal conditions, and to short periods with ohmic behaviour. The ohmic behavior is likely caused by short breakdowns of the lubrication film.

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

10:30 - 11 am
3324910: Dianosing the Root Cause of an Overheated Gearbox
Evan Zabawski, TestOil, Strongsville, OH

A case-study example of a medium-sized gearbox with a seemingly obvious lubricant failure will be presented to illustrate how data can identify a lubricant selection problem. Using oil analysis to find commonly misdiagnosed or overlooked issue, participants will be shown how to apply this knowledge to future oil analysis reports so they can correctly diagnose the true root cause of an alarmed condition.

11 - 11:30 am
3324972: Diagnosing Improper Bearing Lubrication Using Oil Analysis
Evan Zabawski, TestOil, Strongsville, OH

Often an oil change is performed on an asset when poor oil analysis results reveal high levels of wear, yet this does not truly address the root cause of the wear. This presentation will use an example of a bearing with high wear debris alarms but no alarms on the lubricant properties to show how to detect a common issue frequently found in bearing applications. Through guidance on proper interpretation techniques, the presentation will show how to interpret an oil analysis report to determine the causes of the alarmed data, identify commonly misdiagnosed root causes and decide on the best course of action.

5K Michigan 1

Engine and Drive Train III

Session Chair: Raj Chandramohanan, BorgWarner Inc., Arden, NC
Session Vice Chair: Behzad Mahmoudi, Chevron Oronite LLC, Richmond, CA

8 - 8:30 am
3322996: Tribofilm Chemistry for Engine Oils Formulated with Organic Polymeric Friction Modifiers
John Eastwood, Croda, Goole, East Yorkshire, United Kingdom

Tribofilm formation is a complex process dependent upon factors such as conditions (temperature, pressure, materials etc); viscosity; base oil type; dispersant; detergent; viscosity modifier and friction modifier chemistries, be they inorganic or zero Sulphated Ash and Phosphorus and Sulphur (SAPS) organic friction modifiers (OFMs). Inclusion of optimised OFMs can result in tribofilms that form at lower temperatures and are thicker and richer in organic oxygen, calcium, phosphorus, zinc, sulphur and when present, Molybdenum. Whilst there can be fuel economy benefits of Molybdenum dithiocarbamate (MoDTC), the effects can be short-lived, even with high levels. High treat-rates of MoDTC and similar compounds can also result in some harmful effects, such as increased deposits. Tuning OFM chemistry to different styles of engine oil containing MoDTC can result in even lower friction and extended low-friction durability under different tribological conditions, as determined I bench top tests.

8:30 - 9 am

3324584: Organic Polymeric Friction Modifiers Effects on Tribofilm Formation and Properties in HDDEO Formulations

Alexei Kurchan, Croda, New Castle, DE

Historically Organic Friction Modifiers were not an integral part of Heavy Duty Diesel Engine Oil (HDDEO) formulations. In the last decade improved Fuel Efficiency lead to introduction of lower viscosity grades of HDDEO such as SAE 10W-30 and 5W-30. Simultaneously, OEMs are requiring tighter limits on Sulphated Ash and Phosphoros (SAPS) in lubricants. While use of Organic Friction Modifiers in HDDEO is uncommon, it was shown that carefully selected chemistries can improve fuel economy in Heavy Duty Diesel Engines. Due to considerable differences in PCMO and HDDEO formulations it is important to understand how Organic Polymeric Friction Modifiers affect antiwear-film properties, such as rate of formation, friction, and wear levels. Bench tests are used to investigate tribological behavior of ZDDP/detergent film formation with and without Organic Friction modifiers on model systems and commercial HDDEO formulations.

9 - 9:30 am

3286465: Lubrication Property Analysis of Piston Ring in Low Speed Marine Considering Oil Supply

Xuan Ma, Tongyang Li, Bowen Jiao, Xiqun Lu, Harbin Engineering University, Harbin, Heilongjiang, China

Piston ring is one of the most important parts in marine diesel engine. It is lubricated by a special mode that the lubricating oil is directly injected into the liner's inner surface. In this research, taking consideration of the oil supply, a top ring of a two-stroke marine diesel engine lubrication model is developed based on oil mass conservation. The lubrication region of the model is divided into inlet, core lubrication, and outlet regions, with the oil supply being converted into an oil film. The impact of the width of the core lubrication region on squeezing of the oil is considered. To verify the model, friction force measurements are performed in a reciprocating bench test under fully flooded conditions, and the model is further validated by comparing with the minimum oil film thickness with data from the literature.

9:30 - 10 am

3279177: Road to Ultra-Low Viscosity 0W Oils: Quantifying Frictional Benefits on the Journal Bearing Machine and Start/Stop Durability via Sapphire Rig Tests

Priyanka Desai, Shell Global Solutions (US) Inc., Houston, TX, Konstantinos Kalogiannis, Omar Mian, MAHLE Engine Systems (UK) Ltd., Rugby, United Kingdom, Francesco Manieri, Tom Reddyhoff, Imperial College London, London, United Kingdom, Robert Mainwaring, Shell Global Solutions (UK) inc., London, United Kingdom

Shell and MAHLE have worked together to explore the frictional and engine fuel economy benefits offered by ultra-low viscosity oils within the SAE 0W grade envelope. Using the Journal Bearing Machine, we have evaluated the impact of various prototype lubricants such as SAE 0W-8 and 0W-4, using polymer coated journal bearings operated across a range of speeds, loads and temperatures. Additionally, we report the consequences of these choices for their wear and seizure tolerance, highlighting the constraints on engine operation required to realize the economy benefits whilst retaining a 'close to the edge but safe' design ethos.

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

10:30 - 11 am

3310366: Lubricating Behavior at a Fluid-Solid Interface

Yan Chen, Hong Liang, Texas A&M University, College Station, TX, Johnny Yue, Lawrence Berkeley National Laboratory, Berkeley, CA, Mojdeh Rasoulzadeh, The University of Alabama, Tuscaloosa, AL

The confinement and nature of complexity at the fluid-solid interface pose significant challenges to study the nanofluidic behavior of lubricants. Here we report an approach to probe the rheological performance of a lubricanting oil (mineral oil) through dynamic interaction with a harmonic oscillator. A prototype device is developed that is able to vibrate in the range up to hundreds of Hertz. Results show that the interfacial viscosity was similar to that of its bulk in terms of amplitude and frequency. However, an additional phase lag appeared when the amplitude was small, and its response exhibited a certain level of distortion around the natural frequency. Theoretical analysis indicated that potential reason might be due to fluidic memory responding to a moving solid in a non-instantaneous manner. This presentation discusses about such behavior and its potential impacts in real life.

11 - 11:30 am

3320910: Optimizing Lubricant Formulation with Group II Base Oils for Automotive Applications

Yue-Rong Li, Chevron, Richmond, CA

Most engine oils are comprised of 80-90% combination of several base oils with different viscosities. Therefore, the properties of base oil are of importance to make high quality finished oil products. To improve vehicle fuel efficiency, it has been a trend to lower the viscosity of the finished oil and thus reduce the friction loss. While 0W lubricants get a lot of attention they are a tiny fraction of the market. 5W and 10W lubricants represent the major market share which can be blended with 100% GII base oils with no loss in performance, sometimes even better performance. Our study has shown that Automotive engine oils made of pure GII as base oils can outperform some oils marketed as semi-synthetic fluids.

11:30 am - 12 pm

3305842: Low Viscosity Engine Oils, a Comparative Evaluation of Advanced Base Stock Technology

Paula Vettel, Steve Haffner, David Matucha, Novvi LLC, Emeryville, CA

Demand for advanced low viscosity engine oil is expected to grow significantly over the next 10 years as the quest for lower emissions via improved fuel economy continues. To deliver these products, high quality base stocks that can maintain or improve the engine oil performance will be required. These stocks will need to deliver low viscosity without compromising volatility and oil life to deliver improved emissions performance with no sacrifice to engine protection. This presentation will compare the properties of conventional Group III base stock (<130 VI), Group III Plus and Renewable Group III Plus (>130 VI) and PAO. We will show examples of SAE 0W-20, 0W-16, 0W-12 and 0W-8 engine oils, and discuss the specifications that will drive these formulations. Properties investigated include Noack, base oil viscosity, CCS @ -30'C, HTHS@150'C and MRV@ -40'C. The presentation will demonstrate how key base stock properties can impact the ability to meet this need.

Tribotesting I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3277865: On Measuring the Friction Component of Oils
Kenneth Budinski, Bud Labs, Rochester, NY

There is worldwide interest in reducing energy consumption and this project addresses the question: do different oils produce different friction results in the same tribosystem. Is one oil more “slippery” than another? Initial testing with an inclined plane test (ASTM G 214) suggested that higher viscosity fluids produce lower breakaway friction. Bushing vs. shaft tests at three velocities suggested that bearing torques were the same for oils ranging from 0 weight to 40 weight. The overall conclusions of these tests are that oils may have different breakaway friction characteristics under boundary lubrication conditions, but system friction becomes the same under full-film lubrication conditions. In these studies, system friction did not decrease with speed as predicted by the Stribeck curve.

8:30 - 9 am
3285253: Impact-Slide Wear Testing for Evaluation of Hard Coatings for Tooling Applications
Suvrat Bhargava, Ranjan Deshmukh, Rodney Martens, Bradley Schultz, TE Connectivity, Middletown, PA

Due to the growing environmental and health concerns associated with hexavalent chrome chemistry, physical vapor deposited (PVD) hard coatings are being considered as replacements to electroplated chromium in many tooling applications. The large variety of commercially available PVD coatings, along with their different manufacturability costs, make the screening of coatings a necessary step towards finding replacements for applications using electroplated chromium. In several tooling applications, coatings are subjected to wear resulting from repeated impact and sliding movements. This work focuses on evaluating PVD coatings using a custom-built impact-slide wear tester. The wear scars created during the tests were imaged to identify the failure mechanisms. Additionally, the susceptibility of the various coatings to combined conditions of impact and sliding wear were compared. The coatings were also subjected to other tribological tests commonly used for hard coating evaluations.

9 - 9:30 am
3287117: Development of a Novel Test Method for Friction Assessments of Shock Absorber Fluids
Jason Papacek, Calumet Specialty Products Partners, Indianapolis, IN

Reducing friction of shock absorber fluids is paramount for improving vehicle safety, handling and ride quality. Historically, shock absorber dynamometers have been employed to assess shock absorber fluid formulations prior to vehicle road testing. The dynamometers evaluate shock absorber assemblies at the macro level. Isolating shock absorber fluid friction and evaluating it at a micro level in a laboratory was needed to advance shock absorber fluid performance. A novel and effective laboratory test method was developed for assessing shock absorber fluid friction using a commercially available tribometer and correlated with shock absorber dynamometer data. This laboratory test method is a platform for rapid

prototyping shock absorber fluids and correlates to shock absorber dynamometer and vehicle road test data.

9:30 - 10 am
3289046: Statistical Considerations in Wear Scar Measurement in Antifriction Coatings
Melissa Mushrush, DuPont de Nemours, Inc., Midland, MI, Kevin Wier, The Dow Chemical Company, Midland, MI

In the testing of antifriction coatings, perhaps the most difficult aspect to quantify reproducibly is the measurement of the resulting wear scar after a tribological test has been conducted. Common methods used to measure the thickness of the film and the depth of the wear scar generally require the user to assess the planes of the film surface and the bottom of the wear scar, introducing inherent variability into the measurement. In this work, we assess various film thickness and wear scar depth, width, and volume measurements in order to see which methods offer the lowest standard deviation in a statistically significant set of measurements. We also take a look at the largest change that we can detect when using the methods with the smallest standard deviation.

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

10:30 - 11 am
3296301: Investigation of the Sensitivity of the Wire-On-Capstan
Peter Lee, Southwest Research Institute, San Antonio, TX

The wire-on-capstan geometry, shown in Figure 1, is reported to show very small differences in friction response between lubricants. The rig is a steel bearing race on a shaft with an aluminum wire wrapped around it. The wire is connected to a force transducer at one end and has free hanging weights at the other. The bearing race is then rotated through a bath of lubricant, which may be heated, and the resulting force measured. In this work four different lubricants were used to investigate their friction response. In addition, a lubricant was run with a gradual increase in friction modifier to investigate the sensitivity of the rig.

11 - 11:30 am
3321771: Investigation of Lubrication Regime Transitions for High-Speed Reciprocating Applications
Oluwaseyi Ogunsola, Shell Global Solutions, Houston, TX

Piston ring/liner reciprocating system account for a large portion of the fuel consumed in internal combustion engines. Due to short stroke length and frequency of existing tribometers, the lubrication regimes reachable are mostly limited to boundary and mixed lubrication. This has limited application of these tribometers to wear investigations at top-dead center region. With recent advances, some reciprocating tribometers now have the capability to reach hydrodynamic regime. This study involves the use of such a high-speed, long-stroke reciprocating tribometer to investigate friction-velocity response of several lubricants over a wide range of operating conditions and lambda ratios. The impact of base oil, viscosity modifier, anti-wear additives, and friction modifiers on reciprocating friction values are investigated. Discussions will focus on the test method development, impact on formulation choices on friction and regime transitions, and recommendations for friction reduction.

11:30 am - 12 pm
3294506: Depletion of MoDTC and Synergism with OFM in Boundary Lubricated Tribological Contacts
Simon Barnes, Shahriar Kosarieh, Ardian Morina, Anne Neville, University of Leeds, Witney, Oxon, United Kingdom, David Gillespie, Gareth Moody, Croda, Goole, United Kingdom

Molybdenum dithiocarbamate (MoDTC) has proven to be an effective friction modifier (FM), reducing frictional losses through engine contacts. However, recent environmental concerns have sparked efforts to reduce levels used. One such is the use of organic friction modifiers (OFMs) in tandem with MoDTC. Various concentrations of MoDTC in fully formulated oil were tested using a reciprocating pin on plate TE77 tribometer, under harsh boundary conditions to accelerate depletion of the additive. An OFM was then blended in and the effects on friction and wear performance observed. Upon addition of OFM, low friction was maintained for longer than when only MoDTC was present. The MoDTC-OFM blend maintained low friction for a similar length of time as a blend containing just MoDTC at an equivalent treat rate to the sum of OFM and MoDTC and so giving a synergistic effect. Surface films have been characterized using Raman and AFM. The mechanisms behind this effect will be discussed further.

5M — Michigan 3

Lubrication Fundamentals Special Session: Four Decades of Patri-Cheng Average Flow Model and Future Challenges in Tribology (Invited Talks Only)

Session Chair: TBD
Session Vice Chair: TBD

As the lubrication science deepens in understanding and widens in its application to novel fields, time has come to review progress made in the past 40 years and discuss current challenges and future needs. This symposium brings together researchers in the field of lubrication to share their accomplishments in research and present their visions for future research and development.

6A — Columbus AB

Commercial Marketing Forum VI

1:30 – 2 pm – Open Slot

2 – 2:30 pm – Open Slot

2:30 – 3 pm – Open Slot

3 – 3:30pm – Break

3:30 – 4 pm – Open Slot

4 – 4:30 pm – Open Slot

4:30 – 5 pm – Open Slot

6B Columbus CD

Nonferrous Metals I: Biobased and Synthetic Lubricants

Session Chair: Girma Biresaw, BOR, USDA-ARS-NCAUR-BOR, Peoria, IL
Session Vice Chair: Rick Pruhs, Quaker Houghton, Waverly, IA

1:30 - 2 pm
3286625: Cold, Clean and Green: Biomimetic Industrial Lubricants to Support the Cold Chain
Iestyn Stead, David Eckold, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

Aqueous lubricants saturate the natural world. Water is a hugely abundant resource and makes up a significant part of most organisms, providing an impetus for life as well as being the basis for the lubrication utilising polysaccharides, in plants, and proteins, in the animal kingdom. However, in the industrial world, a majority of lubricants are based on crude oil and their derivatives. There are similarities between the two worlds, and so this study was looking at developing a biomimetic lubricant capable of exploiting water's ability to lubricate in hydrodynamic contacts and the long-chained polysaccharides and proteins ability to provide optimum boundary lubrication in biological contacts. The study focuses on pectin and bovine serum albumin as two possibilities as boundary lubricant additives to water. Tests included two contact pressures and two reciprocating frequencies in order to analyse how each performs under a variety of conditions.

2 - 2:30 pm
3305233: A Non-Ferrous Study Investigating the Lubricity and Film Thickness Behavior of Rolling Oils Containing Mixed Ester Packages on Varying Grades of Aluminium
Emma Pates, Stephen Chestnutt, Total UK, London, United Kingdom, Annie King, Total Specialties USA, Inc, Linden, NJ

The global demand for pristine surface finishing within the non-ferrous rolling industry is the driving force behind this investigation surrounding high-performance lubricating oils. Studies relating to the lubrication properties of a modelled base oil formulation, based on current industrial knowledge, will be explored with the addition of different functionality/mixed ester packages on numerous different grades of aluminum alloys using tribological methods developed specifically for non-ferrous rolling applications. The scientific goal is to compare how the effect of these diverse ester packages affect all regimes within the lubrication profile on these different grades of aluminum and relate them directly to their observed film thickness formation/strength and surface polarity. The range of these results will additionally aim to strengthen the accuracy and knowledge of mapping the friction and wear behaviour of lubricants within industrial rolling mills.

2:30 - 3 pm

3308433: Non-Edible Vegetable Oils: Options and Choices for Meeting Different Types Lubricant Requirements

Joseph Pattathilchira Varghese, formerly with Indian Oil R&D Center, Faridabad, Haryana, India

Lubricants, especially used for manufacturing purposes like machining, forming etc., should possess good boundary lubrication, load carrying and EP characteristics, along with suitable physico-chemical characteristics. Conventionally, vegetable oils have been used to meet boundary lubrication requirements. Due to inferior oxidation and hydraulic stability, synthetic esters replaced the vegetable oils. High cost and limited availability of synthetic esters prompted the formulators to look for natural esters with improved characteristics. In many countries, edible vegetable oils cannot be used for industrial purpose due to issue of negative effect on food basket. An attempt is carried out to explore, from authors' as well as from published works, the non-edible vegetable oil options for these applications. Physico-chemical and tribological requirements of different types of lubricants are reviewed and suitable vegetable oils options and choices to meet these requirements are proposed.

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

3:30 - 4 pm

3319543: Vaporization and Flow Properties of Biobased Oils

Tom Karis, TEK Data Systems, Aromas, CA, Girma Biresaw, USDA-ARS-NCAUR-BOR, Peoria, IL,
P. Iaccarino, Raj Shah, Koehler Instruments Company, Inc., Holtsville, NY

There is an ongoing need to improve the fuel efficiency of engines and drive trains by decreasing the viscous dissipation in rolling and sliding contacts. Improved formulation starts with innovative base oils designed to have lower viscosity without increase evaporation loss rates. In this investigation, we focus on biobased oils that have recently become available for commercial formulation. The thermodynamic activation energy and entropy were derived from viscosity and vapor pressure measurements. The derived thermodynamic properties provide insight into the link between the molecular structure of the biobased oils relative to the synthetic and mineral oils. These results suggest that the key to design of a base oil with lower viscosity and comparable vapor pressure is to control how the molecule deforms while transitioning through the flow activation state as measured by the flow activation entropy.

4 - 4:30 pm

3320243: Biobased Disulfide Additive Based on Soybean Oil

Girma Biresaw, Grigor Bantchev, James Lansing, Rogers Harry-O'Kuru, USDA-ARS-NCAUR-BOR, Peoria, IL,
Yunzhi Chen, South China University of Technology, Guangzhou, Guangzhou, China

The development of fully biobased lubricants requires the application of biobased base oils and biobased additives in the formulation. Such formulation will provide the full environmental, health, safety and economic benefits expected from replacing petroleum based products with biobased products. Over the past years, there has been a steady progress in the development and commercialization of biobased base oils. However, the development and commercialization of biobased additives has not been as robust as that for biobased base oils since multiple additives (e.g., anti-oxidant, anti-wear, etc) are required for most formulations. As a result, most current biobased formulations are developed using commercial petroleum based additives and are not capable of providing the full benefit of a fully biobased formulation. In this presentation, recent work on the synthesis and characterization of a new biobased disulfide additive from soybean oil will be discussed.

4:30 - 5 pm
3327894: Gas-to-Liquids (GTL) Technology Advances in Metalworking and Aluminum Rolling Fluids Are Enhancing Safety, Operations and Performance
Gregory Wehr, ChemGroup, Inc, Louisville, LA

Gas-to-Liquids (GTL) technology and its advances in metalworking and aluminum rolling fluids are offering many important benefits today including higher purity, lower viscosity and VOC when compared to traditional crude oil derived fluids. GTL is thus addressing many of the demands for improvements in Safety, Operations and Performance faced by the industry today.

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

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

6C Columbus EF

Synthetic Lubricants and Hydraulics I

Session Chair: Lauren Huffman, Dow Chemical Company, Midland, MI
Session Vice Chair: Robert Davidson, Afton Chemical Corp., Richmond, VA

1:30 - 2 pm
3301723: Novel Base Oil Technologies for Industrial Gear Oils
Justin Langston, Gabriela Fedor, Thomas Schimmel, Evonik Oil Additives, Horsham, PA

Industrial gear oils must protect equipment against wear, micropitting, and oxidation in a wide variety of severe operating conditions. These harsh conditions stipulate the use of higher viscosity grades, most commonly ISO VG 150 to 680. To reach these viscosity targets, and ensure stay-in-grade performance, formulators use shear-stable, high viscosity base stocks in combination with low viscosity base stocks. Additives are then added to provide durability, protect gearbox components, and improve low-temperature performance. In this paper, we will report on the performance of novel high viscosity base stocks. When included in industrial gear oil formulations, they offer unique advantages in viscosity index, low-temperature performance, and solvency. Furthermore, these formulations are designed to meet the most stringent standards for industrial gear lubrication and therefore meet and or exceed standardized testing for scuffing, micropitting, and oxidation.

2 - 2:30 pm
3281345: Oil Miscible Polyalkylene Glycol (OMP) - An Excellent Novel Base Fluid for High Performance Lubricant Formulations
Govind Khemchandani, Sasol, Westlake, LA

Oil Miscible Polyalkylene Glycol (OMP)-an excellent novel base fluid for high Performance lubricant formulations Govind Khemchandani, Ph. D. Technical Lead: Automotive & Industrial lubricants & Additives Sasol Performance Chemicals, West Lake, LA 70669 Conventional PAGs used as additives are often not soluble in higher concentrations in API group I-IV base oils. Authors lab has used unique

greater than C-12 chain length linear and branched alcohol with special catalyst and alkylene oxides therby producing truly 'oil miscible poly alkylene glycols' (OMP) soluble at higher concentration in group I-IV base oils. These OMPs have excellent air release, high thermal and oxidative stability which helps in formulating high performing industrial fluids. Many of these physico-chemical properties of OMPs and OMP based compressor fluid will be discussed in this paper.

2:30 - 3 pm
3285879: New Hydrolytic Stability Testing on Biobased Lubricants and Base Fluids
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Esters are a class of compounds that have performance characteristics and use as a petroleum replacement in lubricant formulations. However, in aquatic applications esters have the tendency to thermally hydrolyze in the presence of water leading to organic acids which catalyzes the subsequent hydrolysis of unreacted esters leading to high total acid number resulting in corrosion of metal working equipment. Estolides are a distinct class of esters that has demonstrated exceptional hydrolytic stability compared to traditional esters. A modified hydrolytic stability test was developed by Biosynthetic Technologies to monitor the extensive stability of estolides versus traditional lubricant esters over a long duration of time under real world applications.

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

3:30 - 4 pm
3295567: Fluid Effects on Mechanical Efficiency of Hydraulic Pumps
Pawan Panwar, Ashlie Martini, University of California, Merced, Merced, CA, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI

Viscosity modifiers that thicken hydraulic fluids are believed to improve the mechanical efficiency of hydraulic systems through multiple mechanisms. These mechanisms are explored here using rheological characterization, molecular simulations and efficiency measured in a pump dynamometer for fluids comprised of low traction synthetic poly(alphaolefin) base oils, bis(2-ethylhexyl) adipate ester, and poly(isobutylene). Lower viscosity fluids directly correlated to better mechanical efficiency but decreasing the viscosity of the synthetic base oil by adding viscosity modifier did not have the same effect. Further, molecular dynamics simulations showed that solution viscosity was directly correlated to elongation of the polymer under shear which, together with calculations of the critical shear rate range in a pump, suggested ways of designing viscosity modifiers to achieve a specific viscosity profile that maximizes mechanical efficiency.

4 - 4:30 pm
3296238: Fluid Effects on Stick-Slip Friction in Hydraulic Cylinder Rod Seals
Paul Michael, Muhammad Khan, Milwaukee School of Engineering, Milwaukee, WI, Fred Ondarza, Shell Global Solutions, Houston, TX

Cylinders are the primary linear actuators in fluid power equipment. They incorporate piston and rod seals. Piston seals isolate rod and cap-end pressures within a cylinder. Rod seals retain the fluid within a cylinder during extension and retraction. In addition, rod seals must resist extrusion, operate in harsh environments, and minimize stick-slip friction. Seal stick-slip is characterized by a start-stop motion of the rod. This motion can produce vibration, noise, and machine oscillations. Machine oscillations are a particular concern in cranes, telescopic lifts, and utility trucks because boom instability affects machine

control and operator safety. In this study, the effects of fluid properties on rod seal stick-slip friction were investigated using a new screener rig that measured rod force and position. Improvements in the lubricating properties of the fluid were found to mitigate stick-slip friction and noise. Results for slipper, U-cup, and V-pack seals are reported.

4:30 - 5 pm
3325464: Could the Latest Oil Technology Give You Cleaner, Longer-lasting and More Productive Hydraulic Systems?
Sravani Gullapalli, Sameer Sathaye, Shell Global Solutions US Inc., Houston, TX

Operators are working their hydraulic systems harder for longer, exerting extra stress on hydraulic oils, including higher operating pressures and temperatures. At the same time, mobile hydraulic systems are becoming more compact. Their smaller oil reservoirs allow less heat dissipation, which means higher oil temperatures. This increases the risk of oxidation and thus sludge and varnish formation. Poor-quality hydraulic fluids are more susceptible to the problem of sludge and varnish as they readily oxidise in the presence of yellow metals, water and air contamination. In addition, they contain additives that are not thermally stable and decompose at elevated temperatures. This presentation will showcase premium zinc-based hydraulic fluid technology, formulated with gas-to-liquid (GtL) base oils, that demonstrate low sludge forming tendency and excellent wear and oxidation protection.

5 - 5:30 pm
3321722: Tribological Performance of Used and Artificially Altered Hydraulic Oils
Nicole Doerr, Serhiy Budnyk, AC2T Research GmbH, Wiener Neustadt, Austria, Daria Kolbas, Gubkin Russian State University of Oil and Gas, Moscow, Russian Federation, Ameneh Schneider, Optimol Instruments Prueftechnik GmbH, Munich, Germany, Franz Novotny-Farkas, Engineer Consultant, Schwechat, Austria

Short-time tribometrical tests were applied to characterize fresh and the respective used or artificially altered hydraulic oils according to friction behaviour and wear formation. Hydraulic oils with different degrees of degradation were obtained from thermal-oxidative stability tests, Bosch Rexroth pump test and from the field after up to 40,000 operating hours. For tribometrial evaluation, a steel-steel contact with ball-on-disk configuration in the Schwing-Reib-Verschleiss-Tribometer SRV® 5 was applied. While conventional oil characterization did not show tremendous oil degradation compared to the fresh oil, tribometrical test results differentiated between fresh and used oil condition. For the understanding of the observed behaviour, surface characterization was performed.

5:30 - 6 pm - **Synthetic Lubricants & Hydraulics Business Meeting**

6D — Columbus G

Fluid Film Bearings II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm

3281808: A New Fully Coupled Aeroelastic Model for Air Foil Journal Bearings

Yang Hu, Yonggang Meng, Tsinghua University, Beijing, China

A new fully coupled aeroelastic model for air foil journal bearings is established by combining the finite volume method (FVM) and the finite element method (FEM). The finite volume method (FVM) is adopted to solve the compressible Reynolds equation for gas lubrication. The finite element method (FEM) is adopted to solve foil structure model. The elastic deformation of the top foil, the interaction between the adjacent bump foils and Coulomb friction effect are taken into consideration in the foil structure model. The validity of the developed model is assessed by comparison of predictions to experimental data available in the open literature. Then, a parametric study is conducted to study the effects of the top and bump foil's geometry on the load carrying capacity.

2 - 2:30 pm

3323393: Numerical and Experimental Investigation of Aerostatic Bearing with Applications to High-Frequency Rotation (More Than 100 kHz)

Rajdeep Deb, Beat Meier, Solid State Nuclear Magnetic Resonance, ETH Zurich, Zurich, Switzerland, Patrick Jenny, Institute of Fluid Dynamics, Zurich, Switzerland, Dirk Wilhelm, ZHAW School of Engineering, Winterthur, Switzerland

Sample rotation around an axis inclined by about 54° with respect to the magnetic field (the "magic angle") is used in solid-state nuclear magnetic resonance spectroscopy to obtain high spectral resolution which is the key to determine molecular structure and dynamic, e.g. in biomolecules or battery materials. The rotation frequencies required exceed 100 kHz and operation in a strong magnetic field (20 Tesla) is required. The aerostatic bearing used for such rotors limit the spinning stability under fast spinning conditions. We describe the optimization of the bearing design for such systems based on a modified Reynolds equation applicable to small bearing size. A stability analysis was performed to predict a suitable bearing design and the results are compared with experimental data for different bearing configurations.

2:30 - 3 pm

3325188: Externally Pressurized Porous Gas Bearings: Measurements of Static Load Characteristics and Rotordynamic Performance

Keun Ryu, Hanyang University, Ansan, Gyeonggi-do, Republic of Korea

High-speed micro turbomachinery requires oil-free gas bearings due to their notable advantages over oil-lubricated or rolling element bearings. Externally pressurized gas porous bearings, with higher stiffness and uniform pressure distribution than other types of hydrostatic gas bearings, eliminate contact and wear issues during startup and shutdown events while offering very low power and frictional losses, as well as controllable bearing force coefficients. The current work presents extensive measurements of static load characteristics and rotordynamic performance of externally pressurized porous gas bearing supported rotor systems. Drag coefficients and friction coefficients of the test journal bearings are estimated from coastdown tests. Pneumatic hammer instability is distinctive at high supply pressure conditions. Gas film thickness and load capacity of the test thrust bearings are also measured while increasing static load on the bearing at various supply pressures.

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

3:30 - 4 pm

3283576: Measuring Oil Films in Dynamically Loaded Journal Bearings

Scott Beamish, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom, Henry Dodson, Ricardo, Leamington Spa, United Kingdom

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

4 - 4:30 pm

3290036: Non-Newtonian Couple-Stress Squeeze Film Behavior between Oscillating Anisotropic Porous Circular Discs with Sealed Boundary

Benyebka Bou-Saïd, INSA Lyon, Villeurbanne, France, Mustapha Lahmar, Guelma University, Guelma, Algeria

In this paper we investigate theoretically the non-Newtonian couple stress squeeze film behavior between oscillating circular discs . The lubricant squeezed out between parallel porous and rigid facings is supposed to be a concentrated suspension. The effective viscosity of the suspension is determined by using the Krieger-Dougherty viscosity model. For low frequency and amplitude of sinusoidal squeezing where cavitation as well as turbulence are unlikely, the governing equations including the modified Reynolds equation coupled with the modified Darcy's equation are derived and solved numerically. The slip velocity at the porous-fluid interface is directly evaluated by means of the modified Darcy's law considering laminar and isothermal squeezing flow. For a given volume fraction, the couple stress effects on the squeeze film characteristics are analysed through the dimensionless couple stress parameter considering sealed and unsealed boundary of the porous disc.

4:30 - 5 pm

3308592: Rotating Gear Supported by a Plain Journal Bearing: A Numerical Analysis of the Dynamic Characteristics

Balint Pap, Florent Lejeune, Ludwig Biadalla, Safran Transmission Systems, Colombes, France

In the present work, a numerical analysis of a plain journal bearing is presented. The analyzed journal bearing is located between a fixed shaft and a rotating gear, which is loaded through a simple spring system. The simplicity of this configuration facilitates a dynamic analysis and the validation of a novel computational method. The computational method presented in this work takes into account the non-symmetric stiffness matrix of the journal bearing. Instead of the classic 4-point small perturbations method, an 8 points computation is realized in order to define the principal axis of the stiffness matrix, thus making it transforming it into a diagonal matrix (in a specific axis system). Finally, a detailed dynamical analysis is presented on the basis of the above described simple system: the system response

to unit force perturbations with the classic and the proposed approach are compared while taking into account the gear meshing and spring stiffness.

5 - 5:30 pm
3323571: Rotating Gear Supported by a Plain Journal Bearing: An Experimental Case Study
Balint Pap, Antoine Pennacino, Safran Transmission Systems, Colombes, France

In the present work an experimental analysis of a plain journal bearing test bench is presented. The analyzed journal bearing is located between a fixed shaft and a rotating gear, which is loaded through a simple spring system. During the first two runs of the test bench two journal bearing seizures occurred between the rotating gear and the fixed shaft at high rotational speeds. Later on, a second verification run was realized with a modified spring system as well as a modified journal bearing geometry in order to avoid future seizures. This verification test run was realized with a high number of thermocouples and accelerometers at different locations on the test bench and on the journal bearing. The present work details the conclusion of the verification run as well as the preventive measures that were taken in order to avoid a future seizure of the journal bearing.

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

6E Columbus H

Wear I

Session Chair: Mathieu Renouf, CNRS University of Montpellier, Montpellier, France
Session Vice Chair: John Bomidi, Baker Hughes, The Woodlands, TX

1:30 - 2 pm
3281805: Suppressed Triboluminescence Attributed to Electron Structure Changes in the Doped Surface
Changhui Song, Liran Ma, Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

Triboluminescence(TL) is a fascinating phenomenon that occurs in the sliding contact surface, which directly transforms the mechanical energy into the light. In our work, the TL experiment between ZnS polycrystalline and SiO2 crystal was carried out, and we found suppressed TL emission when little amount CuS nanoparticles doped into the ZnS. The TL emission attributed to the nitrogen discharge between the contact surface. The microstructure of CuS doped ZnS was characterized by X-ray diffraction (XRD) and transmission electron microscopy(TEM). Conduction-band and Valence-band structures of the doped surface were studied by x-ray photoemission spectra (XPS) and further described by the first principle electronic structure calculation using CASTEP to show how the electron structure change due to the presence of CuS, which further lead to the suppressed TL emission. Our work may provide a possible approach to manipulate the TL emission and further insight into the TL mechanism.

2 - 2:30 pm

3300187: An Analytical Model of Erosive Wear of BioMass Comminution Components

George Fenske, Oyelayo Ajayi, Argonne National Laboratory, Argonne, IL, Jun Qu, Kyungjun Lee, Oak Ridge National Laboratory, Oak Ridge, TN, Jeffrey Lacey, Idaho National Laboratory, Idaho Falls, ID

Biomass feedstocks such as corn stover, and pine residue are often milled (hammer milling, knife milling) and refined to improve transport, and reactivity in downstream processing steps. The presence of intrinsic and extrinsic ash entrained in the feedstock in the biomass has been observed to increase wear of mechanical components (hammers and knives) decreasing throughput through biomass refineries. This presentation reports on efforts supported by the DOE Feedstock Conversion Interface Consortium (FCIC) to develop an analytical approach to model wear of critical components as functions of process parameters, feedstock properties, and material of construction properties. Results will also be presented on validation of the analytical model using feedstock properties of corn stover and pine ash performed at ORNL, and experimental wear studies performed at INL.

2:30 - 3 pm

3279796: Tribo-Corrosion Behavior of AISI 4715 Pipeline Steel Used in Hydraulic Fracturing

Jitendra Panda, Brandon Wong, Philip Egberts, University of Calgary, Calgary, Alberta, Canada, Tom McLoughlin, Keri Yule, Calfrac Well Services Ltd., Calgary, Alberta, Canada

Wear corrosion of surface treating iron used in hydraulic fracturing is a common failure mechanism. In particular, the recycling of water in hydraulic fracturing operations can result in an increase in salinity of the treatment fluid, accelerating the corrosion and limiting the iron lifespan. On-the-fly fluid additives have shown the potential to aid in extending the life of the treating iron. In this study, we examine the wear-corrosion rate of AISI 4715 pipe sections using a reciprocating tribometer operated with three-probe electrochemical control of the pipeline steel. The impact of additive chemistry on the friction coefficient measured between the sapphire slider and the steel pipe, as well as their associated impact on the measured wear rate is determined. Chemical analysis of worn and corroded sections will also be presented, allowing for identification of wear mechanisms and identification of the most promising additives to reduce wear-corrosion of the pipeline steels.

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

3:30 - 4 pm

3301686: Adhesive Wear of the Workpiece Material to Abrasive Grits during the Grinding Process

Matthew Marshall, University of Leeds, Leeds, West Yorkshire, United Kingdom

Many aspects of grinding efficiency has been well researched such as, fracture, removal and blunting of abrasive grains. Adhesive wear of the workpiece material is well documented but not currently fully understood. As grinding takes place the abrasive grain is encompassed by the workpiece material therefore leading to ineffective grinding. Stainless and carbon steel have been ground against abrasives coated with and without supersize (KBF4). This is to study the effect of material selection and the effects of additives on the capping process. Stainless steel with and without KBF4 is shown to adhere whereas carbon steel shows minimal signs of metal capping. KBF4 is shown to drastically reduce the amount of metal capping on the stainless steel samples. The adhesion of the metal caps is also shown to be due to mechanical process, as observed through TEM interface analysis. This work shows that for adhesion to take place, the material at the contact has to be solid.

4 - 4:30 pm
3323520: In-Situ Observation of Friction and Wear Characteristics of Aluminum Alloys
Kazuyuki Yagi, Yuya Abe, Joichi Sugimura, Kyuhu University, Fukuoka, Japan

Aluminum alloys are used for piston skirt systems and conrod bearings in combustion engines. Although friction and wear behaviors are different from steel, research on friction and wear behaviors of aluminum alloys is little compared with that of steel. In the current study, friction and wear tests of aluminium alloys were conducted using in-situ observation system. A contact area was created between a rotating sapphire disc and an aluminum alloy pin with a curvature. Full formulated engine oil of 0W-8 with MoDTC and ZDDP was used. The contact area was observed over the sapphire disk by a high-speed camera. Three kinds of aluminum alloys were used, which were Al-Si alloy, Ai-Sn alloy and Al-Mg alloy to investigate the influence of elements in the alloys on friction and wear characteristics. Chemical reaction film on the alloys was also investigated by SEM and EDS after tests. Friction and wear behaviors with different alloys were compared and discussed.

4:30 - 5 pm
3319067: Anti-Wear and Anti-Corrosion of Polymer-Alloy Composites
Peter Renner, M. Ozaydin, Hong Liang, Texas A&M University, College Station, TX

Improved wear and corrosion resistance has been found in multiphase composites. Here we report a new material consisting phases of quasicrystal, cubic, monoclinic, and geopolymer. Characterization indicated that microhardness and wear resistance were increased with the amount of quasicrystal phase. On the other hand, the corrosion resistance was improved with the existence of geopolymer. This means that by tailoring the microstructures of multiphase composites, it is possible to achieve desired tribological performance and corrosion resistance.

5 - 5:30 pm
3285167: Analysis on Surface Damage of M50 Steel at High-Speed Impact-Sliding Contacts
Che Wang, Harbin Institute of Technology, Harbin, Heilongjiang, China

The surface damage behavior of M50 steel at high-speed impact-sliding contacts is analyzed considering the effect of frictional work and plastic deformation work. A thermo-elasto-plastic finite element model is built for analyzing the temperature rise and plastic deformation. According to the change of the physical properties of the M50 steel at high temperature, the high temperature elastoplastic constitutive relation is built and entered into the thermal elastoplastic impact-sliding coupling model which is solved through a nonlinear time implicit numerical solver. The results show that thermal softening and plastic deformation are the surface damage forms of M50 steel in the impact-sliding contact zone, mainly caused by local high temperature and accelerated by the cyclic thermal coupling action. It is more likely to produce hallow deformation and thermal damage at low impact speed and high sliding speeds, and low plastic deformation can also produce huge heat production.

5:30 - 6 pm
3304314: Investigating and Mitigating Wear of Hammer Mill for Size Reduction of Biomass Feedstock
Kyungjun Lee, James Keiser, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, Jeffrey Lacey, Vicki S. Thompson, Idaho National Laboratory, Idaho Falls, ID, Oyelayo Ajayi, George R Fenske, Argonne National Laboratory, Argonne, IL

The low mass density of biomass pulls down industrial competitiveness in terms of transporting, storing, and processing. Thus, mechanical preprocessing (size reduction) is conducted to increase the bulk density of biomass. However, wear is inevitable for size reducing equipment, as a result of collision and sliding against inorganic extrinsic and intrinsic compounds of biomass. Worn tools lead to significant economic loss due to increased downtime and labor for replacing worn components. That is why we are investigating various candidate materials, surface treatments, and coatings for improving the wear resistance of tools. Candidate materials/coatings/surface treatments are selected based on the wear modes identified by the actual worn components and evaluated using specially designed blasting wear tests as well as 3-body and 2-body abrasion tests. The wear mechanisms are revealed by worn surface morphological examination and compositional analysis to correlate with the wear behavior.

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

6F — Columbus IJ

Lubrication Fundamentals VI

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3285726: Selecting Suppliers for Your Lubricant Additives and Base Oils
Michael D. Holloway, 5th Order Industry, Highland Village, TX

The proper selection of base oils and chemical additives can become very cumbersome and complicated. This session looks to establish the framework and foundation for the minimum requirements necessary. This session helps navigate through the maze of quality, performance, supply considerations, as well as safety and storage. In this session, the attendee will learn how to establish a performance profile for quoted products. Attendees will understand the structure and how to properly utilize a Safety Data Sheet for products quoted and purchased. In this session, the attendees will be able to understand and request the various package and storage options as well as how to navigate geographic and shipping concerns. This session also explores how the procurement process should select product according to performance.

2 - 2:30 pm
3276873: Analytical Approaches to Chemical Structure and Physical Property Measurements of Lubricant Oils
Eleanor Riches, Caitlyn Da Costa, Jeff Goshawk, Gordon Jones, Michael Jones, Waters Corporation, Wilmslow, United Kingdom, James Browne, TA Instruments - Waters Corporation, New Castle, DE

Lubricant oils are typically a formulated product comprising a base oil and additive package that impart fundamental performance characteristics to the base oils such as viscosity control, resistance to oxidation, and overall stability. It is important to understand how both the physical properties and the chemical components of the formulated product may vary. Here we present analytical techniques that offer insight into both the chemical structure and the physical properties of different formulated

lubricant oils. Thermal analysis was used to compare relative stability of the various oils, while high resolution mass spectrometry was used to investigate potential differences at the molecular level; both approaches were found to show fundamental differences between commercially available automotive lubricant oils.

2:30 - 3 pm
3285561: Influence of Base Oils on Heat Transfer Characteristics of Lubricants for E-Motors in HEVs and EVs.
Masato Yokomizo, Narita Keiichi, Idemitsu Kosan Co.,Ltd., Ichihara-shi, Chiba, Japan

Thermal management of e-motors is an important issue to improve the efficiency of hybrid electric vehicles (HEVs) and electric vehicles (EVs). Therefore, the cooling performance is mainly required for lubricants used in e-motors. In this study, it was investigated that the relation between the base oil property and its heat transfer characteristics. As a result, reducing fluid viscosity improve heat transfer in both natural and forced convection conditions. Quantitative analysis could reveal that kinematic viscosity and heat conductivity of base oils give large impact on their cooling performance. Some synthetic oils demonstrated excellent cooling performances, depending on their molecular structures. In addition, we investigated the effect of deterioration of lubricants on their cooling performance by using an oxidation tester. The thermal conductivity of lubricants was decreased due to degradation.

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

3:30 - 4 pm
3286550: Base Oil, Ionic Liquid, Anti-Wear Additive, and Friction Modifier – Which One is at the Solid/Lubricant Interface?
Seong Kim, Dien Ngo, Pennsylvania State University, State College, PA, Jun Qu, Xin He, Huimin Luo, Oak Ridge National Laboratory, Oak Ridge, TN

Lubricants are not a single component liquid; they are a mixture of various additives in base oil. Then, a fundamental surface science is which component is present at the solid/lubricant interface? We studied this question using sum frequency generation (SFG) spectroscopy for lubricants containing ionic liquids ([P8888][DEHP] and [N888H][DEHP]), ZDDP (anti-wear additive), and organic friction modifiers (OFM) in PAO base oil. The SFG analysis results showed that the air/liquid interface is always dominantly populated by PAO due to its lower surface tension in comparison to ionic liquids, modifiers and additives. However, at the silica/liquid interface, it was found that [P8888][DEHP] strongly adsorbs to the silica surface from all mixtures with PAO and organic friction modifier (OFM); adsorption of [N888H][DEHP], however, is insignificant at the same conditions. Results from this study reveal the compatibility among ionic liquids, ZDDP, organic friction modifier and base oil.

4 - 4:30 pm
3277617: Research on Durable Organic Friction Modifiers for PCMO and HDDEO Applications
Brian Casey, Vincent Gatto, Vanderbilt Chemicals, LLC, Norwalk, CT

Organic friction modifiers are a cost-effective approach towards formulating engine oils with improved fuel economy. Traditional organic friction modifiers such as glycerol mono-oleate (GMO) tend to perform best in fresh oils, but are susceptible to oxidative and hydrolytic degradation upon aging. Depending on the additive chemistry, this degradation can result in lower frictional performance, increased wear, and corrosion concerns. The research discussed in this presentation focuses on: 1)

identifying the problematic chemical structures in existing additives, 2) eliminating sites of instability through chemical synthesis, and 3) evaluating the performance and properties of novel organic friction modifiers in comparison to traditional additives in fully formulated engine oils under both fresh and aged oil conditions. The results indicate that small chemical modifications can lead to friction modifiers with simultaneously improved tribological performance and reduced corrosion concerns.

4:30 - 5 pm
3285405: In-Situ Studies on the Adsorption of Lubricant Additives
Alex Mannion, BASF Corp., Florham Park, NJ, Jennifer Honselmann, Fraunhofer IWM, Karlsruhe, Germany, Martin Dienwiebel, Karlsruher Institute for Technology KIT, Karlsruhe, Germany, Thomas Ruehle, Patrick Wilke, BASF SE, Ludwigshafen, Germany

A key factor for improvement and innovation in lubricant development is a fundamental understanding of adsorption processes and mechanisms of action. In our comprehensive study the adsorption of corrosion inhibitors, anti-wear additives and friction modifiers from different base oils on Fe_2O_3 surfaces were investigated. A wide methodological bouquet was used to study the quantitative and qualitative adsorption of additives in-situ. In addition to QCM-D and CLSM, also a UHV-tribometer was used to study the performance of gas phase deposited additives films without environmental interferences. In combination with macroscopic performance tests using a “ball-on-three-plates-tribometer” and corrosion tests, the adsorption, the morphology and the mechanical properties of the additives were correlated with their performance. The multidisciplinary results provide exciting new insights into lubrication fundamentals and reveal so far undescribed phenomes and mechanisms of action.

5 - 5:30 pm
3288324: Fuel Economy Motor Oils: Formulation, Testing and Approval Challenges
Boris Zhmud, BIZOL Germany GmbH, Berlin, Germany

The dominant part of energy losses in the internal combustion engine comes from viscous dissipation. This explains current shift toward lower viscosities, from SAE 40 and 50 in the 1960s-1980s to SAE 20 and 30 nowadays. The definition of “fuel-economy engine oil” is rather vague, as it depends on choice of reference oil and test cycle. ILSAC evaluates fuel economy based on the Sequence VIE/F engine tests using a 2012 3.6 L V6 GM gasoline engine and a 20W-30 reference oil. It is not unexpected that the results of this test may be largely misleading when extrapolated to modern boosted low-displacement GDI and TDI engines. As a result, many OEM-specific fuel economy tests have been introduced, as well as "real life" on-road test cycles, such as NEDC and the newer WLTP. The FE performance of the same oil may change dramatically depending on the driving cycle, and the result will be different for different engines. This makes development of balanced formulations a real challenge.

5:30 - 6 pm - **Lubrication Fundamentals Business Meeting**

Materials Tribology IV - Advanced Engineering Polymers

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3281574: Effect of Temperature and Filler on the Tribological Responses of Sintered Polyimides
Kian Kun Yap, Marc Masen, Imperial College London, South Kensington, London, United Kingdom

A metal-polymer sliding interface can self-lubricate due to the transfer film formation mechanism. This makes it ideal for high-temperature applications where liquid lubricants are not applicable. Although the transfer film formation of PTFE has been investigated in detail by researchers, that of most other polymers remain unclear. Hence, high-temperature polyimide (PI)/AISI 52100 sliding tests were carried out to study how different surface temperatures and filler's contents control the tribological responses. In general, the role of temperature is more dominant than that of filler in governing the tribology of PI. Temperature changes the thermochemistry of PI and then alters the characteristics of transfer materials, namely thickness, orientation, percent coverage, and stability. Then, these affect the friction coefficient, μ, sliding fluctuation, σ, and wear rate, w_s of the system. In brief, the sliding of PI with 40 wt% graphite at 280 degrees Celsius gives the lowest μ, σ, and w_s.

2 - 2:30 pm
3305030: Understanding Friction and Wear Performance of High-Temperature Thermoplastics across Different Lubrication Regimes
Isaac Ballinas, Allegheny Performance Plastics, Leetsdale, PA

This paper will focus on the tribo-performance of PAI, PAEK, PEEK, PPA, and PESU. Each polymer is loaded with equal compositions of CF, graphite, and PTFE. Friction and wear data will be generated on a custom tribological test stand, based on the test stand recommended in ASTM D3702. Mechanical properties (ASTM) will also be provided to compare to friction and wear results. The motivation behind this study is to create a baseline performance mapping for each material. The polymers will be tested at various levels of contact pressure, relative velocity, and lubrication rate. Of interest are the lubrication rate, which will involve dry (no lubricant), a static bath of lubricant, low and high lubrication rates in a recirculating oil setup, and comparison between two or more different lubricants. Additionally, since loadings will be equal and each material will be tested at the same conditions, there will be insight into the effects each base polymer contributes to the tribological system.

2:30 - 3 pm
3285141: Effect of Thermal Aging Treatment on Blend Phase Morphology and Tribological Performance of PI/UHMWPE Blend Composites
Bingxue Cheng, Hongfei Shang, Tianmin Shao, State Key Laboratory of Tribology, Tsinghua University, Beijing, China, Haitao Duan, Jian Li, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China, Song Chen, Hunan Institute of Science and Technology, Yuyang, Hunan, China

Blends of polyimide (PI) and ultrahigh molecular weight polyethylene (UHMWPE) with different

PI/UHMWPE mass ratio were produced. Thermal aging treatment was applied to the blends. Influence of thermal aging on the blends morphology was studied by using Raman Mapping. Wear tests were conducted to study the influence of thermal aging on the tribological performance of the blend composites. The results suggest that the phase morphology of the blends could be changed by thermal aging treatment. At relatively low thermal aging temperatures (100°C,120°C), the blend with high PI/UHMWPE ratio trends to form continuous layered structure, and tribological performance was improved. While for the low PI/ UHMWPE ratio, it was difficult to form the layered phase structure, and improvement of tribological performance was not obvious. For the blends thermal aged at higher temperature (150°C), the tribilogical performance was poor due to significant phase separation occurred after thermal aging.

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

3:30 - 4 pm
3277831: Tribological Performance of Polyimides and Other Engineering Polymers Against Various Metallic Surfaces
Jennifer Vail, DuPont, Wilmington, DE

Polyimides are high performance polymers used in aerospace, transportation, oil and gas, and electronics applications. As the aerospace and transportation industries continue to push for light weighting of vehicles, titanium and aluminum have become more widely used. Additionally, the temperatures of these applications continue to rise to offer better efficiency. It is important to understand the tribological performance of polymers against these metals across a variety of temperatures. This work investigates the tribological performance of polyimides against steel, aluminum, and titanium at ambient and elevated temperatures. Other commonly used high performance polymers such as polyetheretherketon (PEEK) and polyamide-imide (PAI) will also be explored. Intermittent measurements will allow observation of the evolution of transfer films; these films will be analyzed using a 3D confocal microscope and FTIR to investigate material transfer and possible degradation.

4 - 4:30 pm
3286058: Tribological Behavior of Textured Polymer Surfaces
Mohammad Hossain, Emeka Chukwuonu, Bhavinkumar Patel, Texas A&M University-Kingsville, Kingsville, TX, Hung-Jue Sue, Texas A&M University, College Station, TX

Introduction of textures on polymer surfaces has been widely used to improve hydrophobic properties of polymers in various applications such as automotive, aerospace, electronics, and household appliances. However, surface damage resistance of textured polymer surfaces is a major concern as the textured surfaces are highly susceptible to mechanical wear and abrasion. Understanding the development of scratch-induced surface damage in polymers, which arises due to sliding indentation of a rigid asperity, is rather challenging if the surface is textured. In this study, hydrophobic property of model polymers has been improved through introduction of various surface textures. Influence of surface texture on scratch resistance of model polymers is studied. A three-dimensional finite element method (FEM) modeling has been used to understand the stress and strain field development in textured polymer surfaces during scratching.

4:30 - 5 pm

3323158: Lubrication-Induced Softening of Polymeric Materials in Tribological Contacts

Go Tatsumi, Monica Ratoi, Brian Mellor, University of Southampton, Southampton, United Kingdom, Yuji Shitara, Shinji Hasegawa, Kiyomi Sakamoto, JXTG Nippon Oil & Energy Corporation, Yokohama, Japan

Polymeric materials are becoming preferred in many tribological applications because of their advantages such as low weight, self-lubrication and reduced noise properties. Lubrication has the potential to further reduce friction and wear, but both positive and negative effects have been reported and the mechanism is unknown. This study investigated softening of three polymers, Poly-ether-ether-ketone (PEEK), Polyoxymethylene (POM) and Polyphenylene sulfide (PPS), induced by lubrication with poly−α−olefin (PAO) base oil. Tribological tests were carried out with dry and lubricated steel/polymer contacts. Nanoindentation measurements showed that lubrication decreased the hardness and elastic modulus of polymer wear tracks, and this depended on the lubricant chain length (viscosity) and the type of polymer used.

5 - 5:30 pm

3309851: Nanoscale Structures Determined Tribological Behaviors of Styrene-Ethylene-Butylene-Styrene Block Copolymer

Qinghua Fang, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun, Jilin, China

Self-assembling soft materials have been playing an important role in meeting social and economic goals for more efficient processes, hierarchically structured equipment. Styrene-Ethylene-Butylene-Styrene (SEBS) block copolymers are self-assembled soft materials that can be separated at the nanometer scale, making them ideal for emerging nanotechnology. Application of hydrophilic polymer chains for lubricating SEBS surfaces in aqueous environment has been studied. This study reports on interactions of SEBS block copolymers with hydrophilic polymer chains and water, as well as with stainless steel ball surfaces. The friction coefficients under polyvinyl alcohol aqueous solution showed significant improvement compared to pure water condition, which is attributed to the physisorption and subsequent improvement in the lubricating film stability. The results reported herein will broaden our understanding of friction phenomena in self-assembling nanostructures processing applications.

6H — Randolph 1

2D Materials - Materials Tribology and Nanotribology Joint Session III

Session Chair: Shilpa Beesabathuni, Quaker Houghton, Eagleville, PA
Session Vice Chair: Mengwei Han, University of Illinois at Urbana Champaign, Urbana, IL

1:30 - 2 pm

3325478: Probing the Influence of Water and Oxygen on the Friction and Wear of MoS2 Using In-Situ LEIS

Tomas Babuska, Brandon Krick, Lehigh University, Bethlehem, PA, John Curry, Sandia National Laboratory, Albuquerque, NM

MoS2 solid lubricants used in space applications experience a variety of environments before and during use. When stored, water, oxygen and long periods of aging can affect the lifetime performance of MoS2 lubricants through excessive wear and high initial first cycle friction. In orbit, MoS2 is exposed to atomic oxygen which can oxidize the surface inhibiting the tribological performance. The influence of water and oxygen on the degradation of MoS2 is still not well understood. Using depth profiling low energy ion spectroscopy, sequential atomic layers of MoS2 films can be probed to investigate the kinetics of water and oxygen on the surface and bulk of MoS2 films. Combined with in-situ tribometry, friction wear and surface composition can directly be measured without breaking ultra-high vacuum environments.

2 - 2:30 pm
3285663: Nanomechanical Properties of Ti_3C_2 and Nb_2C MXene
Xuanli Zhou, Yanbao Guo, Quan Xu, Deguo Wang, China University of Petroleum, Beijing, China

MXene is a new and popular two-dimensional material with broad application prospects. We analyzed the chemical structure of Ti_3C_2 and Nb_2C MXene using X-ray diffraction (XRD). The adhesion and friction behavior of Ti_3C_2 and Nb_2C MXene were compared by atomic force microscopy (AFM). It was found that the adhesion and friction of MXene increased with increasing pressure, but decreased as the temperature increased. The sliding speed and delay time of the probe have little effect on the friction performance. We used X-ray photoelectron spectroscopy (XPS) to explain the chemical structure changes of MXene at different temperatures. This discovery laid the foundation for understanding the adhesion and friction mechanism of MXene, and made MXene have broad application prospects.

2:30 - 3 pm
3282352: Understanding Interlayer Contact Conductance in Twisted Bilayer Graphene
Zhiwei Yu, Tianbao Ma, Jianbin Luo, State Key Laboratory of Tribology, Tsinghua University, Beijing, China

Bilayer or few-layer two-dimensional (2D) materials showing novel interlayer frictional and electrical properties have aroused increasing interest in recent years. Yet how to obtain a comprehensive understanding of interlayer contact conductance still remains a challenge but is significant for improving the performance of bilayer or fewlayer 2D electronic devices. Here, we report conductive atomic force microscope (C-AFM) experiments to explore the interlayer contact conductance between bilayer graphene with various twisted stacking structures. The current maps show that the interlayer contact conductance between BLG strongly depends on the twist angle. Moreover, the moiré superlattice-level current images of t-BLG show modulations of local interlayer contact conductance. Density functional theory calculations together with a theoretical model show that the modulation is mainly attributed to the overall contribution of local interfacial carrier density and tunneling barrier.

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

3:30 - 4 pm
3286917: Friction and Mechanical Stiffness Measurements on Graphene-covered Substrates: The Influence of Water Intercalation
Philip Egberts, Zahra Aboolizadeh, Peng Gong, Leszek Sudak, University of Calgary, Calgary, Alberta, Canada

Graphene is an excellent materials to examine when determining the fundamental tribological properties of materials at the nanometer length-scale. With this atomically-thin material, you can

change the friction and mechanical properties with the simple addition of one more layer of atoms. While these properties are seemingly easy to measure, ambient humidity have a significant impact on the measured tribological properties. In this study, we show that the out-of-plane bending stiffness of graphene does in fact vary with the number of layers of graphene under UHV conditions. We also demonstrate the influences that the intercalated water has on the measured friction and mechanical properties under ambient air conditions. The impact of this intercalated water on the existing friction reducing models of graphene on substrates will be discussed.

4 - 4:30 pm
3297772: Nanotribology of 2D Transition Metal Dichalcogenides: Friction Contrast between MoS_2, $MoSe_2$, and $MoTe_2$
Mohammad R. Vazirisereshk, Ashlie Martini, University of California Merced, Merced, CA, Kathryn Hasz, Meng-Qiang Zhao, A.T. Charlie Johnson, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Two-dimensional (2D) transition metal dichalcogenides (TMDs) are an emerging class of layered materials with potential applications ranging from nanoelectronics to next generation solid lubricants. Among 2D TMDs, the atomic scale tribological properties of MoS_2 are widely studied, including in our recent work comparing its frictional behavior with graphene (Vazirisereshk et al., Nano Lett., 2018). However, the effects of changing the chalcogens (from S to Se or Te) on the tribology are not well-explored. To address this, we characterized MoS_2, $MoSe_2$ and $MoTe_2$ monolayers using atomic force microscopy (AFM) experiment and molecular dynamics (MD) simulation. Experiments show that $MoTe_2$ has the highest friction among these materials and $MoSe_2$ has the lowest. Simulations reveal that the observed friction contrast arises from the difference in quality of the contact in the tip-TMD interface. These results help establish a fundamental understanding of the nanotribology of 2D TMDs interfaces.

4:30 - 5 pm
3285069: Environmental Effects on Friction of Graphene Step Edges
Zhe Chen, Seong Kim, Pennsylvania State University, University Park, PA

Graphene is an ideal material for lubrication coatings. However, graphene step edges, which are nearly inevitable on the graphene coating, have a much higher friction than the graphene basal plane and thus deteriorate the overall lubricity of the coating. In this work, the friction properties of a single layer graphene edge on highly oriented pyrolytic graphite (HOPG) are investigated with atomic force microscopy (AFM). It is found that distinct friction behaviors can be obtained in various environmental conditions. The adsorption isotherm of vapor molecules on HOPG surface is studied. Then, the friction mechanism is discussed. This work enriches the understanding of frictional properties at atomic step edges and is helpful for the application of 2D materials as lubrication coatings.

5 - 5:30 pm
3283657: The Evolution Mechanism of Ultra-Low Friction Interface Based on Onion-Like Carbon Structure
Jianxun Xu, Tsinghua University, Beijing, China

The onion-like carbon is a spherical carbon material composed of sp^2 phase entirely, whose excellent mechanical properties and unique lubrication mechanism provide broad prospects for the development in many scientific fields. In this project, the tribolayers were formed during friction and then characterized by FIB and HRTEM-EDS, in order to obtain high-resolution structural characteristics and

composition information, which can be used to distinguish the new lubrication structures formed in the friction process. The ultra-low friction and even superlubricity mechanism can be studied in detail. The effect of friction characteristics was analyzed on atomic level, and the ultra-low friction properties of carbon-based materials were studied systematically. Through this project, we can reveal the lubrication mechanism of carbon-based thin films, and provide further structural evidence for ultra-low friction phenomena.

5:30 - 6 pm
3276812: Interfacial Nanostructured Tribofilm of Long-Durability and Ultralow-Wear 2D-Materials/QDs Coating
Xuan Yin, State Key Laboratory of Tribology, Tsinghua University, Beijing, China

The 2D-materials/quantum dots (QDs) composite coating possesses lots of merits. Here, specific efforts were devoted to developing 2D-materials/QDs composite coating and exploiting its anti-wear interfacial performance in ambient environment. Besides, combination with nanoparticles would impose significant effects on improving lubricity of binary composite coating to obtain long-durability ternary composite coating. Meanwhile, macro- and atomic-scale characterizations were utilized to explore the lubrication behavior of binary and ternary composite coating to clarify the influence of compositions in the establishment of ultralow-wear sliding interfaces. A nanostructured-tribofilm with unprecedented bonding features was in-situ formed along the sliding interface. And the ternary coating has long-durability and ultralow-wear during sliding for a long time.

6 - 6:30 pm
3278877: Nanoscale Tribological Behavior of Few Layer Graphene with Considering Material Microstructure and Potential
Shengguang Zhu, Guangdong Xinhui CIMC Special Transportation Equipment Co., Ltd, Jiangmen, Guangdong, China

Atomically thin graphene is an ideal model system for studying nanoscale friction due to its intrinsic two-dimensional anisotropy. For few layer graphene friction contact, an interfacial potential barrier theory to calculate friction and wear is proposed, the relationships between the friction force and the parameters of few layer graphene tribo-system, such as the surface energy, the micro-structural parameters of material, etc., are revealed. It is suggested that the performance of friction and wear depend on the magnitude and distribution of interfacial potential barrier on the contact surfaces. The results of the calculation is consistent with the experimental results of few layer graphene specimen carried out by an ultra high-vacuum atomic-force micro- scope, thus illustrating the feasibility of the proposed method.

6I Randolph 2

Surface Engineering III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm

3317907: Research on the Frictional Performance of Laser Textured and Rough Surface Based on Pin-On-Disk Test

Bo Xu, Bifeng Yin, Xuan Xie, Zhiling Chen, Xuefeng Wang, Jiangsu University, Zhen Jiang, China

Surface roughness and texture both have effects on the friction of the sliding surface. In this research, the Laser Surface Texturing(LST) technology was used to process micro-dimples with different geometric parameters on the steel discs, and several different roughness discs and pins were processed. By conducting the pin-on-disc fiction tests, the tribological performance of textured and rough surface was compared under typical working conditions. The experimental research showed that for the textured disc, the optimal parameter of the micro-dimple is 10% area ratio with 0.1 depth-to-diameter ratio; for the rough disc, the friction force decreases with the smaller roughness. In addition, compared with the rough surface, the optimized laser textured surface could reduce the friction force of the pin-disc sliding pair, especially under the boundary and mixed lubrication states.

2 - 2:30 pm

3281789: Mechanochemical Surface Finishing: The Rehbinder Effect in Action

Boris Zhmud, Applied Nano Surfaces Sweden AB, Uppsala, Sweden

The Rehbinder effect is closely linked to running-in or breaking-in phenomena, and thus constitutes a philosophical basis of mechanochemical surface finishing processes, often viewed as in-manufacture running-in processes. Mechanochemical surface finishing processes combine elements of mechanical burnishing with a tribochemical deposition of a solid lubricant tribofim. This allows one to obtain, via a single finishing operation, a smoother surface with a significantly reduced coefficient of boundary friction and improved wear-resistance and load-carrying capacity. The present study demonstrates how the material type and premachining affect the tribological properties of finished components. Besides that, modifications in the surface roughness profile and tribofilm compositions are investigated using Auger electron spectroscopy (AES) and angle resolved light scattering (ARS).

2:30 - 3 pm

3288844: Surface Functionality Prediction via Curvature Analysis

Mark Malburg, Digital Metrology Solutions, Columbus, IN

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

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

3:30 pm - 4:00 pm

3320195: The Influence of Disc Surface Texture on Tribological Performance of Disc-Ball Sliding Pair under Dry Sliding Conditions

Andrzej Dzierwa, Pawel Pawlus, Rzeszow University of Technology, Rzeszow, Poland, Rafal Reizer, University of Rzeszow, College of Natural Sciences, Rzeszow, Poland

The use of all parameters to assess the surface texture in terms of its functional characteristics is not entirely possible. The attempt to assess the texture using only one parameter, that often happens in industrial practice, is a simplification. Since the functional properties of friction pairs are significantly affected by texture designing, the proper selection of parameters characteristic for a given process is an important issue.
Therefore, the aim of the present work was to investigate the effect of surface preparation on surface texture parameters and correlations between roughness parameters and friction and wear. Discs were prepared by various techniques to obtain the value of the Sa parameter in the range 0.02 – 6.0 μm. It was found that the initial surface topography had a significant influence on friction and wear levels under dry sliding conditions. The correlation between several surface topography parameters and friction and wear was also identified.

4 - 4:30 pm

3325618: Morphology Image-Based Surface Classification by Using Convolutional Neural Network (CNN)

Huan Zhang, Daniel Mosher, United Technologies Research Center, East Hartford, CT

Both machining and additive manufacturing often require a tight control of surface finish, especially for working tribological surfaces. In comparison to 2D profile and 3D topography measurements, high resolution optical surface images also reveal rich morphological information specific to the finishing processes. Meanwhile, rapidly advancing machine learning techniques enable image-based classification and predictions. This paper presents a robust, efficient surface classification and qualification approach developed from transfer-learning of pre-trained CNNs. By using numerically generated surfaces that simulate the roughness of typical finishing processes, the application has been demonstrated with nearly 100% training accuracy and above 90% testing accuracy. The image size and resolution needed for successful classification are determined. It also shows that the classification results can be correlated to the tribological behavior predicted by the FE simulation of sliding contact.

4:30 - 5 pm

3291319: Capillary Force Lithography and Nanodrawing Techniques for Engineering Nanoscale Polymer Patterns for Tribological Applications

Eui-Sung Yoon, Hong Nam Kim, Korea Institute of Science and Technology, Seoul, Seongbuk-gu, Republic of Korea, Prashant Pendyala, Hanyang University, Seoul, Republic of Korea

Nanoscale tribology is complex due to material and surface size effects. Studying and engineering nanoscale tribology was difficult due to limitations in generating surfaces with well-defined geometries and chemistries. We used capillary force lithography and nanodrawing techniques to fabricate well-defined cylindrical, mushroom-shaped, and hierarchical patterned surfaces. Using such well-defined surfaces, we study the role of various nanoscale physico-chemical cues on adhesion and friction. We show that curvature, surface energy and pattern density predominantly affected adhesion. While lateral contact stiffness affected friction. We discovered a correlation between nanoscale adhesion and friction for our patterned surfaces. A master curve in the graph of adhesion vs. friction that defines this

correlation was dependent on the effective lateral stiffness of the contact. Our results will in identification of simple pattern parameters used to engineer the tribology at nanoscale

5 - 5:30 pm
3325943: Investigation of the Evolution of Pores during Scuffing Resistance Tests Performed on Sintered Steel Vacuum Impregnated with Graphite
Nicolas Araya, Aloisio Klein, Cristiano Binder, Guilherme Neves, Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil, Jose Biasoli de Mello, Universidade Federal de Uberlandia, Uberlandia, Minas Gerais, Brazil

Graphite is known as an excellent solid lubricant and can be applied into a tribological contact by aerosol, as an oil additive, as a lubricating phase in composite materials and impregnated in the pores of a porous material [1-2]. This last method allows graphite to form a self-replenishing film as the material wears [3]. To study how impregnated pores behave during the lubricity regime, low alloy sintered steels with varying degrees of porosity were impregnated with graphite using acetone as carrier fluid. Then, the scuffing resistance and wear rates of the specimens were tested using linear reciprocating tests and the wear tracks characterized by SEM, image analysis, micro-Raman spectroscopy and Vickers microhardness. Results show that while porosity is beneficial to the scuffing resistance it is detrimental to the wear rates. A model for the sealing of pores during the scuffing resistance tests is proposed.

5:30 - 6 pm - **Surface Engineering Business Meeting**

6J — Randolph 3

Condition Monitoring IV

Session Chair: TBD
Session Vice Chair: TBD

Open Session

6K — Michigan 1

Engine and Drive Train IV

Session Chair: Raj Chandramohanan, BorgWarner Inc., Arden, NC
Session Vice Chair: Piotr Grzyska, Afton Chemical Corp., Richmond, VA

1:30 - 2 pm
3314847: A Ceramic Nano-Composite Coating for Potential Engine Applications
Swarn Jha, Yan Chen, Hong Liang, Texas A&M University, College Station, TX

For extreme operating conditions such as engines, there is an immense demand for high-performance coatings. Key challenges are maintaining high-temperature stability, low friction coefficient, and high resistance to wear. In this work, nanoceramic based high-temperature coatings are designed and synthesized. The coatings are tough, hard, and show promising lubricating performance. High-temperature ceramics such as SiC, BN were used to develop the coating using a low-cost and simple method. α-zirconium phosphate and hybridizing graphite, which are ideal for use with ceramics, metals, and alloys, were used as friction-reducing agents. The coating showed durability in a wide range of temperatures. Experimental results showed that the friction coefficient obtained for our coating was 66 % lower than that for steel on steel sliding contact. Further details on the microstructure, composition, and tribology of the coating will be discussed in this presentation.

2 - 2:30 pm
3287678: Formulation Approaches to Meet the Latest SAE J306 Standard for Automotive Gear Oils
Justin Mills, Evonik Oil Additives, Horsham, PA

More stringent fuel economy requirements and extended oil drain intervals are driving the need for a new class of synthetic and semi-synthetic automotive gear oil formulations. In response to this need, SAE updated J306 in 2019 for the first time in nearly fifteen years. The 2019 version now includes a tightened SAE 80 viscosity grade, as well as viscosity grades of SAE 65, SAE 70, and SAE 75 which specify lower viscosity gear oils for increased efficiency. With these new viscosity grades and the need to continue meeting rigorous shear stability and low-temperature requirements, may come new formulation challenges that may require a different approach to base stock and viscosity index improver selection. This presentation will explore formulation approaches to meet the latest SAE J306 requirements.

2:30 - 3 pm
3305554: Correlating Viscosity to Fuel Efficiency in the Heavy-Duty Diesel Engine Fuel Efficiency Tests and the Influence of Viscosity Index Improvers.
Lucas Camposo, Phil Hutchinson, Julien Couet, Boris Eisenberg, Evonik Oil Additives, Horsham, PA

Durability has been the primary objective when formulating heavy-duty diesel engine oils. However, fuel economy has recently received increased international attention. For example, the introduction of the API FA-4 performance standard allows lubricant formulators to specify an oil with lower high-temperature high-shear (HTHS) viscosity to help achieve fuel efficiency. Currently there are no internationally recognized fuel efficiency tests for heavy-duty diesel engines, but there have been OEM developments in this direction. For example, Volvo and Daimler have developed their own fired engine tests to determine the fuel efficiency effect of the oil. In this paper, we report our findings regarding the influence of viscosity and viscosity index improver on the Daimler OM501 fuel economy test. These findings include strong relationships between HTHS viscosities at 80 and 100C and fuel economy.

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

3:30 - 4 pm
3307947: Effect of Friction Modifier and Extreme Pressure Agent on NVH of Chain CVTF
Toshiaki Iwai, Idemitsu Kosan, Ichihara, Chiba, Japan

The purpose of this study was to optimize the interaction between friction modifier (FM) and extreme pressure agent (EP) in CVT fluid (CVTF), especially in chain CVTF, to solve the vibration noise problem.

Oleylamine (FM) and tricresyl phosphite (TCP) (EP) were blended with PAO, and the friction performance was evaluated with MTM.The test piece after the test was evaluated by laser microscope and Desorption Electrospray Ionization Mass Spectrometry (DESI-MS) surface analysis technique to observe the surface roughness and the chemical properties of the reaction layer. Friction test as a result, it was clarified that the rougher surface roughnss increased the friction coeffcient. Chemical composition measuring binding fruits, conventional measurement MTM disk sliding surface which is difficult of oleylamine the observation succssful, the friction coefficient by the presence of oleylamine decreases it revealed.

4 - 4:30 pm
3318911: Three-Dimensional Multiphase Physics-Based Model to Study Engine Cylinder-Kit Assembly Tribology
Sadiyah Sabah Chowdhury, Harold Schock, Michigan State University, East Lansing, MI

Controlling wear and emission is pivotal to the improved durability, efficiency and reduced oil consumption of internal combustion engines. The transport of fluids in the cylinder-kit assembly controls friction, wear, oil consumption; influences engine efficiency and emission. This work addresses the understanding of the fundamental aspects of oil transport and combustion gas flow in cylinder kit using simulation tools and high-performance computing. A dynamic three-dimensional multiphase, multicomponent model is demonstrated to study cylinder-kit assembly tribology during the four-stroke cycle of IC engine. The contribution of oil evaporation, oil entrained in the blowby and blowback gas flow for a small-bore engine is investigated. The effect of ring twist on mass flow rate and pressure across the piston is also quantified. The velocity field shows substantial circumferential flow in the piston ring pack leading to high-velocity blowback into the combustion chamber during expansion.

4:30 - 5 pm
3284934: Finite Element Analysis of Cylinder Liner Thermal Deformation Based on Fluid-Solid Coupling
Bowen Jiao, Xuan Ma, Tongyang Li, Xiqun Lu, Zhigang Liu, Harbin Engineering University, Harbin, Heilongjiang, China

The deformation of the cylinder liner will result in the working environment in the cylinder changing, which makes the working performance of the diesel engine fail. Therefore, it is of great significance to control and investigate the deformation of cylinder liner. To calculate the thermal deformation of the cylinder liner of a marine engine, fluid-structure coupling method was used. Firstly, temperature and heat transfer coefficient (HTC) of the fluid domain were calculated by Fluent. Secondly, the temperature and HTC are imported into Abaqus which the data is programming with Matlab to realize mapping from coupling surface of fluid domain to solid. Then the temperature calculated by Abaqus is imported into the Fluent to calculate again. Afterwards, iterating several times according to the above method. When the temperature of the Abaqus is stabilized, the thermal deformation of the whole machine is calculated.

5 - 5:30 pm
3294961: Wear and Friction Simulations for the Main Journal Bearings under Start-Stop and Transient-Loading Conditions
Zhiqiang Liu, Arup Gangopadhyay, Ford Motor Company, Dearborn, MI

A simple numerical approach is presented for computing the wear and friction of journal bearings during start-stop and under transient-loading conditions. In the model, the selected elastic-plastic equations of

random rough surfaces in contact have been combined with well-established elastohydrodynamic equations to calculate highly loaded lubricated contacts by using the load-shearing concept. The model takes into account shear-thinning, thermal effects in EHL, and lubricant starvation effects. Modified Archard's wear coefficient important in describing the bearing wear is introduced. The approach is valid for the calculations of the asperity pressure at low values of the ratio of film thickness to the combined roughness of the two surfaces. Applications are discussed, including association of lift-speed on wear and friction characteristics of journal bearing during a start-stop cycle, instantaneous oil film thickness on wear scar region during engine start-stop cycles.

5:30 - 6 pm - **Engine & Drive Train Business Meeting**

6L Michigan 2

Tribotesting II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3305068: Understanding Friction and Wear Performance of High Temperature Thermoplastics across Different Lubrication Regimes
Isaac Ballinas, Allegheny Performance Plastics, Leetsdale, PA

This paper will focus on the tribo-performance of PAI, PAEK, PEEK, PPA, and PESU. Each polymer is loaded with equal compositions of CF, graphite, and PTFE. Friction and wear data will be generated on a custom tribological test stand, based on the test stand recommended in ASTM D3702. Mechanical properties (ASTM) will also be provided to compare to friction and wear results. The motivation behind this study is to create a baseline performance mapping for each material. The polymers will be tested at various levels of contact pressure, relative velocity, and lubrication rate. Of interest are the lubrication rate, which will involve dry (no lubricant), a static bath of lubricant, low and high lubrication rates in a recirculating oil setup, and comparison between two or more different lubricants. Additionally, since loadings will be equal and each material will be tested at the same conditions, there will be insight into the effects each base polymer contributes to the tribological system.

2 - 2:30 pm
3309375: Localized Scuffing of a Flake Graphite Cast Iron Cylinder Liner by Geometric Contact Pressure Variation
John Walker, Zach Barnes, Peng Jiang, Timothy Kamps, University of Southampton, Southampton, Hampshire, United Kingdom

The trend towards thinner lubricant viscosities is an effective approach to reduce shear losses in an automotive engine during fluid film lubrication, however this can also lead to an increase in scuffing should the film be unable to support the load. Representative laboratory screening of ring-liner material pairs for scuffing behavior is complicated by subtle onset and rapid progression to failure. In this work the dynamic ring loading profile of a heavy-duty diesel was numerically simulated and patterned onto a

flake graphite cast iron test coupon. Reciprocating sliding of this configuration against a flat 52100 steel counter surface enabled a variable contact pressure along the stroke length similar to that experienced in the engine. Scuffing was induced by increasing the temperature of the contact until a rapid rise in friction force was observed. Failure initiated at the reversal position where the contact pressure was highest.

2:30 - 3 pm
3310894: Shoe Tread Can Reduce Slip Risk on Surface Contaminated with Slurry Contaminants
Mahiyar Nasarwanji, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA, Jonisha Pollard, National Institute for Occupational Safety and Health, Pittsburgh, PA

Reducing slip and fall risk has most often focused on surfaces contaminated with liquid contaminants. However, research has indicated that solid contaminants can also pose a significant slip risk. Appropriate treads on shoes can potentially be a solution to reduce slip risk for surfaces contaminated with slurry contaminants. This study investigates the influence of shoe tread design on the available coefficient of friction (ACOF) for walking surfaces contaminated with a layer of wet clay. Ten shoe tread designs were tested against a plexiglass surface using a portable slip simulator while under-floor forces and video images were recorded. Treads do have an effect on the ACOF. Shoes with worn treads performed the worst. Findings suggest that contact area (pressures) and tread channel features, especially at the back of the heel, may influence the ACOF.

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

3:30 - 4 pm
3314683: An Updated Method for Fuel Lubricity: Line-On-Cylinder Lubricity Evaluator (LOCLE)
Greg Hansen, Peter Lee, Southwest Research Institute, San Antonio, TX

In diesel engines, the fuel pumps and injectors are subjected to tremendous pressures, upwards of 30,000 psi in modern systems. In order to generate and maintain this level of pressure, the internal pump and injector components are made to an exacting standard. The drawback is that the moving components are lubricated with only the fuel. If the fuel has insufficient lubricating properties, catastrophic wear and subsequent failures can occur. In an ongoing effort to modernize sliding wear tests, work was undertaken to improve lubricity testing for aviation turbine fuels that are utilized in diesel powered ground vehicles. This is the second part of this work in which unidirectional sliding wear is studied. The end goal is to have two appropriate lubricity tests (oscillating and unidirectional) that are able to screen fuels and their additives for acceptable use in modern fuel system hardware.

4 - 4:30 pm
3316313: Improving Repeatability of Friction and Wear Testing Results on the SRV Test Rig
Howard Benade, University of Pretoria, Pinetown, KwaZulu Natal, South Africa

Friction and wear screening tests are used to rank lubricants in order to select potential candidates for field trials. These tests are also used to evaluate performance of lubricants and form part of OEM specifications. Consequently, good repeatability of friction and wear test results is important to reduce uncertainty. In this study, the running in procedure of the friction and wear test on the SRV test rig was modified to a gradual load increase while the atmospheric conditions were controlled. The repeatability of the results improved compared to results obtained with the step load increase. Results include the friction coefficient, wear scar diameter and wear scar volume. The amount of wear was also measured

after specified test durations for each load increase method.

4:30 - 5 pm
3280430: Nano Diamond as Potential Candidate for Sliding Wear Applications under Lubricated Conditions
Ankush Raina, Shri Mata Vaishno Devi University, Katra, Jammu and Kashmir, India

The present study is aimed to evaluate the lubrication characteristics of diamond nano additives in the PAO base oil. Also, the synergism of diamond nano particles with copper oxide nanoparticles was studied. The experiments were conducted on ball on disc tribometer. The experiments were performed for steel/al alloy contacts in the boundary lubrication regimes. The loads were varied form 10-50 N in the steps of 10. The type of wear and chemical content on the worn surfaces was obtained by Scanning Electron Microscopy (SEM) and Electron Dispersive Spectroscopy (EDS).The results obtained after the testing revealed that nano diamond is a potential candidate in the field of nano lubrication. A substantial reduction in COF and wear volume was observed with the combined use of copper oxide and diamond nanoparticles. The improvement is mainly attributed to the film formation capability of copper oxide nanoparticles and rolling/polishing effect of the diamond nanoparticles.

6M Michigan 3

Nanotribology III

Session Chair: Prathima Nalam, University at Buffalo, Buffalo, NY
Session Vice Chair: Benoit Thiebaut, TOTAL MS, Solaize, France

1:30 - 2:30 pm
3318323: Invited Talk: Mechanical Dissipation of Energy: From Breaking of Bonds to the Release of Adhesive Contacts
Lars Pastewka, Richard Jana, Antoine Sanner, University of Freiburg, Freiburg, Germany

Rate-independent energy dissipation is typically associated with mechanical instabilities. This talk discusses scenarios in which mechanical instabilities give rise to dissipation. At the molecular scale, bond-breaking events are fast mechanical instabilities. Molecular calculations show that bond breaking events in amorphous carbon can be described as a stress-assisted activated process, and that sufficient stress leads to a fold catastrophe that opens the bond. The energy dissipated in the process can be directly correlated with the yield stress of bulk material or the friction force during contact and sliding. At larger scales, adhesive interactions between rough surfaces can give rise to sudden detachment of asperities. This also constitutes an instability that dissipates the energy difference between the attached and the detached state. I discuss the implications of adhesion-induced energy dissipation for the case of a ball rolling on a surface.

2:30 - 3 pm
3303722: Stress-Dependent Adhesion in Nanoscale Contacts
Sai Bharadwaj Vishnubhotla, Andrew Baker, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, Ashlie Martini, University of California-Merced, Merced, CA

Contact mechanics models are extensively used to describe, measure, and predict the properties of nanoscale contacts. An important assumption in these models is that the work of adhesion is constant for a given pair of materials. Recent studies (Milne et al., ACS AMI, 2019 and Vishnubhotla et al., Tribol. Lett., 2019) have shown that this assumption can break down for silicon-diamond contacts, and the work of adhesion can vary with stress. Here, we have conducted more than 70 in situ transmission electron microscopy and molecular dynamics simulation tests to investigate the effect of compressive pressures up to 25 GPa. We have also investigated other covalently-bonded systems to understand the universality of these trends. The results demonstrate how the loading modifies the atomic-scale surface interactions that determine adhesion.

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

3:30 - 4 pm
3282831: Study of Deformation Behaviors of Nanoscale Textured Surfaces in the Contact Using Molecular Dynamics
Pengzhe Zhu, Beijing Institute of Technology, Beijing, China, Baozhen Li, Beijing Jiaotong University, Beijing, China

It is well-known that nanoscale textured surfaces exhibit unique contact behaviors. However, few studies have focused on the deformation behaviors of nanoscale textured surfaces in the contact. In this work, a series of molecular dynamics simulations have been conducted to investigate the deformation behaviors of textured gold surfaces with various texture parameters such as texture shape, texture size and texture density. Special attention has been paid to the plastic deformation behaviors of textured gold surfaces. We found that the texture parameters have a great impact on the load, effective contact area and deformation behaviors during the contact of gold textured surfaces. The insights gained in this work could provide theoretical basis for the design of textured surfaces in the nanoscale contact.

4 - 4:30 pm
3284114: Influence of Crystal Anisotropy on Deformation Behaviors in Nanoscratching of AlN
Baozhen Li, Beijing Jiaotong University, Beijing, China, Pengzhe Zhu, Beijing Institute of Technology, Beijing, China

Molecular dynamics simulations are carried out to study the influence of crystal anisotropy on deformation behaviors in the nanoscratching process of AlN. We investigate the scratching process of AlN(0001), AlN(10-10) and AlN(-12-10) surfaces, respectively. It is found that there exists significant anisotropy of the deformation behaviors of AlN for various crystal orientations in the scratching process. In scratching AlN(0001) surface, most of dislocation loops generated can be divided into two forms: the "u-shaped" half loops with Burgers vector b=1/3<1-210> perpendicular to the contact zone of groove and dislocation loops with Burgers vector b=1/3<-1010> parallel to the AlN(0001) surface. However, in the scratching of AlN(10-10), a large number of dislocation loops with Burgers vectors b=1/6<02-23> are produced perpendicular to the scratching surface.

4:30 - 5 pm
3317629: Super Lubricity of Solids from Quantum Mechanics
Bo Zhang, Saga University, Saga-shi, Saga, Japan

It is proposed that incommensurate contact surfaces is associated with the super lubricity [1]. However engineering surfaces in contact are almost incommensurate because there are always exist misalignment in crystal orientation between two contact surfaces and crystal defects within the surfaces, while the super lubricity belongs to very limited special cases. Friction-induced low energy basal plane [2] and hydrogenation of carbon-contained materials [3] are also considered as possible mechanisms of super lubricity. Both give a good explanation of low friction but they are definitely not sufficient to substantiate the super lubricity. Quantum mechanics shows that tangential force in contact surfaces is not directly associated with frictional force, and super lubricity is possible when some quantum criterion is satisfied. This analysis gives the derivation of the quantum criterion.

5 - 5:30 pm
3294663: Resolution of Stability Issues in Fluid Systems Containing Nanostructured Particles
Stephan Wieber, Michael Hagemann, Roland Wilkens, Aidan Rose, Evonik Resource Efficiency GmbH, Darmstadt, Germany

Nanostructured materials are known in literature to have extraordinary tribological properties. These include high load bearing capacities, very low friction (reaching even super lubricity) and anti-wear properties. In spite of their advantages and intense academic research, this additive class is still not well established nor widely used in the industry. Sedimentation, filtration and stability are concerns constraining broader adoption of nanostructured materials as lubricating oil additives. This paper describes a technology platform which provides stabilization of relevant particles in mineral base oils and low viscosity PAO's. The paper reports on stability behaviors of particle-based concentrates for use in a range of lubricant applications. It demonstrates stable fluid system are obtained without compromising on tribological performances of a range of solid lubricants, as e.g. hBN, graphene and WS2.

5:30 - 6 pm
3323530: Nanomechanical and Tribological Properties of Hardened 60NiTi
Charles Miller, Min Zou, University of Arkansas, Fayetteville, AR

Nanomechanical and tribological properties of hardened 60NiTi were studied using a nanoindenter. The load-displacement behavior of the bulk 60NiTi was obtained using a diamond Berkovich tip with a 150-nm tip radius. A cube corner diamond tip with a 100-nm tip radius was used to selectively indent the NiTi + Ni_4Ti_3 regions and the microscale globular Ni_3Ti precipitates. The Ni_3Ti phase was found to have a significantly higher modulus and hardness than the NiTi + Ni_4Ti_3 regions, which have a similar modulus and hardness to the bulk 60NiTi. Scratch tests were performed using a spheroconical diamond tip with a 5-µm tip radius at various normal loads, and adhesion tests were performed using the same tip at a 1-nm displacement. The coefficient of friction was found to decrease as the normal load was increased. A significant amount of adhesion force was found to be present between the tip and 60NiTi.

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

Roundtable Discussion Session

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.

Thursday, May 7, 2020

7A Columbus AB

Synthetic Lubricants and Hydraulics II

Session Chair: TBD
Session Vice Chair: TBD

Open Session

7B Columbus CD

Nonferrous Metals II: Lubricant Analysis and Filtration

Session Chair: TBD
Session Vice Chair: Andrea Knopp, Constellium, Ravenswood, WV

Session Starts at 8:30 am

8:30 - 9 am
3279624: Analysis of Nonferrous Rolling Emulsions Using Laser Diffraction and Multiple Light Scattering
Tom Oleksiak, Lucinda Knelsen, Novelis, Inc., Kennesaw, GA

Particle size of rolling oil emulsions in nonferrous rolling operations has usually been measured using laser diffraction. These instruments often allow a plant to develop methods to control emulsion stability. Formulators also can use this technique to develop rolling emulsions and test these emulsions as to resistant to hardness and tramp oil contaminants. Recently, technology has been developed which uses static multiple light scattering to measure colloid stability. This technique gives a direct kinetic based determination of emulsion stability by scanning a static emulsion as a function of time. This paper will cover the complimentary features of both analyses and will explore advanced methods for characterizing nonferrous rolling emulsions.

9 - 9:30 am
3284266: Improving and Expanding the Applicability of an Existing Pin & Vee Standardized Test Method for Cutting Fluid Evaluation
Emmanuel Georgiou, Dirk Drees, Falex Tribology NV, Rotselaar, Belgium

Nowadays, a lot of standard tests are done with procedures and equipment designs from many decades ago. However, equipment has evolved and improved, and so have our insights. Thus, it makes sense to look at these ‘older’ standard test methods and consider how to update/modify them to obtain more relevant and repeatable information. In this work, we present an expansion to well-known ASTM D3233A standard, with the aim to create new information that is more relevant to the application

engineer. This standard uses the Pin&Vee Block setup to evaluate cutting fluids, but it is always limited to steel-steel contacts and the test results are limited to the failure load. With our approach, we bring different metallurgies into the equation, and we focus on testing aqueous emulsions, rather than formulated oils. By monitoring the frictional torque throughout the test, significant differences between products can be revealed. We illustrate this with a correlation study with a tapping operation.

9:30 - 10 am
3285657: Chemistry Behind Settling Metal Fines in Aqueous Metalworking Fluids
Stefanie Velez, James Sullivan, Munzing, Bloomfield, NJ

Metal fines will only settle out of the fluid after the liquid effectively wets the surface of the fine. Wetting agents are a specific class of surfactants that expediate this process by reducing a fluid's surface tension, or the interfacial tension, between the fluid and a solid substrate. The chemistry of the surfactants can be specifically identified and formulated to provide a strong reduction in dynamic surface tension, little to no foam generation, and optimal fluid compatibility. A low dynamic surface tension results in rapid spreading on the metal surface during high speed processes. This paper will discuss the theoretical aspects of surface tension reduction using wetting agents and demonstrate how this translates into an improvement in metal fines settling and cleanliness through application testing in metal working fluid systems as well as the reduction in the fluids surface energy as measured by contact angle.

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

10:30 - 11 am
3286026: Filtration of Rolling Oil Fluids
Craig Thomas, JR Schneider Co., Inc., Benicia, CA

The manufacturing of Aluminum foil and sheet requires the metal to be rolled to a precise gauge (thickness) for the particular application. This process requires the use of specific rolling oils to help form, cool, lubricate and remove debris from the process. The used and dirtied oil is then filtered to remove the particulate which is a waste formed from the rolling process. This used oil requires precise filtration to remove the particulate and clean the oil for reuse in the rolling process. Users of this manufacturing process have been using a specific filter aid for use in this process. This filter aid provides for significant filtration and long cycle times for the end user's filter. This discussion will provide background on this type of oil/coolant filtration, the chemistry and mechanics of the filtration and the results from using this type of filtration method.

11 - 11:30 am
3286714: Nuclear Magnetic Resonance as a Useful Tool for Routine Analysis of Emulsions
Josef Leimhofer, AMAG Rolling GmbH, Ranshofen, Austria

The field of application of nuclear magnetic resonance spectroscopy for the analysis of emulsions applied in the hot rolling process of aluminium has been further investigated. As a consequence, NMR spectroscopy using a permanent magnet has been established as a tool for routine analysis of hot rolling emulsions. In order to enable the identification of individual ^{1}H- and ^{13}C-NMR signals, measurements with NMR spectrometers using single components, different solvents and different magnetic field strengths have been carried out, as well as 2D-NMR-experiments. Routines have been established for the acquisition of different emulsions, as well as for the identification and quantification of selected

additives. Results of these measurements are used as additional information for maintenance of the emulsions.

11:30 am - 12 pm
3322954: Tramp Oils - What Are They and How Do You Deal with Them?
Andrea Knopp, Constellium, Ravenswood, WV

This presentation will define what Tramp Oils are and how they effect Emulsion chemistries in Aluminum Hot Rolling. We need to understand what they are, how they effect emulsion chemistry, and how much can you handle before there is a serious issue. We also need to realize that emulsions can adversely effect a standard oil properties too.

7C Columbus EF

Environmentally Friendly Fluids II

Session Chair: Selim Erhan, Archer Daniels Midland, Decatur, IL
Session Vice Chair: Brajendra K. Sharma, University of Illinois Urbana-Champaign, Champaign, IL

Session Starts at 8:30 am

8:30 - 9 am
3288275: A New Generation of Bio-Based Extreme Pressure Additives
Lotje Smolders, Oleon, Oelegem, Belgium

Environmentally friendly lubricants are gaining momentum in various key sectors such as marine, automotive metalworking fluids and other industrial applications. Oleon's natural chemistry enables the development of bio-based solutions, driven by the market's needs and future trends. By combining specific ester geometry with sulfur chemistry a new class of extreme pressure additives is obtained. The additives are based on 100% renewable raw materials and are active in a wide range of operating conditions. They are ideal candidates to formulate more environmental friendly metalworking fluids. Additionally the additives contain very low (active) sulfur and are therefore non-corrosive. This further enlarges their potential use in industrial gear oils and automotive lubricants. The properties of our innovation as well as a comparison of its performance versus existing technologies will be presented.

9 - 9:30 am
3281884: Biobased Bright Stock Replacement: Property-Blending Relationships and Formulation Challenges
Boris Zhmud, Applied Nano Surfaces Sweden AB, Uppsala, Sweden, Ian Bancroft, Natalia Slawniak, University of York, York, United Kingdom

The present study focuses on the physico-chemical properties of binary mixtures of biobased bright stock replacement with various classes of mineral base oils. The biobased bright stock is produced using an innovative process of thermocatalytic thickening of vegetable oils and can be used as a direct replacement for mineral bright stock in a broad range of industrial and marine applications. The whole

value chain – from the vegetable oil manufacture to end-user applications – is described. A specific emphasis is placed upon viscosity-blending relationships, solubility, and seal compatibility. Actual application examples are presented.

9:30 - 10 am
3285681: New Hydrolytic Stability Testing on Biobased Lubricants and Base Fluids
Mark Miller, Alex Kitchel, Biosynthetic Technologies , Indianapolis, IN

There is more and more interest in biobased and biodegradable lubricants in and around the marine environment. The hydrolytic instability of vegetable and ester base oils is well known. Conventional hydrolytic tests do not demonstrate "real world" performance adequately. A new test has been developed that closely simulates the hydrolytic performance of lubricants and base oils in the presence of water and heat. This paper will describe test methodology and demonstrate the results of various biobased lubricants and base oils. The results of the testing is reviewed and supported with the original test data, and compared to standard industry hydrolytic tests.

10 - 10:30 am - B**reak**

10:30 - 11 am
3316323: Biomimetic Tribology: Exploiting Synovial Fluid Lubrication Mechanisms for Mechanical Devices
Manoj Murali, Marc Masen, Philippa Cann, Imperial College London, London, United Kingdom

The replacement of oil-based lubricants with biodegradable water-based lubricants has been a long-standing unfulfilled ambition. The physical instabilities and poor wear performance associated with water-based lubricants has led to minimal adoption within mechanical systems. Biomolecule-based lubricants have been explored but are unsuited for long-term application as they falter in a similar manner. Synovial fluid – a natural lubricant – performs extremely well within native and artificial joints; hence an investigation into mimicking the mechanisms of the lubricant is explored for application within mechanical systems. Focusing on the protein aggregation and polymer brush mechanisms proposed to occur within the fluid; the mechanisms are deciphered and translated to be applicable for the loads and environments within common systems. The mechanisms are mimicked through the exploration of cationic surfactant micelles and polymer colloids, leading to the creation of a bio-lubricant.

11 - 11:30 am
3314861: Nature-Guided Design of Biolubricants Based on the Unique Fatty Acid Structure of Chinese Violet Seed Oil
Diana Berman, Asghar Shirani, Trevor Romsdahl, Kent Chapman, University of North Texas, Denton, TX, Edgar Cahoon, University of Nebraska Lincoln, Lincoln, NE, Robert Minto, Indiana University - Purdue University, Indianapolis, IN

We discovered a unique structure of the estolide molecules highly present in Orychophragmus violaceus (Ov) seed oil. The oil demonstrates excellent lubricative properties and high thermal stability. Specifically, the measured coefficient of friction of the sliding steel pairs lubricated by Ov oil is 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 when tested from room temperature up to 350C.Using the discovered concept, we unravel a new approach for modifying the traditional seed oils, such as castor oil, to enable their high thermal stability and good lubrication characteristics [2]. We connect the

estolide structure to the genetic pathways responsible for its origin, thus providing insights on the Nature-guided mechanisms towards renewable energy-efficient systems. References [1] X. Li, et al, Nature Plants 4, 711-720 (2018). [2] T. Romsdahl et al, Scientific Reports 9, 11711 (2019).

11:30 am - 12 pm
3283219: Latest in Biosynthetic Base Oils – Evaluating Estolide Performance Characteristics in Expanding Viscosity Ranges
Jake Bredsguard, Biosynthetic Technologies , Indianapolis, IN

Estolides are an environmentally acceptable base oil that is referred to as a “biosynthetic”. They are known for their performance characteristics and use as a petroleum replacement in lubricant formulations. The number of estolide products being offered to the market is growing as new viscosities are being offered. We look at how these products compare to each other and to other commercial base oils in the industry. Estolides are very versatile and can be used in several industries and products within the marine, automotive, and industrial markets. Findings from example formulations will show performance benefits of these estolides.

7D — Columbus G

Fluid Film Bearings III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3279210: Effect of Partial Coatings on the TEHD Behavior of Plain Journal Bearings with Considering Wall Slip
Shuhui Cui, Michel Fillon, Institut Pprime, Poitiers, France, Le Gu, Harbin Institute of Technology, Harbin, China

In this work, the effect of partial coatings with wall slip on the thermoelastohydrodynamic (TEHD) behavior of hydrodynamic journal bearings is investigated. A TEHD model with wall slip occurring at oil-coating interface is built. Two-component slip model is applied to calculate the slip velocity. The film-coating-basement temperature is calculated. The effects of slip zone shapes and coating thickness on the TEHD behavior are analyzed, and the optimal slip zone position is roughly determined by considering the maximum temperature, minimum film thickness (MinFT) and friction coefficient. The results show that it is possible to choose the slip zone that can both decrease the maximum temperature and increase MinFT. However, the optimal slip zone that could mostly decrease the maximum temperature would also decrease the MinFT. It is quite necessary to select the slip zone with a great precision.

8:30 - 9 am
3280451: Synthesis of the Experimental Analyses of Thermal Unbalance Effects Induced by Cylindrical and Tilting Pad Journal Bearings
Thibaud Plantegenet, Mihai Arghir, Pascal Jolly, Institut Pprime - Univseristé de Poitiers, Poitiers, France, Mohamed-Amine Hassini, EDF Lab Paris Saclay, Palaiseau, France

The paper describes the experimental analysis of the thermal unbalance effects known as the Morton effect. The test rig consists of rotors guided by a ball bearing and by a cylindrical (CB) or a tilting pad journal bearing (TPJB). A rigid and a flexible rotor were used. The CB was tested for both rotor. The results for the rigid rotor showed an increase of the synchronous amplitudes followed by a stabilization. The results for the flexible rotor showed spiral vibrations of rapidly increasing amplitudes leading to bearing contact. However, the spiral character was not very pronounced. It was considered that the thermal unbalance was accompanied by a seizure effect. This assumption was confirmed by the tests performed with TPJB. The results showed unstable synchronous vibrations of pronounced spiral character. These vibrations could be triggered because the seizure effects were reduced if not absent. Indeed, compared with the CB, the TPJB can better accommodate the thermal dilatation.

9 - 9:30 am
3284942: Effects of Film Temperature Boundary Conditions on the Thermal Wedge Lubrication in Parallel Thrust Bearings
Tae-Jo Park, Gyeongsang National University, Jinju, Republic of Korea

In sliding bearings, viscous shear action raises the oil temperature. One of the mechanisms responsible for pressure generation in parallel surfaces is known as the thermal wedge effect. In this paper, we investigate the effects of film temperature boundary conditions on the thermohydrodynamic (THD) lubrication in parallel thrust bearings. The continuity, Navier-Stokes and energy equations with temperature-viscosity-density relations are analyzed using the commercial computational fluid dynamics (CFD) code FLUENT. Four different film temperature boundary conditions are adopted to investigate the pressure generation mechanism. It was confirmed that the temperature gradients across the film and flow directions are highly contributing to hydrodynamic pressure generation. Due to the thermal wedge effect, parallel thrust bearing can support a considerable load, and its effect is greatly changed with the film temperature boundary conditions.

9:30 - 10 am
3316740: Experimental-Theoretical Correlation Study of the Morton Effect
Alan Palazzolo, Dongil Shin, Jongin Yang, Xiaomeng Tong, Erwin Thomas, Texas A&M University, College Station, TX

The Morton Effect is a vibration instability problem casused by fluid film journal bearings in high perfprmance compressors and turbines. The presentation will compare theoretical predictions with experimental prections on a full size test rig at the author's institution, Texas A&M University, and present advanced modeling methods for the Morton Effect.

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

10:30 - 11 am
3284955: Lubrication Characteristics Analysis of Slipper-Swash Plate Interface in Swash Plate Type Axial Piston Pump
Xiangxu Meng, Xuan Ma, Xiqun Lu, Tongyang Li, Bowen Jiao, Wen Sun, Yongqiang Wang, Harbin Engineering University, Harbin, China

This study presented an analytical approach towards the understanding of the bearing capacity, leakage and friction torque based on the hydrodynamic lubrication model of the slipper-swash plate interface in swash plate type axial piston pump. Further, the influences of spindle speed, load pressure and slipper

posture on the lubrication performance of the slipper-swash plate interface were analyzed. The research showed that the slipper posture could significantly affect the pressure distribution. In order to improve the lubrication performance, a structure with a groove on the sealing tape was proposed by this paper. In particular, the locations and geometric parameters of the groove were analyzed. The results showed that the lubrication performance was better when the groove was 2.0 ~ 3.0 mm wide and 5 ~ 20 μm deep at the inner boundary. Keywords: Swash plate type axial piston pump; Slipper-swash plate interface; Hydrodynamic lubrication; Slipper structure ； Optimization design

11 - 11:30 am
3285598: Effect of Groove Textures on the Dynamic Characteristics of a Water-Lubricated Hydrodynamic Bearing
Huihui Feng, Xiulin Ji, Hohai University, Changzhou, Jiangsu, China

The effects of surface texture on the static performances of hydrodynamic bearings have been thoroughly investigated. However, the dynamic coefficients of textured bearing which are of great importance to the dynamic performances of rotor-bearing system are rarely studied. The present study develops a three-dimensional computational fluid dynamics (CFD) model to investigate the effects of groove textures on the dynamic coefficients of a water-lubricated hydrodynamic journal bearing (WLHJB). A method to determine the dynamic coefficients is provided. The cavitation of water is also taken into consideration. The influences of rotary speed, eccentricity ratio, and texture distribution on the dynamic coefficients of the WLHJB are analyzed. Results show that the dynamic coefficients of the WLHJB are significantly influenced by the texture.

11:30 am - 12 pm
3284425: On Development of 7KW Oil Free Compressor Driven by 120000 r/min Permanent Magnet Motor with Gas Foil Bearings
Guanghui Zhang, Zhansheng Liu, Harbin Institute of Technology, Harbin, Heilongjiang Province, China, Xiaowei Wang, Nanjing University of Aeronautics and Astronautics, Nanjing, China, Shiwei Ji, Nanjing Shenweihuizhogn Me Company, Nanjing, China

The 7KW oil free compressor is designed and fabricated to satisfy the demand of oil free air for hydrogen fuel cell, which is driven by 120,000 r/min two poles permanent magnet motor. The performance of the centrifugal compressor is tested to verify the design parameters. The thermal characteristic of the whole engine is studied in the experiments. The journal gas foil bearing with diameters of 23mm is developed and the thrust gas foil bearing can be operated with maximum thrust load of 200 Newtons. The start-stop and longtime duration test is carried out. It indicates that the oil free compressor can be operated well for the whole operation range without cooling of the gas foil bearing. Several failure cases of thrust foil bearing are presented, and the modification for the bearing is discussed. After operation of 5000 start-stop, the wear inspection shows that it can endure more operation cycles.

Wear II

Session Chair: Yan Zhou, Houghton International, Oak Ridge, TN
Session Vice Chair: Chinpei Wang, Cummins, Inc., Columbus, IN

8 - 8:30 am
3324718: Helium Tribology of Ni-Based Alloys at High Temperature Up to 950°C
Md Saifur Rahman, Andreas Polycarpou, Texas A&M University, College Station, TX, Ali Beheshti, George Mason University, Fairfax, VA

This study investigates the friction and wear behavior of Inconel 617 and ally 800HT, the primary candidate materials for high-temperature gas-cooled nuclear reactors. Helium cooled reactor environment was simulated up to 950°C in a custom-built tribometer. To obtain a comprehensive understanding of the tribological response, the effects of contact load, temperature, air and He environments, sliding speed, and sliding distance was studied. The friction and wear values are the highest at a high-temperature He atmosphere. SEM, EDS, SIMS and XRD techniques were used to analyze the oxide layers. Analysis of the Inconel 617 tested in the He atmosphere showed the presence of Cr-rich oxide with a lower presence of Co-Ni-Mo compared to the samples tested in air, whereas Fe-Cr is dominant for 800HT. Characterization revealed the existence of a very hard protective glaze layer in air while such layer was not observed in the He environment, which was associated with higher wear/friction values.

8:30 - 9 am
3284276: Enhancing Wear Resistance of Selective Laser Melted (SLM) Parts
Yang Yang, Yi Zhu, Zhejiang University, Hangzhou, China

Selective laser melting (SLM) is one type of powder bed fusion technology in additive manufacturing which produces metal parts. Wear resistance of SLMed parts is crucial but often increased using post processing. Various surface treatments are efficient but not always available due to structure complexity and time limitation. This study focuses on enhancing the wear resistance during SLM. Various process parameters, such as laser power, hatch space, and scanning strategy, greatly affect the properties of the fabricated parts, which further affect the wear behaviors of the parts. Microstructures of the samples were observed and analyzed using SEM and EBSD. Wear resistance was accessed using a scratching test rig. Results showed that there are basically two ways of enhancing wear resistance: grain refinements and texture control. To design SLM process parameters which could achieve both is important to increase the wear resistance of the surface, which does not require post processing.

9 - 9:30 am
3300118: A Review of Tribological and Surface Behavior of MAX Phase Based Composites
Surojit Gupta, Maharshi Dey, Sabah Javaid, Caleb Matzke, Quan Tran, University of North Dakota, Grand Forks, ND, Nikhil Murthy, Stephen Berkebile, Army Research Laboratory, Aberdeen Proving Ground, MD

MAX phases (a family of over 70 carbides and nitrides) have emerged as potential materials for structural applications. In this presentation, we will review the tribological behavior of different types of

MAX phases-based composites. More particularly, the tribological behavior of different metal matrices and polymer matrices reinforced with MAX Phases will be presented. Some examples of composites are Ag-MAX, Ni-MAX, PEEK-MAX, and HDPE-MAX composites. The effect of processing parameters on tribological behavior will be also documented. Detailed mechanism of tribological behavior will be presented by evaluating the tribofilms by SEM analysis. In addition, the wettability behavior of these composites by different fluids will be also presented.

9:30 - 10 am
3284171: Wear Mechanisms of DLC: A Reactive Molecular Dynamics Study
Yang Wang, Tohoku University, Sendai, Japan

Diamond-like carbon (DLC) is an excellent solid lubricant widely coated on various industrial applications. Wear of DLC is a severe problem because wear not only cause a deterioration of lubricity but also harm the durability and reliability of coated apparatus. It is essential to firstly understand the mechanisms of wear and then reduce the wear according to the detailed insights into the wear mechanism. Here, through large-scale reactive molecular dynamics simulations, we demonstrate two fundamental wear mechanisms of DLC: 1) chemical wear which indicates the generation of hydrocarbons (e.g. methane, ethane, ethylene, and propylene) desorbing from DLC surfaces and 2) adhesion-induced mechanical wear which is the transfer of carbon atoms to the counter surfaces. Both of the wear mechanisms co-decide the wear behaviors of DLC.

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

10:30 - 11 am
3313790: Load-Carrying Capacity of Aircraft Turbine Engine Lubricants Using the FZG-Ryder Gear Test Rig
Alexander Fletcher, Patrick Hellman, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH, Peter John, University of Dayton Research Institute, Dayton, OH

The commercial and military aviation sectors have historically used the Ryder Gear Test Rig to characterize the load carrying capacity (resistance to scuffing) of aircraft turbine engine lubricants as part of the oil qualification process. There has been recent interest in alternatives to this single source test rig. One possible alternative, the FZG-Ryder, was developed to utilize a commercially available test rig (FZG Gear Tester) and modify it to closer match the operating conditions and performance of the Ryder. This paper reports the results of over five years of research on the load carrying capacity of a variety of turbine engine lubricants using the FZG-Ryder, how results compare to the Ryder, a discussion of best practices with this type of test, and possible future direction of the test rig.

11 - 11:30 am
3293669: Introducing a Next Generation of Anti-Wear Technology for Lubricants
Christelle Chretien, Solvay, Bristol, PA

New regulatory standards, growing environmental concerns, and the impending shift toward alternative transportation solutions are factors rapidly transforming the lubricant industry. Formulation options around using traditional lubricant additives and compositions are shrinking, thanks to more stringent regulations on fuel efficiency and emissions; tougher restrictions on waste management; and increasing limitations on the use of heavy metals, sulfur and phosphorus. 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.

11:30 am - 12 pm
3281367: Fretting Friction and Wear of Flange Gasket
Zheng Zhang, China University of Petroleum, Beijing, China, Deguo Wang, Yanbao Guo, China University of Petroleum, Beijing, China

Gasket is the core sealing element in the pipeline system, especially in gas station, which plays a vital role in the safety performance. This current work demonstrates the friction and wear mechanism of fretting wear on spiral wound gasket (SWG), taking into account the impact of pipeline vibration on flange joints. Moreover, it is found that the friction coefficient, fretting behavior and wear state of sealing interface are all affected by its own winding structure and environmental factors, such as normal load. Overall, this study can provide new ideas and directions for the development of sealing mechanism and new gaskets.

7F Columbus IJ

Lubrication Fundamentals VII

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3288865: Mechanochemistry in High Pressure EHD Contacts
Hugh Spikes, Jie Zhang, Janet Wong, Daniele Dini, Imperial College, London, United Kingdom

It has previously been shown that the antiwear additive ZDDP can form tribofilms on surfaces at high shear stress in full film EHD conditions when there is no asperity-asperity contact. This confirms that the reaction is driven by a mechanochemical process in which the rate of reaction depends on both temperature and shear stress. A limitation of this work is that it used tungsten carbide contacts to attain the high pressures and thus stresses required to stimulate ZDDP reaction at realistic temperatures. This presentation describes new work using a high load test rig in which tribofilm formation in full EHD film conditions can be studied using steel/steel contacts. The influence of ZDDP alkyl structure on film formation rate is analysed and compared to that in thin film rolling-sliding conditions where asperity contact drives ZDDP reaction. Then the extent to which tribofilm formation is controlled by mechanochemistry for a range of other lubricant additives is explored.

8:30 - 9 am
3293309: Adsorption Behaviors of Organic Friction Modifiers on Iron Oxide Surfaces: A Nonequilibrium Molecular Dynamics
Junqin Shi, Haifeng Wang, Northwestern Polytechnical University, Xi'an, Shaanxi, China, Jie Lu, Q. Jane Wang, Jannat Ahmed, Northwestern University, Evanston, IL, Ning Ren, Valvoline Inc., Lexington, KY

Organic friction modifier (OFM) is important lubricant additives to reduce friction and wear under boundary lubrication conditions, and the nanoscale adsorption/desorption behavior of OFM between friction surfaces during shearing friction is required to deeply understand. A nonequilibrium molecular dynamics simulation is used to explore the atomistic structure and friction properties of stearic acid (SA) adsorbed on iron oxide (Fe_2O_3) surfaces and separated by a dodecane layer. In the adsorption process, the amount of SA molecules adsorbed on Fe_2O_3 surfaces decreases while some dodecane molecules tend to diffuse into SA layers with the increasing temperature. In the shear process, SA molecules show clear orientation distribution with shear direction, but there are no clear differences in velocity profile. The coefficient of friction decreases dramatically with temperature increasing from 300 K to 350 K, and the potential parameters play an important effect on the adsorption behaviors.

9 - 9:30 am
3301806: Tuned Polar Methacrylate Viscosity Index Improvers for Enhanced Shear Stability and Wear Prevention
Lelia Cosimbescu, Pacific Northwest National Laboratory, Richland, WA, Robert Erck, Argonne National Laboratory, Argonne, IL, Kristen Campbell, Marie Swita, Pacific Northwest National Laboratory, Richland, WA

Multigrade advanced hydraulic fluids and comprised of a mixture of functional additives such as viscosity index improvers (VIIs), friction- and wear-reducing agents, pour-point depressants, antioxidants, etc., blended into a base fluid. VIIs can be designed to perform secondary roles, most commonly friction- and wear-reducers. A major consideration for VIIs design in applications which encounter shear, such as hydraulic fluids, is permanent shear loss of the polymer. Our strategy is to employ a controlled-radical polymerization technique to design PAMAs of moderate polarity and molecular weight, with linear architecture, which are expected to have good viscosity index, good shear stability and have the added benefit of lowering friction or wear. Herein, we present the synthesis of copolymers containing varying amounts of polar methacrylate and a lipophilic methacrylate as multifunctional VIIs, with anti-wear and shear stability benefits.

9:30 - 10 am
3293985: Mechanochemical Reactions between Di-Tert-Butyl Disulfide and Ferrous Surfaces
Karen Mohammadtabar, Ashlie Martini, University of California Merced - Merced, CA, Merced, CA, Stefan Eder, Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria

The observation of tribofilm formation between sliding surfaces is challenging. For a better understanding of the action of extreme pressure additives, we used reactive molecular dynamics to study the mechanisms of di-tert-butyl disulfide confined between ferrous surfaces. The simulations captured reactions with Fe(100) and amorphous iron oxide surface as well as the effect of base oil on additive-surface reactivity. The reactants were subject to heat, load and then shear. Different steps of reactions in the process were tracked to quantify the reaction yield during each step. The activation energy for these reactions was calculated and shown to be lowered by mechanical force applied along the reaction coordinate. The simulations demonstrated that increasing pressure further lowered the reaction barrier and the results were analyzed in the context of mechanochemical reaction theory.

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

10:30 - 11 am
3310741: An Investigation of Anti-Oxidant Expression in Naphthenic Base Oils
Thomas Norrby, Jinxia Li, Nynas AB, Nynashamn, Sweden

Oxidation stability is a key parameter for industrial lubricants, improving durability and efficiency. Antioxidants can increase the oxidation stability and improve the resistance to change, by slowing down the oxidation rate and by changing the oxidation mechanisms. In this study, aminic and phenolic antioxidants, alone or in combinations have been employed in five different naphthenic base oils, spanning viscosities from 90 to 600 cSt, and representing three different levels of deep hydro treatment refining. The Oxidation Induction Time (OIT) has been determined for the base oils with different dosage (treat rate) of antioxidants by High Pressure Differential Scanning Calorimetry (HP-DSC). The additional effect of reaction temperature, oxygen pressure, and sample size has been investigated as well. A proposed antioxidant selection guideline has been developed, based on the results obtained in this study

11 - 11:30 am
3308132: Tribological Properties of Sulfur- and Phosphorus- Free Organic Molybdenum Compounds as Additives in Oil
Wenjun Huai, Zhang Chenhui, Tsinghua University, Beijing, China

Oil-soluble organo-molybdenum additives are promising in the oil-based lubrication field. In this work, A sulfur- and phosphorus-free organo-molybdenum (SPFM) was successfully synthesized. The friction-reducing and anti-wear properties of SPFM combined with zinc dialkyldithiophosphate (ZDDP) in base oil were assessed, revealing SPFM additive efficiently reduces the friction coefficient and exhibits good synergistic anti-wear relationship with ZDDP. The smoother wear scar surface further supports the improvement in the anti-wear behavior and synergy effect between SPFM and ZDDP. Energy dispersive x-ray spectroscopy unravels the existence of Mo and S in the tribofilms formed on the rubbing surface, and the formation of MoS_2 crystalline is verified by x-ray photoelectron spectroscopy and high-resolution transmission electron microcopy. The mechanism promoting the in situ formation of MoS_2 is proposed via the synergistic chemical reaction between SPFM and ZDDP during rubbing.

11:30 am - 12 pm
3316347: Influence of Rubbing Material on ZDDP Tribofilm Formation
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 tribofilm on steel substrate, the understanding of tribofilm formation on non-ferrous substrates is limited. It has recently been shown that ZDDP tribofilms on steel can have either a nanocrystalline or amorphous structure and that tribofilms with a nanocrystalline structure are more durable than amorphous ones. This presentation describes the influence of rubbing material, including non-ferrous surfaces, on ZDDP tribofilm formation and investigates the relationship between tribofilm properties and durability on these surfaces.

Materials Tribology V - Metallic Materials Fundamentals & Extreme Applications

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3279771: Tribological and Mechanical Properties of High Entropy Alloys
Morgan Jones, Brendan Nation, Ping Lu, Andrew Kustas, Nicolas Argibay, Sandia National Laboratory, Albuquerque, NM

High Entropy Alloys (HEAs) show great promise for applications including coating technologies, anticorrosive high-strength parts, and integrated circuit foundries. Since the publication of Cantor's work on equi-atomic multicomponent alloys in 2004, there has been over 1000 publications on the chemical, mechanical, and electrical properties of this new material class. We present results of the tribological and mechanical properties of these materials in a range of environments and contact conditions, including air, inert gas, and ultra-high vacuum. Test specimens include the Cantor (CoCrFeMnNi) and 3- and 4-component refractory HEAs that were prepared with additive manufacturing methods. We present evidence of a low friction regime ($\mu<0.3$), and the link to extreme grain refinement achievable even in non-oxidizing environments. Scratch tests were also used to probe strain rate sensitivity and strengthening mechanisms, supported by transmission electron microscopy and chemical analysis.

8:30 - 9 am
3276302: Tribological Behavior of Light Weight Al Matrix Composites Reinforced with Silicon Carbide and Tungsten Disulfide
Juanjuan Zhu, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom

Lightweight metal matrix composites (MMC) are becoming more popular for high efficiency applications, including automobile, aerospace and telecommunication industries. SiC and WS_2 particle reinforcement will further improve the composite properties by enhancing the mechanical strength and reducing the friction and wear. In this study, aluminium matrix composites reinforced with 10-15 wt% WS_2 and 15 wt% SiC particles were powder metallurgy sintered and investigated for the tribological behaviors using a ball-on-disc configuration, subject to the normal pressure of 0.86-1.46 GPa, room temperature and 110 °C, sliding speed of 22.5 mm/s, and lubricant of PAO base oil. The worn surfaces and the tribo-layer generated were studied by optical profilometry, SEM and EDX. It was found that the mechanical properties of the composites were improved by the SiC reinforcement. Under all testing conditions, the composites exhibited much lower friction coefficient and outstanding anti-wear property.

9 - 9:30 am
3284265: Establishing a Methodology for Studying the Tribological Properties of Cold Sprayed Nanostructured Coatings
Emmanuel Georgiou, Dirk Drees, Falex Tribology NV, Rotselaar, Belgium

This research focuses on evaluating the wear behavior of a variety of nanostructured cermet and/or intermetallic cold sprayed coatings. In this perspective, tribology tests were designed to simulate some typical potential applications, namely in the mechanical, biomedical and aeronautical field. For mechanical applications, emphasis is given to evaluating the abrasion and sliding properties of nanostructured Fe-Cu-Al+Al_2O_3 and Co-Al-WC cold sprayed cermets. In the case of biomedical applications, the main focus is the analysis of the tribo-corrosion behavior of Ti-TiC cermets in artificial body fluids. For aeronautical applications the aim is to investigate the high temperature wear behavior of intermetallic Ni-Sn coatings. In all cases, a different tribological approach had to be designed based on input of the end-users, in order to simulate actual wear conditions. These methods then provide an efficient comparison with existing industrial benchmarks.

9:30 - 10 am
3337937: Large-Scale Molecular Dynamics Simulations Studies of Microstructural Evolution in Sliding Cu-Ni Surfaces
Daniele Dini, Imperial College London, London, United Kingdom, Stefan Eder, Carsten Gachot,TU Wien, Vienna, Austria, Manel Rodriguez Ripoll, Ulrike Cihak-Bayr, AC2T, Vienna, Austria

Binary alloys have received much renewed interest in the fields of material science and material tribology. In particular, CuNi alloys are used in shipbuilding, offshore oil production, power plants, for pipes and fittings, coinage, as well as in the aviation industry. It is generally accepted that sliding contact may cause irreversible changes to the involved surfaces. However, many of the mechanisms that govern microstructure evolution are not well understood, and this limits the development of tailor-made solutions based on the tuning of specific microstructural properties. While experiments are indispensable for studying the occurring phenomena, it is often not easy to identify permanent deformation mechanisms from a set of “before/after” pictures. Here we propose to perform computer experiments to study the microstructural response of five FCC CuNi alloys with a broad range of stacking fault energies subjected to sliding using large-scale molecular dynamics (MD) simulations.

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

10:30 - 11 am
3293730: Reduced Cost NiTi-Alloy Bearings Made via Near Net Shape Powder Metallurgy Processes
Christopher DellaCorte, NASA, Cleveland, OH

NiTi alloys are emerging as an attractive bearing race material for bearings exposed to high static loads and highly corrosive environments. One obstacle yet to be overcome is the intrinsically high relative cost of these materials compared to traditional bearing steels. Traditional net-shape powder metallurgy methods, such as cold-press and sinter, are not applicable to NiTi alloys because they require hot isostatic pressing (HIP) to achieve full density, flaw free microstructures. Recently, innovative powder metallurgy processing has been successful in forming bearing ring blank shapes through the use of geometrically tailored HIP containers. Microstructural evaluations show that ring blanks made from this process are comparable to material made using conventional HIP containers while substantially reducing material usage.

11 - 11:30 am
3320997: Development of Self-Adaptive Lubricating Silver Aluminum Borate Composite for Wide Temperature Range
Ashish Kasar, Pradeep Menezes, University of Nevada-Reno, Reno, NV

An alumina self-lubricating composite is developed for a wide temperature range by the formation of in situ phases (boron oxide, aluminum borate, and silver aluminum borate). The composition used in the study helps to control the insitu phases and adds in achieving liquid phase sintering and densification. The composites were characterized using X-ray diffraction to confirm the phases present, and strength was measured in terms of microhardness. Sliding tests on the composites were carried out using alumina ball at different temperatures from room temperature to 500 °C. The wear resistance and hardness were increased with aluminum borate concentration. However, the friction results showed a strong dependency on the boron oxide and silver concentration. The fabricated composites are self-adaptive lubrication at different temperatures due to the formation of desired phases. The mechanisms for friction and wear behavior at different temperatures and loads are explained.

11:30 am - 12 pm
3321728: Influences of ZrO_2 Crystal Structure on the Tribological Properties of Copper Metal Matrix Composites
Haibin Zhou, Pingping Yao, Central South University, Changsha, Hunan, China

Comprehensive measurement of ZrO_2, as a promising novel abrasion component, is highly needed for assisting in material composition design of high performance friction material. In this study, the micro-tribological properties of ZrO_2 with different crystal structure and their effects on the tribological properties of Cu metal matrix composites (Cu-MMCs) were tested. The results indicated that the fragile monoclinic ZrO_2 (m-ZrO_2), exhibiting a high coefficient of friction (COF) and strong bonding with the matrix, evidently enhanced the COF of Cu-MMCs at low and medium braking energy densities (BEDs). However, the harder cubic ZrO_2 (c-ZrO_2) showed a relatively low COF and weak bonding with the matrix, promoting mechanical mixing layer formation, resulting in relative high COF and low wear rate of Cu-MMCs. The wear mechanisms of Cu-MMCs with m/c-ZrO_2 transformed from plough to delamination with an increase in BED.

7H — Randolph 1

Gears I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3285653: Experimental Study on Lubricants and Methods to Enhance the Survivability of Rotorcraft Gearbox Under Loss of Lubrication Condition
Azhaarudeen Anifa Mohamed Faruck, Carsten Gachot, Michael Weigand, Vienna Universtity of Technology, Vienna, Austria

The goal of this research work is to study the influence of different lubricants under loss of lubrication conditions for rotorcraft transmission applications. Loss of lubrication is a severe event leading to starvation and failure of aircraft propulsion systems. In this work, standard gears and bearing steels are used for the evaluation of aviation lubricants using a FZG gear test rig, a cylinder on ring and a modified ball on disk setup with a defined oil supply. The lubricants are tested under high speed contact

conditions for determining the load carrying capacity and duration until the initiation of scuffing failure from the start of loss of lubrication at the contact. Complementary to other research articles on loss of lubrication, this work aimed to provide an in-depth investigation on lubricating oil chemistry. The demonstrated results can confine the type and quantity of certain additive elements for a better oil formulation to use under loss of lubrication conditions.

8:30 - 9 am

3285724: Approach for the Development of an Alternative Classification Method for Gear Oils for High-Loaded Hypoid Gears According to API GL-5

Alexander Drechsel, Josef Pellkofer, Michael Hein, Karsten Stahl, Technical University of Munich, Garching bei München, Germany

In general, it is not possible to determine the influence of the lubricant on the load carrying capacity of gears solely on basis of physical or chemical oil data. For this reason, some practical test methods have been developed to evaluate and classify the load carrying capacity of lubricants. A common used classification of hypoid gear oils are the guidelines of the American Petroleum Institute (API). The properties and performance characteristics of the oil are evaluated in complex axle test bench tests (L37 and L42), taking into account the tooth flank damage occurring on the gears. The tests planned for API GL-5 oils can only be carried out with great effort. Currently it is not possible to perform L37- and L42-tests in Europe due to a lack of missing institutes. By means of extensive experimental and theoretical investigations, an alternative method for the classification of gear oils according to API GL-5 is to be developed. The planned approach is presented in this publication.

9 - 9:30 am

3305164: Starvation Tests on FZG Test-Rig: Experimental Method and Thermal Modelisation

Pierre Navet, Fabrice Ville, LaMCoS - INSA Lyon, Villeurbanne, France, Christophe Changenet, ECAM Lyon, Lyon, France, Dhafer Ghribi, Safran Transmission Systems, Colombes, France

Windmilling occurs when an aircraft engine rotate because of the wind, while it is turned off. During this functioning mode, the input rotational speed and torque are low but no oil is injected on gear contacts. This mode generates starvation conditions which may lead to scuffing damages on gear teeth. The aim of this work is to study emergence of scuffing damage on gear teeth in a case of a priori low energy dissipated in the contact but extreme lubrication conditions. The experimental study was performed on FZG test rig, adapted to starvation tests and equipped with type A standard FZG gears which are developed to emphasize scuffing damage. Gears are equipped with embedded thermocouples to measure bulk temperature, which enables to supply a thermal model of the FZG test-rig [1] based on thermal network method [2]. Experimental and numerical results will be presented including experimental method, scuffing emergence and its impact on total losses and thermal behavior

9:30 - 10 am

3313567: Analysis Method of Pressure Field and Temperature Field Distribution of the Gearbox

Jialiang Yu, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

The gearbox is the core part of the locomotive transmission especially for trains. The rotating motion is transmitted from the motor to the train wheel with the help of the pinion and wheel inside the gearbox. The performance of gearboxes becomes increasingly demanding nowadays due to the higher requirement of operating speed and energy efficiency. Structural failure, component overheating and excessive leakage are common problems of the gearbox. It is important to investigate the structural

behaviour of the gears and pressure and temperature field distribution in the gearbox so that the aforementioned issues can be minimized through better designs. Therefore, a multi-phase computational fluid dynamics model of the gearbox is developed in this research. The work presents analysis methods to study the gear transmission, heat transfer and pressure/temperature distribution. The results can be used to optimize the gearbox components such as lubricant immersion depth and sealing design.

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

10:30 - 11 am
3323607: The Effect of Contact Conditions on the Initiation and Progression of Micropitting Damage
Benjamin Wainwright, Amir Kadiric, Imperial College London, London, United Kingdom

Micropitting is a type of surface damage that occurs in lubricated rolling-sliding contacts operating under low specific film thickness. It is caused by the mechanism of rolling contact fatigue acting on asperity contact level and manifests itself as numerous pits that are tens of microns in size but cover large surface areas. Despite its increasing importance, there are currently no established design criteria for prevention of micropitting. This study uses a triple-disc contact fatigue rig to investigate the influence of contact conditions on the onset and progression of micropitting damage in rolling-sliding lubricated contacts, with particular focus on the influence of specific film thickness and surface roughness properties. Presented results aim to differentiate between the effects of lambda-ratio and those of the roughness structure. The observed trends are discussed in terms of the continuous interaction between the competing damage mechanisms of surface fatigue and mild wear.

11 - 11:30 am
3330016: Influence of Grease Composition on the Service Life of Heavily Loaded Spiral Bevel Gears
Sergei Glavatskih, KTH Royal Institute of Technology, Stockholm, Sweden, Joel Olsson, Per Forsberg, Atlas Copco Industrial Technique AB, Nacka, Sweden, Johan Leckner, Rene Westbroek, Axel Christiernsson International AB, Nol, Sweden

The influence of thickener system and additives on grease lubricating performance in gear contacts is examined in this study. It was previously shown that in sliding contacts greases with the polypropylene thickener could outperform greases with the lithium complex thickener [1]. It was also shown that the additive expression was better when the propylene thickener was used. We explore further performance characteristics of these thickener systems, this time, in spriral bevel gears in an industrial application. Hertzian contact pressure reaches 4 GPa. The results are presented in terms of the gear service life, efficiency and temperature. [1] J. Shu, K. Harris, B. Munavirov, R. Westbroek, J. Leckner, S. Glavatskih, Tribology of polypropylene and Li-complex greases with ZDDP and MoDTC additives, Tribology International 118 (2018) 189–195.

Power Generation I

Session Chair: Salvatore Rea, Lanxess Corp, Perkasie, PA
Session Vice Chair: Matthew Hobbs, EPT, Calgary, Alberta, Canada and Jatin Mehta, Fluitec International, Bayonne, NJ

8 - 8:30 am
3332465: Power Generation Tribological Success Stories
Ken Brown, Eco Fluid Center Ltd., Toronto, Ontario, Canada

In many ways the power generation industry is very conservative and not wanting to take what might be percieved as a risk, but there are many opportunities to make use of better tribological products and practises. These might reduce risk, extend maintenance intervales, reduce friction, reduce energy consumption, provide fuel savings and/or have environmental benefits. The presentation will cover a few examples including steam turbine main bearing design, steam turbine oils, low cloud point oils, high viscosity index oils, valve greases, coupling greases and wicket gate greases as well as new maintenance materials for phosphate ester steam turbine control fluids.

8:30 - 9 am
3332098: Understanding Deposit-Derived Bearing Temperature Excursions
Jatin Mehta, Fluitec International, Bayonne, NJ

Lubricants used in rotating equipment degrade due to thermal stresses forming deposits commonly referred to as varnish. The impact on reliability is the escalation of bearing temperatures, often to a point which risks safe operation and can force an unplanned outage. This paper reviews the principles behind these temperature excursions and potential disruptions in the hydrodynamic film. It also presents case studies illustrating solutions to bearing temperature excursions, which in some cases can be solved in a matter of hours.

9 - 9:30 am
3320199: K_{sp} and Thermodynamic Considerations Relevant to Effective Varnish-Removal
Matthew Hobbs, Peter Dufresne, EPT, Calgary, Alberta, Canada

Varnish is a result of unmanaged oil breakdown and its deleterious impact on reliability is well-documented. Traditionally defined as an insoluble deposit, varnish exists in soluble and insoluble states. The relative amount of soluble and insoluble varnish in an oil and, therefore, its potential for varnishing are controlled by the solubility product K_{sp}. Since K_{sp} depends only on the concentration of dissolved species, particles/deposits have no impact on an oil's varnish potential. Many strategies exist to mitigate the effects of varnishing. Most rely on filtration which removes insolubles that have no impact on oil K_{sp}. Filtration, therefore, fails to meaningfully address varnish problems. Resin-based systems, however, remove soluble varnish. Since they remove the contaminants that influence K_{sp}, thermodynamic first principles allow them to remove all forms of varnish. They can, therefore, be used to effectively manage oil breakdown and varnishing where alternative strategies fail.

9:30 - 10 am

3301562: Determination of Relative Concentrations of Phosphate Ester Isomers in Turbine Control Systems by Matrix Assisted Laser Desorption Ionization - High Resolution Mass Spectrometry (MALDI-HRMS).

John Duchowski, Johannes Staudt, HYDAC FluidCareCenter®, Sulzbach, Saar, Germany, Gerard Palmer, HYDAC Technology Ltd., Witney, Oxfordshire, United Kingdom

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

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

10:30 - 11 am

3272921: Salvaging Poorly Stored Turbine Oil

Nnamdi Achebe, Petrosave Integrated Services Ltd., Amuwo-Odofi, Nigeria

Turbine lubricant drums poorly stored outdoor were rusty and severely contaminated by water. All forms of water – Free, Demulsified and Dissolved were present in the oil sample taken. Turbine oils are expensive and that Plant Management hoped for a solution to cut losses.
Unique combination of Filtration and select oil analysis tests including RULER and ISO 4406 Cleanliness proved effective in reconditioning severely water contaminated lubricants. Earlier, Free and Emulsified water layers were drained off and elements oven-dried to increase their water absorption capacity. After turning over every drum 5 – 7 times, bright and clear oil sample measuring dissolved water content of <100ppm using the KF method was achieved and within OEM Fresh Oil limit. However, that water can damage oil additives, made it significant to check the remaining anti-oxidant additives. Matched against in-service oil, all recovered drums recorded higher % anti-oxidant and within Target ISO Cleanliness.

11 - 11:30 am

3332142: Using Solvency Enhancing Technology as an Alternative to Traditional Flushing

Jatin Mehta, Fluitec International, Bayonne, NJ

System decontamination is an essential part of lube oil maintenance strategies, as identified in ICML 55.1, Chapter 11. This paper will identify the key components of system decontamination identified in this industry reference document with a focus on solvency enhancing technology as a preferential technique over traditional flushing in certain cases. Methods for selecting a solubility enhancing technology and measuring the decontamination process will be discussed, as well as case studies from the field.

11:30 am - 12 pm - **Power Generation Business Meeting**

7K **Michigan 1**

Engine and Drive Train V

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3286639: Developing a Framework to Address LSPI through a Better Understanding of Lubricant and Fuel Effects
Abhishek Kar, Allen Aradi, Sarah Remmert, Shell Global Solutions US Inc, Houston, TX, Jennifer Kensler, Shell International Exploration and Production, Houston, TX, Karin Haumann, Shell Lubricants, Houston, TX, Robert Mainwaring, Shell Global Solutions (UK), London, United Kingdom

Downsized turbocharged gasoline direct-injection (TGDI) engines are one way to reduce fuel consumption in passenger cars while improving performance compared with larger naturally aspirated engines. However, high torque levels at low speeds can lead to abnormal combustion phenomena such as knock, mega knock, or Low Speed Pre-Ignition (LSPI). Here, we characterize the impact of lubricant and fuel composition on LSPI in a TGDI engine in addition to exploring the correlation between fuel composition, particulate emissions, and LSPI events. Our research shows that oil composition has a substantial impact on pre-ignition frequency and severity. In addition, we show evidence of the linkage between the electrical properties of the oil and LSPI. Finally, fuels with high polyaromatic content increase LSPI and particulate emissions. In this talk, we discuss the above results along with the use of a high-fidelity test method to measure LSPI under steady-state test conditions.

8:30 - 9 am
3325364: Friction at Ring-Liner Interface with Systematic Surface Characterization
Arman Mohammad Khan, Q. Jane Wang, Northwestern University, Evanston, IL, Zhe Li, Yuchuan Liu, General Motors Corporation, Detroit, MI

The ring-liner interface of an IC engine is a critical interface as it directly affects the fuel efficiency of a given automobile. The liner surface is a complex surface with honing features on top of the machined roughness, which helps in oil retention during operation. Moreover, liner surfaces of our concern also contained pores that are completely random both in terms of their shapes and distribution. The work reported here attempts to model the ring-liner interface formed with such porous surface with a highly systematic approach, starting with a characterization of surfaces. A single pore computational fluid dynamics analysis is then conducted on the representative pore shape obtained from the characterization to quantify the effect of pores on friction. Lastly, the full Reynolds equation for a section of the ring-liner interface is solved, where the surface contains both honing features and the random pores. Numerical results are validated against benchmark experimental data.

Tribotesting III

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3323446: Online Surface Topography Evolution of a Unidirectional Dry Sliding Contact Using a Chromatic Confocal 3D Line Sensor
Timothy Kamps, Mark Gee, John Nunn, Christopher Jones, National Physical Laboratory, Teddington, United Kingdom

In situ real-time observation of wear mechanisms provides detailed insight into material removal and surface topography evolution. In situ measurements negate the need for periodic sample removal for inspection and the associated finite re-insertion accuracy that affects the ongoing wear mechanism. Real time measurement enables a continuous understanding of the wear mechanism to be obtained, and creates opportunities for measurement error correction. This presentation details the integration of a chromatic confocal 3D line sensor into a novel pin on disc test machine. The 3D line sensor acquired in situ height maps of the wear scar on the disk as the test progressed. Wear scar evolution as well as the growth of plastically deformed ductile disc material at the wear scar edges caused by the ploughing action of the indenter were observed. Results for a steel ball against a ceramic disc and a Rockwell indenter against a stainless steel disc in dry sliding conditions will be presented.

8:30 - 9 am
3325120: Development of a Friction and Wear Screener for Main Bearings
Carlos Sanchez, Peter Lee, Southwest Research Institute, San Antonio, TX

A new method for evaluating friction and wear performance of lubricants against main bearings was developed. Modeled after a block-on-ring test configuration, this new test experiences dynamic speeds and loads under fully lubricated conditions in an effort to simulate the real system. Main bearings from heavy duty diesel engines were machined to fit the test geometry which presents an opportunity to evaluate new bearing materials and coatings in addition to lubricant formulations. The work presented herein will discuss the development of a screener test to evaluate new materials and lubricants.

9 - 9:30 am
3325243: A Glimpse into Smart Tribology Lab
Deepak Halenahally Veeregowda, Ducom Instruments Europe B.V, Groningen, Netherlands

Smart tribology lab is a futuristic lab concept developed by Ducom, that can drive productivity of professionals in tribology research and teaching. As it encompasses the value generators such as connected tribometers and related services, remote access to continuous real-time data stream, data centralization, data analytics - predictive maintenance and optimization of R&D processes. All of this will aid the creation of digital twin of materials, lab spaces and tribometers. Learning objectives: Experience the 3D digital technology like Augmented Reality, discover its use in the tribology lab. Demonstrate the use of smart sensors and its enablement in tribometers using Internet of Things (IoTs) Cloud based data

analytics and lab management tools. Key benefits: Understand the infrastructure required for a smart tribology lab, Introduce digital transformation as a course component in tribology curriculum.

9:30 - 10 am
3323481: Tribology TRL Methodology for Drive System Technologies
Lavern Wedeven, William Black, Graham Wedeven, Robert Homan, Nelson Forster, Wedeven Associates, Inc., Edgmont, PA

The technology readiness level (TRL) approach reduces the risk of launching new materials into service. New technologies are generally pushed upward from TRL 2 property testing, through TRL 3 lubrication and failure attributes, into TRL 4 component simulation testing. A more appropriate approach, particularly for disruptive technologies like additive manufacturing, is to start from the design needs of TRL 4 component simulation testing. Having the controlling mechanisms, as manifested in service, creates a technology target for enhancement. It assures no attribute is left behind. The TRL methodology uses the interaction of special testing and analysis tools. Aviation drive system bearings and gears, where little or no wear can be tolerated, use a tribology strategy based on measurement and modeling of traction at the interface. Precision fabrication and finishing of surfaces is shown, along with flexible testing machines for simulation and comprehensive single contact modeling.

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

10:30 - 11 am
3340476: A New Test Method for Direct Measurement of Friction in Biomass Material
M. Cinta Lorenzo Martin, Oyelayo Ajayi, George R Fenske, Argonne National Laboratory, Lemont, IL, Jordan Klinger, Yidong Xia, Idaho National Laboratory, Idaho, ID, Troy Semelsberger, Los Alamos National Laboratory, Los Alamos, NM

The reliable and controlled flow of solid particulate biomass materials from bins, hoppers, etc. is essential for successful operation in every biorefinery. Friction is one of the critical material properties governing the flow of biomass materials and an important input into material handling equipment design. The current approach by industry to assess friction is different variants of shear testing. A new test method was developed and demonstrated to directly measure the particle-particle friction in biomass materials. A bench top tribometer was adapted to measure friction of biomass materials by attaching copious amount of biomass materials unto sliding surfaces. The pressure within the biomass during friction measurement was mapped using a pressure sensitive film technique. The new friction measurement method was demonstrated for two different biomass materials, namely grass and pine wood chips.

11 - 11:30 am
3325291: Effect of Important Surface Texture Parameters on the Initiation of Scuffing Failure under High Frequency Reciprocating Motion
Ali Kolivand, Zahed Huq, Emerson, Sidney, OH

An increase in the friction coefficient leads to a temperature rise under starved lubrication conditions in high speed tribo-systems. This leads to the initiation of scuffing failure that results in shorter component's life. This study investigates the effect of micron-level surface parameters change to reduce friction coefficient under starved lubrication condition. Different surface textures/patterns and roughness effects were tested under identical operating conditions. Certain textured surfaces have

shown promising performance in terms extending component's life time. In this investigation it was revealed that Ssk, Sku, and Sq surface parameters play an important role in the performance of components.

11:30 am - 12 pm
3326341: Inorganic Fullerene-Like Nano Tungsten Disulfide (WS_2) as Grease Additives: A Study of Concentration Effects on the Tribo-protective Mechanism
Manish Patel, NanoTech Industrial Solutions, Lake Charles, LA, Sedhuraman Mathiravedu, Pranesh Aswath, University of Texas at Arlington, Morris Plains, NJ

This study aims at evaluating the Anti-wear (AW), Anti-Friction (AF) and Extreme pressure (EP) performance of Inorganic Fullerene-like Tungsten Disulfide (IF-WS_2) nanoparticle additives at different treat rates and at dynamically varying load conditions. This unique class of additives has been known for its outstanding AW, AF and AF performance at low treat rates. The main purpose of the study is to investigate the different tribological protection mechanisms coming into play at different particle concentrations by analyzing performance data as well as by characterization techniques such as Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDS). This study implements dynamic spectrum loading conditions that simulate the real-life operating scenarios and help in developing an interdependence between each mechanism that comes into play at different surface contact conditions.

7M Michigan 3

Nanotribology IV

Session Chair: Zhijiang Ye, Miami University, Oxford, OH
Session Vice Chair: Sai Bharadwaj Vishnubhotla, University of Pittsburgh, Pittsburgh, PA

8 - 9 am
3286429: Invited Talk: The Fascinating Frictional Properties of Layered Materials: Insights from Atomistic Modeling
Michael Urbakh, Tel Aviv University, Tel Aviv, Israel

Structural superlubricity may provide a viable route to the reduction of friction and wear. In this talk I will present results of fully atomistic numerical simulations of static and dynamical properties of graphite/hexagonal boron nitride (h-BN) heterojunctions, performed adopting a recently developed inter-layer potential. We found that structural superlubricity at interfaces between graphite and h-BN persists even for the aligned contacts sustaining external loads. A negative friction coefficient, where friction is reduced upon increasing normal load, is predicted. It is demonstrated that further control over the physical properties of 2D layered materials can be gained via tuning the aspect-ratio of nanoribbons. Our results are expected to be of general nature and should be applicable to other van der Waals heterostructures.

9 - 9:30 am

3286643: Understanding the Impact of the Structural Ordering of Organic Molecules at 2D Confined Spaces on Nanotribological Properties

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

Two-dimensional (2D) nanomaterials, when adsorbed from organic solvents (base oil), form a low-shear interface leading to a significant reduction in friction coefficient and wear. The atomic force microscope measurements have shown that the weak interactions between the single-layer 2D material and the underlying substrate allow the diffusion of the organic molecules from the environment into the confinement. In this study, the impact of the molecular ordering of the diffused organic molecules such as hexadecane, cyclohexane and benzene underneath the graphene layer on the nanotribological properties will be presented. Understanding the impact of steric hindrances presented by the molecular structure (linear vs. cyclic, planar vs. chair conformation) and the binding affinity (polarity) of the organic solvent with graphene on the dissipation mechanisms of confined spaces will enable the development of design strategies to tune the interfacial friction.

9:30 - 10 am

3328462: Friction Characteristics of HOPG and 2D Transition Metal Di- Chalcogenides under Cryogenic Conditions- Role of Interfaces

Praveena Manimunda, Syed Asif, Douglas Stauffer, Bruker Nano Surfaces, Edina, MN

Superior mechanical properties and chemical inertness of 2D TMDs made them ideal candidate for lubricating coatings in micro- and nano-electromechanical devices. However, the temperature effects on frictional characteristics of vertically stacked 2D materials are not well understood. In this study, a cryo-environmental stage was integrated with a Hysitron TI-980 to probe temperature effects on microscale friction characteristics of HOPG, vertically stacked atomically thin MoSe2, WSe2 and MoS2/WS2 hetero structures. On monolayered samples, under wearless sliding conditions, an increase in friction was observed from 0 to -120 °C. On multilayered structures, interlayer shear dominated friction characteristics. Changes in inter layer interaction as a result of external deformation and temperature was investigated using in situ Raman spectroscopy. Sliding speed dependency and the effect of the number of layers on friction characteristics is explored in detail.

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

10:30 - 11 am

3285286: The General Reference Lever: A Simple, Reliable and Traceable Calibration Method for Arbitrary Normal and Friction Forces

Arnab Bhattacharjee, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

No reliable calibration method has yet been developed for scanning probe friction measurements.The tribology basic science literature sits on a foundation of uncalibrated measurements that may or may not be comparable across studies. This paper aims to resolve this critical problem. We have adapted a mature and widely accepted technology, pre-calibrated reference lever, as a means to store forces from a traceable calibration standard of fixed range (e.g. microbalance) and scale them to accommodate the load ranges (normal and lateral) of an arbitrary scanning probe. This paper presents the theory, demonstrates a prototype device and method of use, and validates the approach along several independent analysis. As the results demonstrate, the generalized reference lever method is simple,

reliable, and traceable. The concept, approach, and validation will be especially easy to grasp and implement by those who are practiced with the reference lever method of normal force calibration.

11 - 11:30 am
3282964: Experimental Determination of Pair Potential Parameters Using Frequency Modulation Atomic Force Microscopy
Nicholas Chan, Carrie Lin, Philip Egberts, University of Calgary, Calgary, New Brunswick, Canada, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA, Robert Carpick, University of Pennsylvania, Philadelphia, PA

The atomic pair potential for a material couple is critical to modelling tribological behavior of sliding contacts. Both potential forms and potential parameters require experimental validation for modelling accuracy. Here, we perform dynamic force spectroscopy measurements between a silicon probe and KBr, highly oriented pyrolytic graphite, and diamond substrates. A comparison is made with a theoretical pair potential model combined with transmission electron microscopy images of the probe. Relevant pair potential parameters are determined for the three substrates. Spatial variances in these parameters are obtained on the rough diamond substrate and are compared to those on atomically flat KBr and HOPG surfaces.

11:30 am - 12 pm
3286113: Inorganic Fullerene-like Tungsten Disulfide (if-$WS2_2$) Nanoparticles as Performance Additive in an Industrial Lubricant: Field Trial Results, Constraints and Opportunities
Benoit Thiebaut, Frédéric Michel, Stéphane Gavand, TOTAL MS, Solaize, France

Inorganic fullerene-like (IF) nanoparticles composed of metal disulphides (MoS_2/WS_2) are known to present very promising tribological properties and have been massively studied during the last decade. Chemical inertness and unique tribofilm growth capability, make this nanoparticle a perfect candidate for demanding industrial applications requiring long lasting performance. This presentation will present the results of a field test carried out over one year on an Stone crusher gearbox as well as some key aspects related to IF-WS2 introduction in industrial lubricants such as lubricant formulation compatibility, suspension quality, industrial scale availability and health and safety.

7N Michigan 1

Engine and Drive Train and Lubrication Fundamentals Joint Session: Lab to Field: Bridging the Gap Between Bench and Engine I

Session Chair: Brendan Miller, Chevron Oronite LLC, Richmond, CA

This session includes papers that cover the transition from lab scale bench tests to full implementation in actual application.

9 - 9:30 am

3285424: The Tribological Performances of MoDTC with Highly Branched Alkyl Groups and Highly Sulfurized Core in a Fully Formulated Engine Oil

Hui Xiang, Changqi Liu, Guangzhou Jetsun Lubrication Technology Co., Ltd., Guangzhou, Guangdong, China

A variety of friction modifiers exist for improving the fuel economy contribution of engine oils.Among friction modifiers,molybdenum dithiocarbamate (MoDTC) is known to reduce friction and improve fuel economy. In our work, Four-ball, Oscillating Friction and Wear (SRV) testers, Mini-Traction Machine (MTM), Pressure Differential Scanning Calorimetry (PDSC), high temperature Panel Coke Tester, and automobile field tests were employed to evaluate the tribological performances of novel liquid MoDTC with Highly Branched Alkyl Groups and Highly Sulfurized Core (HBHS-MoDTC) in engine oils. The experimental tests show that, HBHS-MoDTC is powerful in reducing frictions under boundary and mix lubrication regimes,which is confirmed by the field tests in fuel economy improvement. However, a slight reduction in anti-oxidation performances of the engine oil by MoDTC was also found, but the good anti-oxidation capacities can be recovered by the implementation of more antioxidants in the engine oils.

9:30 - 10 am

3308455: Interactions between Nanoparticles and Extreme Pressure Additives: Toward High Performance Low Viscosity Lubricants

Robert Carpick, Meagan Elinski, Parker LaMascus, Andrew Jackson, University of Pennsylvania, Philadelphia, PA, Lei Zheng, Robert Wiacek, Pixelligent LLC, Baltimore, MD

Low viscosity (LV) lubricants reduce viscous losses, but increase the risk of boundary contact, thus requiring new antiwear (AW) additives. We have found that ZrO_2 nanoparticles (NP) in base oils form AW tribofilms[1]. However, their performance in fully-formulated LV gear oils is unknown. To study this, particularly interactions with S- and P-containing AW/anti-scuffing compounds, we evaluate tribofilm growth by comparing NPs in pure base oil to a fully-formulated LV gear oil with and without NPs. Using a mini traction machine, we explore the effect of slide-to-roll ratio on tribofilm growth, and use in situ AFM-based tribofilm growth experiments to assess NP/co-additive interactions. Surface-active additives did not prevent ZrO_2 tribofilm growth. Moreover, NP/co-additive interactions are synergistic to tribofilm development. We will discuss the proposed underlying mechanisms. [1] Khare et al. ACS Appl.Mat.Interf. 10, 2018 Approved for public release;distribution unlimited. OPSEC #: 3358

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

10:30 - 11 am

3321894: Correlation of Engine Oil Degradation in Large Scale Alteration Device and Engine Test Rig

Nicole Doerr, Adam Agocs, Serhiy Budnyk, Andjelka Ristic, Marcella Frauscher, AC2T Research GmbH, Wiener Neustadt, Austria

Engine tests are typically performed with fresh oils whereby long-term effects such as oil degradation are neglected. A time-consuming, therefore expensive engine test would be necessary to gain insight into component performance dependent on the degree of oil degradation, fuel dilution, soot contamination, just to tell a few. A laboratory-based large scale alteration device is proposed for the provision of sufficient quantities of a defined used engine oil. The example of a soot-contaminated oil from a diesel engine test rig shows how oils from the field are reproduced in the laboratory. The

correlation between field and laboratory is determined by conventional oil parameters, molecular structure information provided by mass spectrometry, soot analysis and tribometrical experiments.

11 - 11:30 am
3324592: The Use of Microcapsulated Friction Modifier Additives for Fuel Economy Enhancement
Stephen Hsu, Govindaiah Patakamuri, George Washington University, Washington, DC, Tim Cushing, GM, Detroit, MI

Microcapsules provide timed-release of additives to replenish depleted additive during service. As such, it has tremendous potential for long drain intervals. This potentially could be used in autonomous vehicles to prolong the maintenance intervals. Microcapsules can also enable isolated protection for additives that are antagonistic to existing inhibitors to enhance additive effectiveness that otherwise unavailable. In this study, we test this concept on encapsulated friction modifiers to provide long term friction reduction beyond the normal effective period. We have demonstrated that such capsules can be made, scaled up, and their effectiveness in bench tests. But when it comes to actual engine testing, how to design the engine test protocols? What kind of engine test procedure would be appropriate? This presentation will describe such an effort.

11:30 am - 12 pm
3287491: Piston Deposit Control: A Fundamental Mechanistic Study
Anil Agiral, Anthony Gilbert, Christopher Kabb, Nico Proust, Binbin Guo, Lubrizol Corporation, Wickliffe, OH

Preventing piston deposit formation is a critical performance property for engine oils. In the current study, we investigated the complex mechanisms of piston deposit control in the Sequence IIIH engine (ILSAC GF-6). We utilized advanced colloid and surface science and new experimental methods to present a unified approach. We will define the molecular and macromolecular structures of oil insolubles in their natural state with spectroscopy, laser reflectance, light scattering and probe microscopy. We will discuss the electrosteric mechanisms of controlling rate and extent of aggregation and deposition of oil insolubles. Our findings confirm the connection between colloidal stability and deposit control.

8B — Columbus CD

Nonferrous Metals III: Lubricant Additives and Tribology

Session Chair: Annie King, Total Specialty Lubricants, Linden, NJ
Session Vice Chair: Tom Oleksiak, Novelis, Inc., Kennesaw, GA

1:30 - 2 pm
3298424: Insights into the Formation of Protective Tribo-Layer on Ti6Al4V in the Simulated Body Fluid Environment
Jiahui Qi, University of Sheffield, Sheffield, United Kingdom

Ti-6Al-4V is the most extensively use Ti alloy in a wide range of industries. It has been used as the surgical implant material for long time because of its good strength-to-weight ratios, corrosion resistance and bioavailability. The tribo-corrosion property and the formation of the tribo-layer in simulated body fluid condition has been studied extensively and reported, however, the nature of the formation process is not clear yet because of the highly complexity of the process. Here in this study, the dynamic formation process of the protection layer is revealed. The structure and composition of the tribo-layer was investigated by using Raman spectroscopy, HR-TEM, STEM_EDX and EELS. The deformed structure of the subsurface under the worn surface are characterized by precession electron diffraction technique (PET). The micro-mechanic property of the worn surface is measured micro-pillar compression method.

2 - 2:30 pm
3285603: Structure-Performance Evaluation of Synthetic Metalworking Fluid Additives
Tiffany Meyers, Clariant, Mount Holly, NC

Meeting today's performance requirements is no easy task. While manufacturing and processing nonferrous materials (e.g. rolling, cutting, forming, grinding) a metalworking fluid can be exposed to a variety of conditions that it must withstand. In this challenging market it is essential for a formulator to select the right additives during fluid development. Corrosion inhibitors can be a valuable tool used for formulating synthetic fluids by protecting the aluminum surface and, at the same time, can deliver additional functionalities which help metalworking fluid formulators address other formulation challenges. Additionally, lubricity additives can vary with shape, size and solubility, contributing to the overall fluid performance. As improved health and safety attributes are becoming a necessity, it's important to understand how molecular structure can impact product labeling. This paper highlights the relationship of molecular structure to performance for a variety of additive types.

2:30 - 3 pm
3285880: Lubricant Additive Response Comparisons, in a Commercial Post Lubricant, on 3104 Aluminum D&I Can Stock, 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 compare coefficients of friction and adhesion prevention performance of lubricants. A common problem in the D&I can drawing process is bleedthrough or blush. Factors affecting bleedthrough include tool setup, sheet metal surface characteristics, post lubricant (PL) amount and compatibility with cupper lubricants (CL), lubricant cleanliness, and boundary and hydrodynamic lubrication. Control of friction is critical in metalforming operations. In this work, TCT is used to compare additive responses, in a commercial PL formulation, on 3104 aluminum can stock. Lubricants evaluated include polymers, acids, esters, alcohols, and phosphorus bearing additives. The aim is to provide useful empirical data for formulation of lubricants to address issues like bleedthrough on aluminum.

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

3:30 - 4 pm
3321043: Wear-Corrosion Synergism Behavior of Additive Manufactured Ti-6Al-4V Alloy
Pradeep Menezes, Ashish Kasar, Arpith Siddaiah, Pankaj Kumar, Manoranjan Misra, University of Nevada - Reno, Reno, NV

The Ti6Al4V components in the marine and aerospace environment experience a high degree of vibration/sliding combined with a varying degree of the aqueous environment, a condition known as wear-corrosion synergism. Additive manufacturing of Ti-6Al-4V alloy has also been achieved in the recent past. However, a limited study has been reported on wear-corrosion synergism behavior of Ti-6Al-4V alloy. In this study, the characteristics of Ti-6Al-4V alloy fabricated using laser powder-bed fusion (L-PBF) when exposed to wear and corrosion conditions are presented. In an attempt to understand the impact of the manufacturing process, the wear-corrosion behavior of Ti-6Al-4V made by powder metallurgy (PM) process, wrought, and L-PBF are compared in 3.5% NaCl aqueous solution. The impact of sliding velocity and normal load on the wear-corrosion behavior is also studied.

4 - 4:30 pm
3324656: Correlation between Microscopic Surface Damage and Frictional Behavior of Lubricants for Stamping Automotive Aluminum Sheet Products
Mehdi Shafiei, Shania Polson, Novelis, Novi, MI

Three different types of lubricants, namely a mineral oil-base lubricant, a wax-base dry film lubricant and a polymer-base dry film lubricant were applied to aluminum sheet samples. The frictional behavior of the samples were evaluated using a single draw bead simulation tool. The contact and non-contact surfaces of the samples were characterized using optical microscopy, electron microscopy and topography measurements. The results showed a significant difference between the ability of the lubricants to reduce mechanical contact and surface damage during forming simulations. A direct correlation between forming friction and microscopic surface damage was observed.

4:30 - 5 pm
3324704: Metal Corrosion: Looking Farther Than the Eye Can See
Clayton Cooper, Nicole Clarkson, Soraya Kraszczyk, ANGUS Chemical Company, Buffalo Grove, IL

While the adage “Don’t judge a book by its cover” is relevant for various aspects of everyday life, like humans and books, it’s a completely different matter when discussing metal machining. Physical appearance of metal is often indicative of future complications. For example, metal corrosion of all types not only impedes adhesion of various coatings, it can also impact the integrity of the metal. A recent study investigating metal leaching in the absence of aluminum staining, uncovered another aspect of metal corrosion. In the presence of certain amines, increased leaching was observed without a visual increase in staining. Not only can metal leaching impact the next step in the machining process and overall metal quality, it can also impact the stability of a metalworking emulsion. This study further investigates staining in correlation to metal leaching on a wide variety of metals and outlines potential impact to the overall formulation.

5 - 5:30 pm
3332316: Hot Rolling Emulsions and the Importance of Antioxidant Additives
Bill Poynor, Kaiser Aluminum, Spokane, WA, Annie King, Wayne Jenkins, Total Specialty Lubricants, Linden, NJ

Emulsions are a type of coolant commonly used throughout the aluminum manufacturing process. This presentation will specifically review emulsions used in the Hot Rolling of aluminum and the importance of antioxidant additives. In many Hot Rolling applications the emulsion is heated either directly or indirectly to elevated temperatures. In this presentation I will focus on the chemical and physical effects on the in-use emulsion if emulsion chemistry isn’t maintained and antioxidants are not managed at an

appropriate level.

8C **Columbus EF**

Environmentally Friendly Fluids III

Session Chair: Daniel Garbark, Battelle Memorial Institute, Columbus, OH
Session Vice Chair: TBD

1:30 - 2 pm
3323643: Addressing the Thermo-Oxidative Stability and Other Issues Facing the Biolubricant Formulation
Ashok Cholli, Polnox Corporation, Lowell, MA

Today, improving the performance and lowering toxicity associated with lubricants and biolubricants is of paramount importance. This is possible with new molecular engineering technologies developed by Polnox. Antioxidants are additives that delay the onset of oxidative changes lubricant products improving the useful life. The extent of oxidation is dependent on the nature and quality of an oil. It is necessary to improve the oxidative stability of biooil using novel antioxidants. Polnox has developed new and high performing DT-mPM™ antioxidant additives to improve the useful life of bio oils. Their eco-toxicity (minimally toxic) nature and superior performance help to advance the use of biolubricant products. Their effectiveness and benefits will be illustrated with example for eco-friendly oils.

2 - 2:30 pm
3290027: Lubricity Improvement of the Ultra-Low Sulphur Diesel Fuel with Vegetable Oils.
Andrew Sakyi, University of Pretoria, Pretoria, Gauteng, South Africa

Diesel is a complex mixture of hydrocarbons. To reduce pollution, some regulations have been framed to limit the amount of harmful components such as sulphur in diesel. Until the 1990s, sulphur was accepted up to a maximum value of 500 ppm. But keeping the green environment in view, the regulations have been made more stringent and presently sulphur should not be present beyond 50 ppm in most countries. So, it is required to be removed through desulphurization. But unfortunately during desulphurization, many components that give diesel its natural lubricity also get removed, leading to loss of lubricity in the produced diesel. Most fuel manufacturers substitute the loss of lubricity with additives that may either be expensive, artificial or potentially hazardous to the environment. Vegetable oils such as castor, moringa and canola oil are excellent candidates as lubricity additvies for diesel because they have good lubricity, are renewable and environmentally friendly.

2:30 - 3 pm
3270649: Evaluation of Chaulmugra Oil (Hydnocarpus Wightiana) as a Potential Environment-Friendly Lubricant Base Stock
Jayadas Haridas, Cochin University of Science and Technology, Ernakulam, Kerala, India

In this paper, the efficacy of chaulmoogra oil, a non-edible vegetable oil, as an environment-friendly base stock for lubricants is evaluated. Chaulmoogra oil, extracted from the seeds of chaulmoogra tree

(Hydnocarpus Wightianus), has a unique long-chain cyclic fatty acid composition with chaulmoogric acid, hydnocarpic acid and gorlic acid. First, the chemical structure and composition of the oil were determined, and various tests were performed to determine the lubricant properties of the oil. Chaulmugra oil has a viscosity of 9.2 cSt at 100 degrees Celcius and has friction and wear characteristics comparable to a commercial SAE20W30 oil. Oxidative and thermal stabilities are similar to coconut oil and sunflower oil. Pour point of the oil is found to be high, necessitating the use of appropriate pour point depressants (PPD). Environmental advantage, coupled with non-edible nature of chaulmoogra oil makes it an excellent base stock for lubricants.

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

3:30 - 4 pm
3279513: Bacterial Toxicity and Biodegradability of Ionic Liquids Studied for Using in Lubrication
David Blanco, Paula Oulego, Javier Faes, Rubén González, Jose Luis Viesca, Antolin Hernández Battez, University of Oviedo, Gijón, Asturias, Spain

Despite the numerous studies about ionic liquids (ILs) in lubrication made since 2001, only few studies have dealt with their environmental impact. Due to this reason, this work compares the environmental properties (bacterial toxicity and biodegradability) of 18 different ILs, potentially applicable as lubricant additive, with two types of the lubricant additive ZDDP. Aquatic toxicity was determined by means of Vibrio fischeri and Escherichia coli bacteria, while biodegradability was evaluated through biological oxygen demand (BOD_5) and chemical oxygen demand (COD) measurements. The $[N_{8881}][C_{6:0}]$ and $[N_{8881}][C_{8:0}]$ were the less toxic ILs (acute 3 according to GHS), whereas ZDDP fell into acute 1 category (very toxic). Although all samples turned out to be not readily biodegradable (BOD_5/COD below 0.3), the 6 fatty acid anion-based ionic liquids (FAILs) showed biodegradability index values at least 2 times higher than the other 14 lubricant samples.

8D — Columbus G

Fluid Film Bearings IV

Session Chair: Aurelian Fatu, Iinstitut Pprime, Angouleme, France
Session Vice Chair: TBD

1:30 - 2 pm
3322976: Loading Performance of Metal Rubber-Bump Foil Gas Bearings
Chuanbing Zhang, Hongrui Ao, Hongyuan Jiang, Harbin Institute of Technology, Harbin, China

We designed and fabricated an air lubricated metal rubber-bump foil bearings (MR-BFBs) to solve the problems of low bearing capacity and operate unstable in traditional compliant foil bearings (CFBs), while maintaining a nearly constant dynamic stiffness over working. In the work described herein, a theoretical model of lubrication in radial sliding bearing is developed considering the effect of rarefied gas and surface roughness, which was solved by using finite element difference method to obtain numerical solution of load capacity. We found that in micro scale there is a significant effect of rarefied gas and surface roughness on air film pressure, resulting in its distribution randomness. Bearing capacity

decreases, while friction force of gas film increases with increasing surface roughness. In addition, the influence of the fractal dimension on bearing capacity in the circle direction is greater than that in the axis direction.

2 - 2:30 pm
3323240: Coupling Transient Mixed Lubrication and Wear for Journal Bearing Modeling
Guo Xiang, State Key Laboratory of Mechanical Transmission, Chongqing, China, Yanfeng Han, Chongqing University, Chongqing, China

A transient Mixed Lubrication-Wear coupling model (MLW coupling model) is developed to investigate the mixed lubrication and wear performances of journal bearings, and a wear experiment for journal bearing is performed to support the validity of the developed numerical model. In the coupling numerical model, the transient interaction between the behavior of mixed lubrication and wear is considered by incorporating the wear depth distribution, which is determined by the developed friction fatigue wear model, into the film gap equation. The evolutions of the worn surface profile, wear rate, fluid pressure and asperity contact pressure over operating time are calculated by the developed numerical model. The simulated results demonstrate that the transient wear process affects the distribution trend of lubrication performances significantly, and a worn surface profile may exist that provides an optimal tribology performance of journal bearings.

2:30 - 3 pm
3322243: An Optimization Research of Journal Bearing under Steady Operations Using Taguchi and Grey Relational Analysis Methods
Chongpei Liu, Bin Zhao, Xiqun Lu, Wanyou Li, Harbin Engineering University, Harbin , China

Journal bearing with double parabolic profiles can eliminate bushing edge wear, but it also reduces load carrying capacity and increases friction loss in some cases. To overcome these drawbacks, in this study, a multiobjective optimization of journal bearing with double parabolic profiles and square dimples is researched theoretically under steady operations based on Taguchi and grey relational analysis methods. Taguchi's orthogonal array L_{27} is adopted and five factors, i.e., dimple width, depth, numbers, radial height of double parabolic profiles, and axial width of double parabolic profiles are considered in orthogonal tests. Based on the orthogonal results, main effects analysis and analysis of variances are performed to reveal the influence trends and significance of factors on response variables. Grey relational analysis is used to determine the final optimal profile design, which may give maximum load carrying capacity and minimum friction loss.

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

3:30 - 4 pm
3322422: Optimization of Oil Supply to a Starved Slider Bearing Based on Wettability Gradient
P.L. Wong, C.L. Liu, City University of Hong Kong, Kowloon, Hong Kong, F. Guo, Qingdao University of Technology, Qingdao, China

Bearings running under starved lubrication are quite common in practice, especially for those lubricated with grease. Actions to rectify the shortfall can be differentiated in two aspects: to enhance the lubrication effect of the limited oil supply under starvation condition, and/or to change the means of oil supply to achieve fully flooded lubrication. The present study addresses the former using the concept of wettability gradient, which creates the driving force to drive a liquid droplet toward a region of higher

wettability. Our concept is to retain as much of the limited amount of oil on the lubrication track of the bearing by using wettability gradient on the two sides of the track. Wettability gradient is facilitated by micro-texture patterns produced using femtosecond laser in the present study. The effect of wettability gradient on bearing performance in terms in terms of bearing load-carrying capacity is evaluated. Experimental results are very promising.

4 - 4:30 pm
3338294: Simulating the Effect of Micro-Textures for Friction Reductions in Conformal Bearing Systems
Francisco Profito, University of São Paulo, Sao Paulo, Brazil, Sorin-Cristian Vladescu, Tom Reddyhoff, Daniele Dini, Imperial College London, London, United Kingdom

In the past three decades there has been a pervasive application of micro-texturing to enhance the performance of bearings and machine components. While both experimental and modelling work have shown the potential benefit and unwanted drawbacks of such solutions, only recently there has been a consistent effort to develop new techniques to explore the underlying mechanisms that govern their behaviour under different lubrication regimes. In this presentation we will discuss recent progress made to develop a general finite volume method to study the effect of the complex geometries associated with micro-textures. This has been used to explain the friction reduction observed in a number of applications. The methodology, as also shown in combination with advanced experimental techniques, can help shedding light on the fundamental mechanisms that are responsible for changes in performance due to the presence of micro-textures under different lubrication conditions.

8E — Columbus H

Wear III

Session Chair: Ali Beheshti, George Mason University, Fairfax, VA
Session Vice Chair: Arnab Ghosh, EtaGen, Inc., Menlo Park, CA

1:30 - 2 pm
3322854: Insights Learned from Fretting Fatigue FEA Simulations and Surface Characterization of Metal Substrates
Iyabo Lawal, Matthew Brake, Rice University, Houston, TX

FEA models that include frictional response of the contact patch, can provide insights about the fretting fatigue phenomena observed in metal samples subjected to high cycling at low slip amplitudes. Do different friction models produce different contact response? If so, which model best validates results from fretting experiments and supports observed surface response from Confocal Microscope, SEM and EDAX characterization techniques. This work attempts to verify three different friction models: Coulomb, Stribeck and Bouc-Wen to help predict how the contact patch topology and local material properties changes in response to a known loading condition for metals substrates. In addition, the impact of a Hertzian versus a conformal contact geometry will be studied. Results of this study can provide a tool to evaluate interface response and can provide insights about how to design interface geometries and assemble sub-structures to limit the onset of surface defects.

2 - 2:30 pm

3314627: Principal Tensile Stress Predicts Locations of Shoe Wear Consistent with Natural Wear Patterns

Kurt Beschorner, Sarah Hemler, University of Pittsburgh, Pittsburgh, PA, Takeshi Yamaguchi, Tohoku University, Sendai, Miyagi, Japan

Principal tensile strain causes crack nucleation and contributes to elastomer wear [1]. Tensile stress (a correlate of strain) also appears to explain differences in tread wear rates across individuals [2]. In this pilot study, load cells attached to individual shoe treads recorded local 3-axis forces during human gait of five participants. The location of the peak principal tensile stress was identified across the 52 tread lugs. Wear locations were also identified for five naturally worn shoes. Two peaks in tensile stress were observed (1: 12% anterior to the heel; 2: 9% posterior to the toe). Similarly, two worn regions were observed (1: 9% anterior to the heel; 2: 18% posterior to the toe). Thus, preliminary evidence supports using principal tensile stress for identifying wear distribution across shoe outsole. [1] Mars and Fatemi, 2002, Int. J. Fatigue 24, 949-961. [2] Hemler et al., 2019, Influence of required coefficient of friction on rate of shoe wear, ISPGR.

2:30 - 3 pm

3318528: Elevated Temperature Fretting Wear Analysis of Additively Manufactured Inconel 625 with Surface Strength Improvements

Manisha Tripathy, Ali Beheshti, George Mason University, Fairfax, VA, LLoyd Hackel, Curtiss-Wright Surface Technology, Livermore, CA, Keivan Davami, University of Alabama, Tuscaloosa, AL

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

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

3:30 - 4 pm

3319943: Elevated Temperature Fretting Wear Study of Additively Manufactured 17-4 PH Stainless Steel

Manisha Tripathy, Ali Beheshti, George Mason University, Fairfax, VA, Pooriya Nezhadfar, Nima Shamsaei, Auburn University, Auburn, AL, Keivan Davami, University of Alabama, Tuscaloosa, AL

Additive Manufacturing is a novel manufacturing process only a few decades-old with great potential to carve out better and more efficient manufacturing techniques. While investigations on mechanical properties such as strength, fatigue and to some extent corrosion are abundant in the literature, friction and wear studies of additively manufactured materials are scarce especially for metals at high temperatures. This presentation reports the fretting friction and wear properties of traditionally and additively manufactured 17-4 PH from room temperature up to 700^{o}C for less than 1mm stroke length.

The samples are manufactured using laser powder bed fusion process at different orientations prior to fretting tests. SEM/EDS analysis is also performed to further investigate the wear and friction behaviors. At higher temperatures, lower friction coefficient and higher wear volume are observed with the significant deviation between the additively manufactured and wrought samples.

4 - 4:30 pm
3340519: Effects of Wear on Dynamics Characteristics of Mechanisms with Multi-Clearance Joints
Zhengfeng Bai, Jijun Zhao, Junsheng Zhou, Harbin Institute of Technology, Weihai, Shandong, China

Clearance in joint of mechanisms is unavoidable due to assemblage, manufacturing errors and wear. The existence of clearance will cause contact-impact forces in joint, which contribute to surface wear and incessant material loss of surface during the motion of joint elements of mechanisms . Further it will increase the clearance size and change the dynamic characteristics of mechanisms. In this work, the wear phenomenon of dry revolute clearance joints in flexible mechanisms are studied using a computational methodology. First, the normal contact force model and the tangential friction force model are established to describe the contact-impact in clearance joint. Second, the dynamic Archard's wear model is used to predict the wear phenomenon of clearance joints in mechanisms. Finally, a flexible slider-crank mechanism with multi-clearance joints is used as numerical example to perform the wear effects on mechanisms with multi-clearance joints.

4:30 - 5 pm
3281561: Microstructure Based Material Model to Predict Wear Rate and Wear Depth during Manufacturing
Burak Bal, Abdullah Gul University, Kayseri, Turkey

In this study, the effects on the material model on the wear rate and wear depth were studied. The studied material was Inconel superalloy due to its extraordinary mechanical behavior at elevated temperatures. Specifically, two different material models were used to simulate wear through Finite Element Analysis (FEA). The material models were 1) Classic Johnson-Cook material model and 2) Crystal plasticity based material model which includes the effect of microstructure. It was shown that the latter material model predicts better results, which are closer to experimental observations, over the former one. Tool wear results were observed on the rake face. Experimental observations were conducted via optical microscopy. Other inputs for FEA were depth of cut, surface speed, tool geometry & coating and other boundary conditions. Therefore, the distinction of the material model on machining output was demonstrated in this study.

5 - 5:30 pm
3284846: Adhesive and Abrasive Gear Wear Prediction Models: Utilization of Statistical Analysis
Surapol Raadnui, KMUTNB, Bangkok, Bang-Sue, Thailand

In extreme spur gear wear conditions, some of the tooth damages such as pitting are not the main type of teeth flank failure anymore. For certain wear limits of teeth flanks, experimental results will be presented by statistical analysis approach. A series of experiments will be carried out which simulates the operation of spur gears in contaminated SiC media and clean lubricating oil. In general, a statistical model and statistical parameters are suitable for the development of adhesive and abrasive wear model of tested gear pairs. Design of Experiments (DOE) will be utilized against the background of spur gear wear tests, a multiple correlation model with a limited test conditions are anticipated in this particular work. The effect of wear variables such as SiC concentration, applied load and sliding distance will be

statistically and physically analyzed in details.

8F Columbus IJ

Lubrication Fundamentals VIII

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3318381: Evaluation of Interactions between Molybdenum-Based Friction Modifiers and Other Additives in Lubricants.
Yu Min Kiw, Philippe Schaeffer, Pierre ADAM, University of Strasbourg, Strasbourg, France, Benoit Thiebaut, Chantal Boyer, Géraldine Papin, TOTAL MS, Solaize, France

Molybdenum based friction modifiers are amongst the most efficient technologies for high performance fuel economy lubricants. The mixture of molybdenum-based compounds used in combination with other additives in lubricants can lead to synergistic or antagonistic effects which affect engine fuel economy performance. We report here the study between Mo-derivatives, Zinc dithiophosphates and polysulfide species, notably, and re-evaluate their impact on the formation of MoS_2 tribofilms by means of laboratory and tribology experiments. A ball on flat pure sliding method has shown the effect of the formulation components on MoDTC tribochemical activation kinetic. Sulfurization and ligand-exchange reactions of Mo-species and their impacts on tribological performances and persistence under thermo-oxidative conditions have been investigated in detail at a molecular level using LC-MS and NMR (^{1}H, ^{13}C, ^{31}P).

2 - 2:30 pm
3323327: High-Throughput Design of Organic Friction Reducers in Engine Oils
Jing Yang, Jon Paul Janet, Fang Liu, Heather J. Kulik, MIT, Cambridge, MA

In the quest for green tribology, designing effective friction-reducers (FRs) remains an outstanding challenge that can be solved via computational materials design. Traditional FRs contain metals, sulfur, and phosphorus, which can poison exhaust system catalysts and diesel particulate filters. Thus, if suitably designed, organic friction reducers (OFRs) present a promising alternative solution. Here, we apply molecular dynamics simulations together with first principles methods under a high-throughput workflow to enable the OFRs design. By computing the friction coefficients of OFRs on model-engine iron oxide surfaces at different temperatures and coverages, we are able to develop direct physical insight into the nanoscale properties of OFRs that lead to the criteria of friction-reducing characteristics. These studies allow us to build a quantitative-structural-property relationship for predicting OFR candidates, enabling an iteratively improving materials design workflow.

2:30 pm - 3:00 pm
3324150: Oxidative Stability of Estolides
Travis Thompson, Biosynthetic Technologies, Indianapolis, IN

A set of base oil samples, including estolides, esters, PAGs, PAOs, and mineral oils were tested for their resistance to oxidation, according to the industry standard RPVOT test (ASTM D2272). The raw data from these experiments suggest that the RPVOT method underestimates the oxidative stability of estolides and esters relative to the other base oils tested. Different oxidative stability methods were also explored and a comparative analysis was performed.

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

3:30 - 4 pm
3324202: Practical Considerations for the Development of Amine and Phenol Synergies
Jun Dong, Songwon Industrial Group, Glen Allen, VA

To meet the ever-escalating performance requirements for oxidative stability, it has become a common practice to employ synergistic antioxidant systems in lubricants. One recognized system is the use of an alkylated diphenylamine (ADPA) with a hindered phenolic ester (HPE). The mechanism between the two antioxidants is understood and sound. However, in practice, successful reproduction of the synergy can still be a challenge from formulation perspective. In this presentation, some of the key elements such as base oil chemistry, presence of natural sulfur and sulfur containing additives, antioxidant treat level and ratio were examined. It was found that all of them can play a profound role to influence the synergy. Further consideration also goes to the type of the bench tests employed and the test conditions. Mechanistic hypotheses are provided to assist understanding of the lab observations.

4 - 4:30 pm
3286456: An Optimization Routine to Obtain Lubricant Parameters from EHD Friction Measurements
Marcus Björling, Andreas Almqvist, Luleå University of Technology, Luleå, Sweden

Numerical models to predict friction in EHD contacts often require many lubricant parameters for accurate prediction. These parameters are used to describe the lubricants compressibility, pressure-viscosity behavior, temperature-viscosity behavior, shear-dependence etc. In many cases these parameters must be obtained in high pressure viscometers which are not very common. In this work, we aim to investigate if it is possible to obtain realistic lubricant parameters from a low-degree of freedom optimization routine with friction datasets from ball-on-disc measurements performed at different operating conditions.

4:30 - 5 pm
3283796: A Molecular Dynamics Approach to Predict Pour Points of Fluids
Jannat Ahmed, Jie Lu, Q. Jane Wang, Northwestern University, Evanston, IL, Junqin Shi, Northwestern Polytechnical University, Xi'an, China, Ning Ren, Fran Lockwood, Valvoline Inc, Lexington, KY

Pour point, or the temperature below which a fluid ceases to flow, is an important lubricant property. A molecular dynamics-based approach is used to explore and identify the pour points of a number of fluids. Diffusion properties are investigated at a varying range of temperature and a change in trend around the pour points is observed. A correlation of Solvent Accessible Surface Area (SASA), which is defined as the locus of the center of the solvent probe when it rolls over the molecular surface, and pour point is established. The pour points obtained from the MD simulations are compared with experimental results from literature, and good agreements are observed.
Keywords: Pour Point, Diffusion Properties, Solvent Accessible Surface Area

Materials Tribology VI - Additives & Fluid Lubricated Contacts

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3286543: Tribological Performance of Hard Coatings in Low Viscosity Fuels
Tyler Torgerson, Asghar Shirani, Thomas Scharf, Diana Berman, University of North Texas, Denton, TX, Satish Dixit, Plasma Technology Incorporated, Torrance, CA, Stephen Berkebile, Army Research Laboratory, Aberdeen Proving Ground, MD

High-pressure common-rail diesel fuel delivery systems in internal combustion engines (ICE) are not designed to tolerate low viscosity, low lubricity fuels. However, jet fuel of varying viscosity is routinely used in diesel ICE engines for some applications, and there is a desire to expand the allowable fuel envelope further. To make this transition to low viscosity fuels, further examination of fuel delivery components with state-of-the-art materials and surface treatments is required to determine the tribological mechanisms/interactions and their corresponding performance for optimal efficiency operation in low viscosity fuels. To this end, several surface treatments were investigated as possible solutions to address scuffing and wear in fuel pump components. Potential coatings and surface treatments were examined using reciprocating sliding in ethanol and dodecane followed by microscopy/spectroscopy characterization to quantify friction, wear, and tribological mechanisms.

2 - 2:30 pm
3323741: Tribological Study of PDA+PTFE Coating in Oil-Lubricated Condition
Sujan Ghosh, Min Zou, University of Arkansas, Fayetteville, AR

In this study, the coefficient of friction and wear properties of spray-coated, 45-µm thick PTFE and PDA+PTFE coating on cast iron substrate were investigated in oil-lubricated conditions. The addition of PDA in PTFE increased the modulus of elasticity and adhesion of the PTFE coating from 0.62 GPa to 0.97 GPa, and 154 nN to 172 nN, respectively. Tribological test results showed that the PDA+PTFE coating lasted 13,667 s, which is 7 times longer than the PTFE coating. The higher modulus of elasticity was responsible for the longer wear life of the PDA+PTFE coating compared to that of the PTFE coating. It was also observed that the addition of PDA to the PTFE coating slightly reduced the coefficient of friction of the coating from 0.056 to 0.049. The better nanomechanical properties and the crosslinking between the PDA and PTFE were responsible for the better durability of the PDA+PTFE coating in oil-lubricated conditions.

2:30 - 3 pm
3320789: PDA/PTFE + Graphite Particles Coating on 60NiTi: Effect of Coating Thickness and Substrate Roughness
Dipankar Choudhury, Charles Miller, Min Zou, University of Arkansas, Fayetteville, AR

Polydopamine (PDA)/polytetrafluoroethylene (PTFE) + graphite particles (GrP) thin-film coated 60NiTi shows a significantly reduced coefficient of friction and extended wear life in dry contact. In this study,

the coating wear life was investigated by changing the coating thickness and substrate roughness. Durability tests were conducted using a linear reciprocating motion at 2, 5 and 10 N applied normal loads against Si_3N_4 balls of 6.35 mm diameter. Increasing the coating thickness to 10-13 µm enabled PDA/PTFE+0.25 wt% GrP coatings to continue lubricating 60NiTi through 123K rubbing cycles under 2 N normal load. The coating wear life was further boosted to 150K rubbing cycles by creating a substrate with an average roughness of about 200 nm. However, the wear life of the coating declined to 13K cycles and 5k cycles under 5 N and 10 N, respectively.

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

3:30 - 4 pm
3303737: Compatibility of Polar Oils and Anti-Wear Additives with Steel-Coating Contacts
Xin He, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Two commercial hard coatings, diamond like carbon (DLC) and chromium nitride (CrN), were investigated for the compatibility with polar oils and anti-wear additives. Two polar base oils, hydrophilic polyalkylene glycol (PAG), and oil-soluble PAG (OSP), were used and a non-polar mineral oil blend was brought in for comparison. Ball-on-flat reciprocating sliding tests were performed in boundary lubrication regime to study the two coatings in rubbing against a bearing steel ball at 82 °C. The polar base oils were found to be incompatible with the steel-coating pairs, leading to high wear on the steel ball surfaces. Worsened steel ball wear in sliding against the two hard coatings was observed when a ZDDP or phosphate ionic liquid (IL) was introduced to either a polar or non-polar oil. Results suggested tribo-corrosion supported by wear scar morphological and compositional analysis.

4 - 4:30 pm
3301476: SLiPP Film and Bearing
Hong Liu, Lanzhou Jiaotong University, Lanzhou, China

SLiPP film is inspired by articular cartilage's structure. The ultralow friction and wear are achieved by combining solid lubrication with fluid lubrication for this material, where solid lubrication material provides load-carrying capacity while oil mainly provides liquid lubrication (Solid-liquid synergistic lubrication). SLiPP film and bearings are designed to carry higher loads and speeds with lower coefficient of friction and wear rate to meet higher requirement than common self-lubricating film and bearings. Moreover, SLiPP film and bearing can cover a wide range of applications with a variety of materials and their different properties.

4:30 - 5 pm
3282835: Reversible Light Controlled Friction Achieved by Diarylethene Molecules
Shuangxi Tang, Liran Ma, Tsinghua University, Beijing, China

Reversible friction regulation have attracted substantial interest in industry and scientific research, yet little materials and theories have been developed to solve this problem. Photo-sensitive materials are promising due to controllable properties and structures. Here, we shown a reversible light controlled friction between silica and steel with rotary motion across a self-developed diarylethene solution. In this work, symmetric diarylethene and asymmetric diarylethene had been designed and synthesized as functional materials. The friction forces were obviously increased exposed to ultraviolet light and it decayed to the initial value under visible light. In addition, the friction coefficient changed alternately with ultraviolet and visible light. The behavior was attributed to the shear stiffness difference of

diarylethene molecules with two wavelength lights. This work not only provides a new friction regulation technology, but also develops intelligent engineering materials.

8H Randolph 1

Gears II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3285540: Permissible Water Content of Gear Lubricants Regarding the Pitting Performance of Case-Carburized Gears
Nadine Sagraloff, Thomas Tobie, Karsten Stahl, Technical University of Munich, Garching by Munich, Germany, Christian Engelhardt, Patentanwälte von Bezold, Munich, Germany

In most high power density gear applications, high performance lubricants are required. Contamination of water can alter the performance of lubricants negatively, particularly regarding the pitting resistance. Especially gears in offshore wind turbines are at high risk. The influence of water contamination on synthetic oils in industrial applications is unknown. A characteristic value and a threshold limit for the amount of water in lubricants would be helpful. In order to gain a better understanding on the effect of water contamination on the pitting performance, experimental investigations on lubricants with different water contents were conducted on FZG-back-to-back gear test rigs with case-carburized gears. As a result, relative humidity was defined as a suitable characteristic to evaluate measured water contents in practical applications. As a recommendation for the practical industrial usage, this paper gives guidelines regarding the relative humidity of lubricating oils.

2 - 2:30 pm
3286616: Pitch Line Fracture: A Frictional Problem in Polymer Gears?
Sutartip Wittayapiyanon, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

Pitch line fracture is a unique failure mode in polymer gears - Why does this happen? It may be due to reversed sliding about the pitch point, a combination of tooth kinematics and frictional effects - both affected by material compliance, induced tooth deflections and bending stresses, particularly at high machine cycles. A Finite Element Method for dynamic simulation (FEM-DS) model simulates pitch line fracture in polymer gears. The transient simulation includes a new friction model to recreate the initial pitch line crack formation and propagation. A series of experiments using dry-running Nylon-PA66 and PEEK-450G gears calibrate the model. Further optimization accounts for load-sharing between teeth, stress intensity factors, and dynamic frictional effects, showing good correlation with the test results. Finally, alignment errors, due to the shifted plane of action of two gear pairs are also included. The output is a model for predicting frictional fatigue failure in polymer gears.

2:30 - 3 pm
3288465: Sodium Presence in Gearboxes, What Are the Inconveniences for Lubrication?
Jorge Alarcon, Bureau Veritas, Stafford, TX

In a typical lubrication analysis and interpretation Sodium presence is common contamination from coolants, seawater or any production fluid. Almost all the OEM and equipment manufacturers indicate that this element is a contaminant from seawater, lube manufacturers doesn't mention the presence of this element in their formulation. Although the presence of Sodium is completely unknown in certain cases, there is very little information about it and in many cases, the answer from the oil analysis lab is the possibility of wind currents containing seawater.
Sodium presence in gearbox oil shouldn't be a problem but it can be an indicator of an unusual situation and a potential cause of future and undesirable lubrication issues. This abstract includes data analysis for sodium determination and some chemical investigations to find the potential source of the element, but most importantly, it covers the potential damage that sodium may cause during lubrication.

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

3:30 - 4 pm
3298112: The Appropriateness of Laser Sintered PEEK for Gear Applications
Zainab Shukur, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

The main benefits of additive layer manufacture (ALM) lie in those areas where conventional manufacturing methods reach their limitations; it enables the manufacture of components to be design-driven rather than production driven. This work aims to investigate and reports on the direct application of the laser-sintered material poly-ether-ether-ketone (EOS PEEK HP3) to power transmission gears. Specific efforts are made to establish the reaction of the material to bending failure. A closed-loop, power recirculating test rig running dry and with oil lubrication, over a range of loads and speeds determined the dynamic response of the printed gears. Bending fatigue was the predominant form of failure in the printed gears. However, samples were shown to be sensitive to changes in both load and speed, with lubrication significantly improving the durability of the gears for a given load.

8J — Randolph 3

Wind Turbine Tribology I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3281806: Detection of White Etching Cracks (WECs) Using Electrostatic Sensing Techniques
Kamran Esmaeili, Ling Wang, Terry Harvey, Neil White, University of Southampton, Southampton, United Kingdom, Walter Holweger, Schaeffler Technologies GmbH & Ko. KG, Herzogenaurach, Germany

The reliability of bearings in wind applications has been substantially affected by white etching crack (WEC) formation. While the exact mechanisms of WEC formation are still under debate, electrical

discharging and/or stray currents could be one of the main causes. To date, limited research has been conducted to quantify the influence of electrical discharging and stray current on WEC formation. Electrostatic sensing techniques have shown to be able to monitor health-state of bearings by measuring charge generation at bearing interface, thus has been investigated in this study for WEC monitoring. RCF tests have been conducted on a TE74 twin-roller test rig under the influence of electrical potential, where WECs have been found to form in the rollers under a range of conditions. Algorithms developed in this study for charge quantification have revealed that electrical discharges on the rollers detected by the electrostatic sensors are closely associated with the WEC formation.

2 - 2:30 pm
3319018: Efficiency and Lifetime Improvement for Wind Turbines by Using Silicon-Based Additive Technology
Stefan Bill, REWITEC GmbH, Lahnau, Hesse, Germany

REWITEC® is a medium-sized business that develops an innovative silicon-based nano- and micro-particle surface treatment technology. The active particles use lubricants as a carrier and build through adsorption a protective and repairing silicon-based coating in gears or bearings of the wind turbine. In this way it reduces friction, wear, surface roughness and temperature. This talk will look at scientific tribological tests on our newest study about standstill damages of bearings, which can be significantly reduced and repaired through our coating technology. Generally, a 20 to 50% reduction in friction is achieved in running systems like gears and bearings. At the same time the surface roughness and wear are also significantly reduced. Due to the system modification the surface temperature decreases too. All in all, these effects provide a longer lifetime and higher efficiency of the wind turbine.

2:30 - 3 pm
3285610: Early State Processes in White Etching Crack Formation
Tarek Lutz, NMI, Reutlingen, Germany

White Etching Cracks and their formation under field operation remain a matter of unreliability in drive train constructions. The influence of lubrication, loading and the presence of electricity have been identified to cause WEC in previous research. While imposed electricity has shown to lead to WEC the presence of electricity in real applications with an external source of current has not been quantified or confirmed. Using an FE8 test stand, without external source of current being applied, the occurrence of electrical effects during the early stage of WEC formation has been detected by high frequency impulse analysis.The progression of those impacts has led to the formation of visible distortions on the bearing surface, with WEC and crack networks underneath the surface. Extended microstructural investigations using FIB/EDS and TEM show, that micropore arrays are visible as an early state before cracks appear. TEM shows severe distortion of the microstructure around the pores.

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

3:30 - 4 pm
3337339: Validation of Combined Analytical Methods to Predict Slip in Cylindrical Roller Bearings
Yi Guo, Jon Keller, National Renewable Energy Laboratory, Golden, CO

This paper presents a combination of analytical models that together calculate the cage and roller speeds of a cylindrical roller bearing. The models consider elastohydrodynamic lubrication and contact elasticity between the roller and raceway, roller centrifugal forces, hydrodynamic lubrication at the cage

pocket, and frictional forces. The predicted cage and roller speeds and the extent of slip are compared to measurements acquired on bearings in a commercial gearbox in steady-state and transient operating conditions of a wind turbine. The statistical results calculated by the model match experimental measurements well in general for a wide range of wind speed that determines transmitted gearbox torque and rotor speed. Significant bearing slip is present when the turbine experiences dramatic operation changes during a highly-dynamic start-up event. Roller and cage slip is a combined effect of the bearing design, applied load, shaft speed, and lubricant properties and temperature.

4 - 4:30 pm
3318691: Credibility Analysis of Thermal Coupling Finite Element Model of Friction Pair of Wind Power Spindle Brake Based on Response Surface Method
Ying Liu, Nanchang University, Nanchang, Jiangxi, China

The braking process of main shaft brake in wind turbine has complex thermal coupling problem. Finite element method can be used to study the thermal coupling traits of friction pairs. Due to the deviation between finite element model and actual condition, the reliability of the model should be evaluated. This paper introduces a response surface model for credibility analysis. A thermo-mechanical coupling finite element model of brake friction pairs is established. The response surface model is established with reference to the finite element model. The small sample is sampled by MonteCralo method and substituted into the fitted response surface model. The average value of temperature response value is 294.3°C. Compared with the measured value of wind turbine brake friction sub-frame 310°C, the error is 0.051, less than the allowable value. The finite element model is believable. This method has certain reference value for the credibility of other complex heat flow analysis problems.

4:30 - 5 pm - **Wind Turbine Tribology Business Meeting**

8K Michigan 1

Engine and Drive Train and Lubrication Fundamentals Joint Session: Lab to Field: Bridging the Gap Between Bench and Engine II

Session Chair: Piotr Grzyska, Afton Chemical Corp., Richmond, VA
Session Vice Chair: TBD

This session includes papers that cover the transition from lab scale bench tests to full implementation in actual application.

1:30 - 2 pm
3285016: Optimizing the Piston-Bore Tribology through Honing and Tribofinishing
Boris Zhmud, Applied Nano Surfaces Sweden AB, Uppsala, Sweden, Konstantin Risse, Florian Welzel, Otto-von-Guericke-University of Magdeburg, Magdeburg, Germany

Advanced surface finishing methods, such as mirror-like thermally sprayed bores, mechanochemical surface finishing, helical slide honing etc. as well as availability of high-sensitivity testing rigs and “digital twin” simulation tools create new opportunities for engine tribology optimization. In the present

communication, we are going to show that conventional one-component optimization is often nothing less than misleading, and advocate the use of a system approach. Experimental data and simulation results will be presented to demonstrate the role of cylinder bore finishing, ring pack, and lubricant on the piston/bore tribology. Friction, wear and combustion chamber sealing will be considered. The importance of in-design "pairing" of low-viscosity motor oils with the engine design, including the ring pack and cylinder bore characteristics, in order to achieve maximum reduction in GHG emissions and improvement in fuel economy without sacrificing the endurance will be elucidated.

2 - 2:30 pm
3296303: Piston Ring Coating Development - From Bench To Vehicle
Peter Lee, Southwest Research Institute, San Antonio, TX

Novel piston ring coatings were developed in the coatings lab and tested in the tribology labs using a reciprocating rig. The lowest friction coating that also survuved the testing were then applied to a gasoline engine and diesel engine ring set. These were tested for friction response in a fired single cyclinder gasoline engine and for durability in a fired single cylinder diesel engine. Having responded favourably for both friction response and durability in these teast, an engine froma vehicle was operated and the fuel economy measured before the rings were removed, coated and then the engine reassembled and vehicle tested for fuel economy again, yielding favourable fuel economy gains.

2:30 - 3 pm
3286302: Determination of Scuffing and Wear for Materials in Low-Viscosity Fuels
Stephen Berkebile, Nikhil Murthy, Army Research Laboratory, Aberdeen Proving Ground, MD, Kelly Jacques, Diana Berman, University of North Texas, Denton, TX, Caleb Matzke, Maharshi Dey, Surojit Gupta, University of North Dakota, Grand Forks, ND

High-pressure common-rail fuel delivery systems for internal combustion engines are typically designed to operate with diesel fuel. The pumps in these systems often fail prematurely by scuffing when used with fuels of low viscosity and lubricity. Materials resistant to scuffing in fuel-lubricated mechanical interfaces may expand the envelope of allowable fuel properties for such systems. However, fuel lubricity standard measurement methods are designed to evaluate fuel rather than material properties and typically measure wear rather than scuffing. We developed a measurement method designed to evaluate materials in low viscosity fuels and favor scuffing over wear as a material failure mode. Using this method in F-24 jet fuel, ethanol, and dodecane, several hard coatings (iron boride and tungsten carbides) experienced less wear and increased scuffing resistance overall, while composite materials (MAX/metal and MAX/polymer) demonstrated highly fuel-dependent behavior.

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

3:30 - 4 pm
3285127: Research on Mechanism of Cylinder Score of Diesel Engine Based on Starved Lubrication of Piston Ring Pack
Yongqiang Wang, Xuan Ma, Xiqun Lu, Wanyou Li, Tongyang Li, Harbin Engineering University, Harbin, China

Cylinder score is a common major fault of diesel engine. The starved lubrication of piston ring pack is one of the main reasons leading to cylinder score. In this paper, the experimental and theoretical analysis of cylinder score caused by starved lubrication of piston ring pack is studied. Firstly, experiments

were carried out to simulate the running condition of cylinder score. Besides, the model of lean oil mixed lubrication considering elastoplasticity of the micro-convex and adhesive wear is established. Finally, the effect of the degree of lean oil on the boundary conditions of the friction pair is analyzed. In general, a theoretical model is built, and the tribological characteristics are calculated according to the oil supply quantity, so as to achieve the purpose of predicting the degree of cylinder score according to the actual working conditions.

4 - 4:30 pm

3318418: An Efficient Approach to Estimate the Groove Pressure at the Piston-Ring and Cylinder-Liner Contact

Lyu Xiuyi, Xuan Ma, Harbin Engineering University, Harbin, China, Abdullah Azam, Anne Neville, University of Leeds, Leeds, United Kingdom

Lubrication and sealing are the two main functions of the piston-ring assembly. The groove pressure at this interface is a critical factor influencing the performance of the piston-ring and cylinder interface. Therefore, it is crucial to be able to estimate these grove pressures to optimize lubrication. The current study proposes two approaches for the calculation of groove pressure. A comparison of the two approaches suggests that each of these techniques has its own limitations. To address these limitations, an integrated numerical approach is utilized. First of all, the results from both calculation methods are verified against literature. Then, a parametric study is performed to highlight the key structural parameters affecting groove pressures. A correlation coefficient is introduced into the analysis to obtain critical values of pressure. The use of these critical pressure values can greatly simplify the dynamic and lubrication model of piston rings.

4:30 - 5 pm

3302226: Ionic Liquid-Enhanced Low-Viscosity Engine and Rear Axle Oils in Dynamometer and Vehicle Testing

Jun Qu, Sougata Roy, Chanaka Kumara, Huimin Luo, Oak Ridge National Laboratory, Oak Ridge, TN, Michael Viola, Khaled Zreik, General Motors, Warren, MI, Lake Speed, Driven Racing Oil, Olive Branch, MS

Ionic liquid (IL)-enhanced, low-viscosity lubricants have been prototyped for both engine and rear axle/gear applications. The viscosity grades of the candidate engine and gear oils were SAE 0W-12 and 70W-80, respectively. Based on compatibility studies of the ILs with other additives supported by bench tribological tests and chemical analysis, oil formulations were optimized for both energy efficiency and durability. A series of dynamometer engine and gear tests were conducted on candidate lubricants to measure the efficiency gain and wear reduction to identify the best formulations. The top-performing IL-additized engine oil and rear axle fluid were then evaluated in a vehicle using the Federal Test Procedure (FTP) city cycle and Highway Fuel Economy Driving Schedule (HWFET). A combined improvement in fuel economy from engine and rear axle lubrication by using the IL-additized oils has been demonstrated.

Tribotesting IV

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3285906: Tribological Investigation of Nano-Talc as Additive in Oil Nanolubricants
Vinay Saini, Jayashree Bijwe, Indian Institute of Technology (IIT) DELHI, Delhi, India, Sarita Seth, SSV Ramakumar, Indian Oil Corp Ltd. R&D Centre, Faridabad, Haryana, India

This present work aims to explore the investigate the tribological and physical performance of NPs of Talc as an additive in oil that has not been addressed explicitly. The flakes of talc of thickness less than 100 nm were selected for the investigations. The Nano-oils of various (0.5- 4) wt.% concentration of talc particles were formulated using Group III base oils. The oils were characterized on a four-ball tester for anti-wear (AW) and EP (weld load) as per IP 239 test standard. An ↑ in Weld load upto 122 % was observed in case of EP performance. Furthermore, to understand the working mechanisms of these nano-oils detailed worn surfaces analysis (Raman spectroscopy, XPS, EDAX, SEM and 3D profilometer) of the balls will be carried out to investigate the nature and type of tribofilm formed. Tribo-sintered talc particles were observed on worn surfaces of in raman spectra, suggesting the formation of complex tribofilm enriched in C, O and Si elements.

2 - 2:30 pm
3325283: Investigating Thermal Behavior of Lubricants Using Bench Top Tribometers
Deepak Halenahally Veeregowda, Fabio Alemanno, Ducom Instruments Europe B.V, Groningen, Netherlands

Friction between lubricated contacts is converted into heat that could negatively affect the lubrication of equipments. Tribometers are used to measure friction however its relation to changes in lubricants heat carrying capability in situ is to be established, yet. In this study we have developed new methods like BL temperature test in four ball tester and EHL temperature test in KRL shear stability tester, that can measure friction and lubricant temperature in real time. Both the test methods showed that low friction lubricants kept the system cooler than high friction lubricants. Friction measurements during EHL test was more sensitive to changes in lubricant temperature compared with BL test. Poor shear stabiilty of lubricants reduced the friction in EHL test, however the friction profile in BL tests remained unchanged. BL and EHL test methods can be used to investigate lubricants with variety of base oils or additives designed for lowering friction and heat carrying capability.

2:30 - 3 pm
3340369: A Paradigm Shift in Wear Debris Analysis
Ronn Lawrence, GasTOPS Inc., Huntsville, AL

Monitoring equipment through wear debris analysis is essential in determining machinery life. The traditional technique has been bulk elemental analysis of debris in oil. This presentation demonstrates a fundamental shift in wear debris analysis through individual particle sizing and alloy identification. Alloy

analysis provides more reliable and significantly advanced detection of failure modes. Particle alloy analysis differs from bulk elemental analysis in that each particle is identified by alloy and size. Particle alloy analysis improves the ability to trace the root cause of impending failures that are often missed by bulk elemental analysis. ASTM test method D8182 specifies a method of analyzing particles as small as 70 microns using LIBS. Other excitation technologies have shown the ability of identifying particle alloys in oil as small as 0.5 microns. Case examples on these techniques are presented.

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

3:30 - 4 pm
3321588: Extracting More Value from Tribofilm Images
Oluwaseyi Ogunsola, Shell Global Solutions (US) Inc., Houston, TX, Chaitanya Pradhan, Aarthi Thyagarajan, Vishal Ahuja, Nitish Nair, Shell India Markets Pvt. Ltd., Bangalore, India

One of the functions of a lubricant is to form tribofilms that reduce wear of contacting surfaces. Tribofilms are formed through the chemical bonding of additives in the oil with the metal engine surfaces. Stronger and thicker tribofilms offer wear protection by preventing metal-to-metal contact. Analysis of tribofilm thickness is crucial to development of lubricant formulations that exhibit enhanced wear protection as engine oil viscosities are becoming lower, to increase fuel economy. Tribology-based test methods generate many wear images that are post-processed and analyzed to determine the tribofilm thickness. This presentation features the development of a method to extract more value out of tribofilm images from MTM Spacer Layer Imaging experiments via automated extraction of the tribofilm region and generation of thickness distribution. Extracting more value from tribofilm images is crucial to develop lubricants with enhanced tribofilm attributes and protection capabilities.

8M Michigan 3

Nanotribology V

Session Chair: Praveena Manimunda, Bruker Nano Surfaces, Edina, MN
Session Vice Chair: Behnoosh Sattari Baboukani, Materials Design and Innovation, University at Buffalo, Buffalo, NY

1:30 - 2 pm
3284603: A Balancing Act: Dispersion and Lubricity Performance of Nanoparticle Additives in Metalworking Fluids
Shilpa Beesabathuni, Yan Zhou, Yixing Philip Zhao, Quaker Houghton, Conshohocken, PA

Colloidal stability of nanoparticle additives in metalworking fluids is required to prevent agglomeration and a reduction in the effective concentration, which can be achieved using dispersants. However, while well-dispersed nanoparticle additives produced promising results, the dispersants can adversely affect the friction and wear properties, due to the possible prevention of tribofilm formation. In this study, we explore the effect of the dispersant to nanoparticle ratio on the lubricity and wear to determine the optimal ratio which will enhance performance.

2 - 2:30 pm

3332656: Formation and Nanomechanical Characterization of Tribofilms Enhanced by Inorganic Nanoparticles as Lubricant Additives

Kora Farokhzadeh, Praveena Manimunda, Steven Shaffer, Bruker Nano Surfaces, San Jose, CA

Inorganic nanoparticles are introduced as lubricant additives to maintain low friction under extreme pressure and boundary lubrication regimes due to their ability to enhance load bearing capacity and thermal stability. To implement model lubricants on large scale and optimize performance it is essential to understand the mechanisms of lubrication and tribofilm formation in mixed or boundary lubrication regimes. In this study MoS_2, ZrO_2, and CeO_2 nanoparticles were suspended in base (PAO, 75-P) and formulated (10W-30) oils and tested under pin-on-flat reciprocating conditions in steel-steel contact. The tribofilms generated during experiments were characterized using nanomechanical tests to characterize adhesion and shear characteristics of tribofilms. The findings were used to understand how the intrinsic properties of the nanoparticles affect tribofilm formation, friction behavior and interfacial phenomena at different length scales.

2:30 - 3 pm

3286629: Synergistic Effect of MoS_2 and SiO_2 Nanoparticles in Reciprocating Steel Contacts

James Firth, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

The present study explores the combination of hard SiO2 nanospheres and 2D MoS2 nanoparticles as additives in a base oil between reciprocating steel contacts. In tribological regimes, SiO2 nanospheres are known to act as nano-bearings, rolling between the contacts generating a surface polishing effect. MoS2 produces a low friction coefficient as a result of weak van der Waals force, improves sliding and forms robust transfer layers to reduce wear. This study combined SiO2, and MoS2 nanoparticles with SN100 oil at 0.5 and 1.0 %wt respectively, both on their own and together in a hybrid lubricant. In a ball-on-flat experiment between AISI 52100 steel contacts, the hybrid mixture facilitated improved sulphide tribofilm formation and reduced wear when compared to either of the particles on their own. This improvement was due to a mechano-chemical effect caused by the SiO2 bombarding the steel surface and improving potential chemical reactions between the MoS2 and the steel.

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

3:30 - 4 pm

3321340: Synergistic Effect of Combining TiO2 and Montmorillonite Clay Nanoparticles as Lubricant Additives for Milling Processes

Laura Pena-Paras, Demófilo Maldonado, Martha Rodríguez, Marcela Guajardo, Claudia Rico, Gerardo Elizondo, University of Monterrey, San Pedro, Nuevo Leon, Mexico

In this work, nanoparticles of TiO2 and montmorillonite clay were mixed with varying proportions and added to a cutting fluid for milling of an AISI 4340 steel. Due to its semi-spherical shape and small size nano TiO2 fill surface valleys reducing friction; montmorillonite, being a multilayer flake-like nanomaterial may reduce friction and wear through exfoliation of their weakly-bonded layers. Laboratory experiments were performed in a four-ball tribotester to determine the best proportions of TiO2 and montmorillonite clay that provided a synergistic effect. Milling experiments were performed in a CNC equipment with varying feed rate, depth of cut and cutting speed. Plates of AISI 4340 steel were milled with cutting inserts of cemented carbides. A Box Behnken experimental design was performed in order to optimized the milling input parameters and nanoparticle combinations that provided the

lowest surface roughness of steel plates, spindle load and wear of cutting inserts.

4 - 4:30 pm
3286669: Nanoparticle Sintered Tribofilm Removal Study: An Experimental Approach
Steven Thrush, Gary Barber, Oakland University, Rochester, MI, Allen Comfort, James Dusenbury, US Army Ground Vehicle Systems Center, Warren, MI

A research effort was conducted to investigate tribofilm removal mechanisms of a novel zirconia (ZrO_2) nanoparticle antiwear additive. Spherical five nanometer diameter ZrO_2 nanoparticles were dispersed in polyalphaolefin (PAO) synthetic base oil and tested between AISI 52100 steel counterfaces in a ball-on-disk tribometer. The apparatus allowed tribofilm thickness data to be tracked in-situ at set intervals and tribofilms reaching a maximum thickness of 150 nanometers were measured. Tribofilm removal was quantified over time by subsequent tribological test in unadditized PAO, which revealed a thinner tribofilm resilient to further wear. Comparatively, lack of an existing tribofilm would result in scuffing within the first 10 minutes when testing the unadditized PAO. Scanning electron microscopy (SEM) was employed to investigate the wear processes and potential failure modes of the sintered tribofilms to include pore coalescence leading to crack formation.

4:30 - 5 pm
3279178: Superlubricity of Fullerene Derivatives Induced by Host-Guest Assembly
Shanchao Tan, Yuhong Liu, Tsinghua University, Beijing, China

Fullerenes have been recognized as good candidates for solid lubricants. Herein, the assembly structures and superlubrication properties of host-guest assemblies based on fullerene derivatives are investigated at the molecular level. The host-guest assembly structures of fullerene derivatives are successfully constructed on a highly oriented pyrolytic graphite (HOPG) surface by introducing the macrocycles as the templates. Meanwhile, the nanotribological properties of the host-guest assemblies are measured, revealing ultralow friction coefficients below 0.01. The interaction energies calculated by density functional theory (DFT) method indicate the correlation between friction coefficients and interaction strength in the host-guest assemblies. In a word, the effort on fullerene-related host-guest assembly and superlubricity could provide a novel and promising pathway to explore the solid lubrication and microscale friction mechanisms at the molecular level.

5 - 5:30 pm
3278471: Analyzing Lubrication Properties of Magnetic Lubricant Synthesized in Two Lubricating Oils
Kinjal Trivedi, P D Patel Institute of Applied Sciences, Gujarat, India

Nanoparticle technology has a huge impact on the development of lubricants. However, there is a need to understand the influence of various parameters of base oil and nanomaterials individually as well as in combination. To understand the influence of identical nanoparticle material, magnetite nanoparticle (MNP) synthesized in two different base oils: synthetic oil and mineral oil having the same order of viscosities. The MNP concentration varied from 0 to 10 wt% in both oils and the lubrication properties studied using Four-ball tester. For synthetic oil, the minimum Coefficient of Friction (reduced by 45 %) and Wear Scar Diameter (by 30 %) obtained at 4 wt% of MNP compared to the base oil. In the case of mineral oil, COF decreased by 56 % and WSD by 46 % for 6 wt% of MNP. The surface characterization and lubrication mechanisms studied using various microscopy techniques. The results explained using the difference in molecular structure as well as nanoparticle stability in both oils.

3292269: Tribological Performance of Bearing Bushes Made of Light Weight Mg Matrix Composites
Juanjuan Zhu, Rob Dwyer-Joyce, the University of Sheffield, Sheffield, United Kingdom

With the rapid development of engineering materials, self-lubricating and high strength lightweight metal matrix composites (MMC) have become a high demand candidate material for tribological components due to their significant potential in downsizing and weight saving. In this study, magnesium composites reinforced with 5 wt% WS2 and 15-20 wt% SiC particles were metallurgy sintered and made into bearing bushes. The tribological performance was studied using a purpose built pin joint test rig. The bearing contact was lubricated by the Aero Shell grease 33, subject to the articulating speed 10 - 60 deg/s, and the contact pressure up to 100 MPa. By using the optical profilometry, SEM and EDX, the friction and wear mechanisms were assessed and discussed. It was found that the mechanical properties of the composites were enhanced by the SiC reinforcement. The friction property of composite bushes was improved due to the predominantly physical action of WS2 under all testing conditions.

3285647: Lubricants Tribology Measurements on Different Surfaces
Giulio Assanelli, Claudio Barzaghi, Marcello Notari, Paolo Cambise, Eni S.p.A, Milan, Italy

CO2 emissions reduction is a global challenge which involves the whole energetic field. In particular, in ICE vehicles, only the 15 % of the energetic source is actually employed for vehicle motion, the rest of the energy is lost. A huge part of such reduction in energy efficiency is due to friction. A good lubricant is able to reduce these friction phenomena increasing the energy efficiency. Friction forces and the subsequent CO2 emissions can be reduced through particular oil additives known as “Friction Modifiers”. These molecules are subdivided into two main groups: metal organic friction reducers and organic friction reducers (OFRs). The latter are the most promising additives, since they are the most compatible with modern after treatment systems. The submitted abstract for poster proposal reports the tribology measurements (traction and oil thickness) on six different binary mixtures composed by a model group III base oil (squalane) and six different ashless OFRs.

3281005: Leaf-Surface Wax of Tall Arbor as a Potential Lubricant Additive
Yanqiu Xia, North China Electric Power University, Beijing, China

The leaf-surface waxes of three kind of tall arbor were extracted from the leaves of persimmon tree(PT), Amur honeysuckle(AH), Firmiana simplex(FS) as green lubricant additives and their chemical compositions, friction reduction and anti-wear abilities were investigated in detail. The results show that the leaf-surface wax extracted from different leaf-surface as additives in synthetic ester exhibit superior friction reduction and anti-wear abilities for steel/aluminum pairs. Gas chromatography–mass spectrometry (GC-MS) analysis was performed to identify the composition of the PT, AH and FS leaf-surface wax, scanning electron microscopy (SEM) and time-of-flight secondary ion mass spectroscopy (TOF-SIMS) were used to investigate its friction mechanisms. Its lubricating properties are attributed to fatty acids, alcohols, esters, hydrocarbons in the waxes, and forming adsorption films and chemical reaction films with the metal.

3281017: Identification and Content Prediction of Lubricating Oil Additives Based on Extreme Learning Machine

Xin Feng, North China Electric Power University, Beijing, China

In order to quickly identify the type and content of additives in the lubricating oil, the 3 kinds of different lubricating oil additive are mixed in the base oil at different proportion, using an extreme learning machine trains and tests the infrared spectral data construction model of the mixed additive, the greedy algorithm and genetic algorithm are used to optimize the input band, while the optimization results are compared. The optimal band interval combination is selected to eliminate the high excessive correlation band and improve the computational efficiency. The test results show that the ELM model can effectively identify the type and predict content of lubricant additives. And after the genetic algorithm band filtering optimization, the model output is better. The accuracy of identification of three additives reached 100% after band screening, and the content prediction determinant coefficient (R2) increased by 43.8%,39.0% and 24.4%, respectively.

3283538: Effect of Surface Energy on Nanofriction of FCC Metal Asperities Contact

Danyang Yu, Yonggang Meng, Tsinghua University, Beijing, China

Observing the atomic-scale deformation of a frictional interface in real-time is important to elucidate the mechanism of friction and wear. Based on the experiment results of Fujita et al, we conducted a non-equilibrium molecular dynamics simulation, which modeled two single silver asperities, to reproduce the experiment process. Our results agree in trend with the experiment. Simultaneously, we analyzed the influence of some key parameters including velocity, crystal orientation and indentation depth during the sliding process. Comparison between experiment and molecular dynamics simulation gives complete information which is believed to be untouchable in experiments. The investigation of different FCC material systems has shown that the key factor of the friction is not only the plastic deformation, but also the surface energy especially under micro-nano scale. A linear dependence is discovered between the total work and the surface energy.

3284941: Effect of Surface Structure of Cylinder Liner on Lubrication Performance of Piston Ring-Cylinder Liner Tribo-Pair

Bowen Jiao, Xuan Ma, Xiqun Lu, Tongyang Li, Zhigang Liu, Harbin Engineering University, Harbin, Heilongjiang, China

Surface structure, roughness and texture, is of great significant to piston ring -liner tribo-pair lubrication. And this research is to investigate the influence of different surface structure of liner on the tribo-pair lubrication performance. In this investigation, specimen test is selected as the main experimental method, so Rtec MFT-5000 friction-abrasion testing machine was selected as the test rig and suitable piston ring and cylinder liner samples are designed at first. To achieve the purpose, several different roughness and texture on the surface of cylinder liner samples are designed to carry out the reciprocating friction test in full oil lubrication condition. Study indicate that it is not true the smaller the roughness of cylinder liner is the best the lubrication performance of the tribo-pair is. There is a suitable roughness which make the lubrication performance of tribo-pair the best.

3285121: The Influence of Asymmetric Piston Skirt Profile on the Secondary Motion of Piston and the Lubrication Characteristics of Piston Skirt

Yongqiang Wang, Xuan Ma, Xiqun Lu, Wanyou Li, Xiangxu Meng, Harbin Engineering University, Harbin, China

In recent years, with the development of diesel engine towards high strength, the piston lubrication problem is more prominent. In this paper, the asymmetric piston skirt profile is studied owing to the significance of the piston skirt shape to the piston lubrication. Considering the top ring friction, knocking force of corner points and etc, the mixed lubrication model is built using the average Reynolds equation and micro asperity model. The effects of asymmetric longitudinal profile with different type and circumferential profile with different ellipticity on the piston secondary motion and lubrication characteristics of the piston skirt-cylinder friction pair are explored. Finally, the knocking force, severity of secondary motion, maximum friction force and friction loss are comprehensively compared. The asymmetric profile combination and ellipticity with better performance are selected.

3323496: Influence of Interfacial Chemistry and Role of Adsorbed Water on the Tribological Behavior of 2D Material - Steel Interfaces

Taib Arif, Guorui Wang, Rana Sodhi, University of Toronto, Toronto, Ontario, Canada, Guillaume Colas, 3Univ. Bourgogne Franche-Comté FEMTO-ST Institute CNRS/UFC/ENSMM/UTBM, Besançon, France, Tobin Filleter, University of Toronto, Mississauga, Ontario, Canada

This work compares the tribological behavior of ultrathin graphene and MoS2 nano-sheets at varying humidity against 440C-steel counter-surfaces using friction force microscopy. X-ray photoelectron spectroscopy analysis on the 440C-steel counter-surface identified the presence of primarily Fe-oxides with traces of Mn- and Cr-oxides. The presence of oxides is known to influence the strength and nature (i.e. chemical vs. physical bonding) of the interaction with the basal planes of 2D-materials. The stronger chemical interaction between steel/MoS2 was found to lead to higher friction, interfacial-shear-strength (ISS) and adhesion as compared to the steel/graphene interface which exhibits a weaker physical interaction. Interestingly, water was observed to play a contrary role for differently interacting interfaces as it was found to increase both friction and adhesion for the physically interacting interface, yet it was observed to reduce friction for the chemically interacting interface.

3325688: An Investigation on Tribological Failure of Conventionally Oil Lubricated Journal Bearings of Sugarcane Crushing Mills

Prashant Nagare, Amrutvahini College of Engineering, Sangamner, Maharashtra, India, Hari Kudal, SND College of Engineering, Yeola, Maharashtra, India, Vishnu Wakchaure, M. A. Venkatesh, Amrutvahini College of Engineering, Sangamner, Maharashtra, India

In sugar factories three roller mills in triangular form are used for sugarcane juice extraction. Five such mills in tandem extract sugar cane juice. Squeezing rollers are mounted on split bronze bearings in mill head. These split journal bearings are lubricated by high viscosity bituminous oil. The wear on top half of split journal bearing is common problem. Failure of split bearing causes stoppage of complete sugar factory. These bearings operate in extreme hostile envirnoment.Journal speed of 3 rpm is not sufficient to built-up continuous oil film between journal and bearing surface. It is necessary to search alternative lubricant for journal bearing operating in boundary lubrication regime. Theoretical and experimental investigation for tribological failure of these journal bearings was carried out, which also included selection of lithium grease with appropriate proportion of molybdenum di sulphide as an additive to improve extreme pressure and anti-wear properties.

3285176: Grease Lubrication Behavior Analysis and Life Prediction at High Temperature Environment
Hyeongju Lee, Byeong Lyul Choi, Byoung-Ho Choi, Korea University, Seoul, Republic of Korea, Jeong Hoon Son, ILJIN Enterprize Co. Ltd., Seoul, Republic of Korea

Grease is one of the most commonly used lubricants for bearings since it can extend the service life of bearings in various environment. Therefore, proper selection of grease is required in ball bearing design process. In this studiy, life span tests of greases were conducted in high temperature to shorten the experiment period. Also, greases' F50 values based on the life time data we obtained by using Weibull distribution are used as evaluation criteria. Greases consisted of different compositions of mineral oil, synthetic oil and thickener were used and evaluated those composition factors' effects on grease life time. In a future study, we will build a database of grease lubrication life. By establishing a test method for the evaluation of grease lubrication life through this study, it is expected to contribute to the technical development and competitiveness enhancement of the bearing industry and the grease industry in the future.

3285593: The Influence of Hydrothermal Aging on the Dynamic Friction Model of Cylinder Seals
Jian Wu, Hang Luo, Youshan Wang, Xuebo Yuan, Benlong Su, Zhe Li, Harbin Institute of Technology,Weihai, Weihai, Shandong, China

Sealing performance of the cylinder directly affects the normal operation of the whole mechanism and its safety and reliability. However, hydrothermal aging of rubber sealing ring directly affects the dynamic friction performance of cylinder under the service conditions. In this paper, the dynamic friction model of cylinder has been developed based on the LuGre friction model, which considers the influence of hydrothermal aging. Then, the aging characteristic equation of rubber is introduced into the model to reveal the influence of aging on the friction coefficient of the model. Results show that the aging temperature, aging time and compressive stress effects the friction coefficient; the variation of static friction coefficient is larger than that of coulomb friction coefficient; the improved cylinder friction model can describe the influence of aging process on cylinder friction characteristics, which is of great significance to the study of cylinder dynamic performance.

3285623: Bearing Characteristics of Journal Bearing with Micro-Structure Inspired by Dragonfly
Kairi Furukawa, Masayuki Ochiai, Hiromu Hashimoto, Tokai University, Hiratsuka, Kanagawa, Japan

Since global warming has become a social issue, there has been a strong demand for energy conservation in automobiles. In particular, since about 20% of energy loss is caused by friction, many journal bearings used in engines have been studied. In this study, we aimed to improve the bearing characteristics of journal bearings by incorporating biomimetics. The texture was inspired by the micro spike structure on the dragonfly wing, and the effect was verified by measuring the friction torque and the shaft center locus. At that time, we also examined the difference in the effects of texture placement. Furthermore, the effect of the spike structure on oil film formation was confirmed by photographing the oil film distribution using X-ray Computer Tomography.

3318443: NMR Investigations (1H, 13C, 31P) of Dithiophosphate/Dithiocarbamate Ligand Exchange Reactions between Mo and Zn Derivatives
Yu Min Kiw, Philippe Schaeffer, Pierre Adam, University of Strasbourg, Strasbourg, France, Benoit Thiebaut, Chantal Boyer, Géraldine Papin, TOTAL MS, Solaize, France

The tribological performance of Mo-derivatives in oils are dependent on other additives such as sulphur-containing additives like ZnDTP. Being two key components in lubricant formulations, it is important to understand the mechanisms of the interactions between Mo and Zn derivatives, which are postulated to play a role in the tribofilm formation and involved in ligand exchange reactions. Our work describes the NMR investigations (1H, 13C, 31P) of ligand exchange reactions occurring between molybdenum dialkyldithiophosphates [Mo(DTP)2] and zinc dialkyldithiocarbamates [Zn(DTC)2] at room temperature. According to the NMR spectra acquired when Mo(DTP)2 and Zn(DTC)2 are mixed in solution, ligand exchange reactions take place very quickly, leading to the quantitative formation of Mo(DTC)2 and Zn(DTP)2 complexes. Conversely, when Mo(DTC)2 and Zn(DTP)2 are mixed, no ligand exchange was observed, which is in sharp contrast with previous reports from the literature based on indirect evidence.

3318695: Observation of Oil Film of Floating Bush Bearing Using X-ray CT and Examination of Effect of Oil Film Area on Friction Loss

Shinpei Kotani, Masayuki Ochiai, Tokai University, Hiratsuka, Kanagawa, Japan

The floating bush bearing has a double oil film on the inner and outer surface of floating bush. Because the floating bush is inserted between the bearing and the rotating shaft. Generally, floating bushes that rotate in high speed tend to block the inflow of oil. Therefore, oil film visualization is one of the most prime concerns in the bearings. However, due to the special structure of the bearing, it has been difficult to observe the oil film using conventional methods. Therefore, X-ray computer tomography (X-ray CT) was used for this observation. This method can observe the oil film regardless of the bearing structure. In this study, the oil film was observed in a wide area from low speed to high speed. In addition, the friction loss and bush rotation speed were measured to clarify the relationship with the oil film area.

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