5A 101A

Lubrication Fundamentals V: Wear & Engines

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3805121: Lubrication Fundamentals of Threaded Fasteners
Bryan Bergeron, Mark Guenther, A.W. Chesterton, Groveland, MA

Properly designed and applied anti-seize to threaded assemblies is critical to support global industrial demands in various markets and applications. Yet most lubrication engineers focus and have expertise on formulated oil and grease. This comprehensive session will provide a broad overview of anti-seize and bolting systems. It will include risks and failure modes, chemical compositional considerations, frictional coefficient and nut factor, lubrication, and tensioning procedures. Recognition of some OEM and end-user specifications and concerns associated with the formulation are indicated. There will be emphasis on particle size, compatibility, and temperature limits of typical ingredients. Test methodology by use of a Skidmore-Wilhelm apparatus is introduced. Impact of scatter on tension is shown through various calculations.

8:30 - 9 am
3833745: Plastic Deformation of a Steel Ball During Impact Loading Against a Lubricated Flat
Roland Jones, Hugh Spikes, Amir Kadiric, Imperial College London, London, South Kensington, United Kingdom

When a ball impacts a flat covered with a thin lubricant film, a pocket of high-pressure oil is entrapped between them. This phenomenon has been investigated in the past to study lubricants at very high pressures. In contrast, this paper studies the potential for such impact to cause plastic deformation of the ball which has practical implications in machine elements such as rolling bearings. The study uses a custom-made ball impact rig with high-speed duo-chromatic interferometry to observe the transient film thickness and pressure distributions during impact. It is found that for certain conditions, and in particular certain lubricant viscosities, the hard steel ball suffers unexpected plastic deformation at loads which would be within its elastic limit if dry contact is considered. Results are discussed in terms of the ability of the lubricant to concentrate the impact pressure over an area smaller than the equivalent dry contact.

9 - 9:30 am
3812529: Steel Ball on Flat Fretting Test Results using Grease Lubrication
Robert Erck, Nicholaos Demas, Aaron Greco, Argonne National Lab, Lemont, IL

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

9:30 - 10 am
3811763: Correlation of Friction and Surface Condition in Rolling-sliding Contacts With Oil-impregnated Sinter Materials
Nicolai Sprogies, Thomas Lohner, Karsten Stahl, Technical University of Munich, Garching near Munich, Bavaria, Germany

Whereas self-lubricating journal bearings having oil impregnated are state of the art, the lubrication method has been poorly investigated for rolling-sliding contacts in gears. In this study, self-lubrication via oil impregnation of sinter metals is investigated for gear applications. Therefore, the tribosystem of a gear contact is transferred to a rolling-sliding model contact. The friction and temperature behavior of various material-surface-pairings are analysed by a twin-disk tribometer. High-resolution 3D topographical

measurements during tests are used to record the surface alteration. The experimental results show the functionality of self-lubricating rolling-sliding contacts under high load and sliding. The friction is drastically reduced and the lifetime strongly increased compared to dry rolling-sliding contacts. The surface analyses emphasize a significant influence of the surface condition and in particular of the surface porosity on the self-lubricating tribosystem.

10 - 10:30 am - Break

10:30 - 11 am
3801630: Detailed Simulating Test Rig Experimental Results for Piston-ring Lubrication
Polychronis Dellis, ASPETE, Athens, Attiki, Greece

Experimental data and analysis is given regarding cavitation in oils evident in LIF, pressure and capacitance measurements. Parametric study for minimum oil film thickness through the stroke and LIF for point measurements were the basic tools. A pressure sensor provided data that were combined with imaging via a modified liner and high speed camera. Power losses were derived from friction measurements. These modifications and new additions were imposed prior to engine testing in two different set-ups. Different forms of cavitation were identified and their shape and size is dictated from operating conditions and lubricant properties. The formulation affects cavitation behaviour. Further engine studies were conducted after its initial identification, to get a clearer picture of the different stages. Signals are analyzed for the experimental set-ups and interpreted according to the lubricants' properties. Results are presented in combination to cavitation initiation, size and number.

11 - 11:30 am
3830729: Impact of Lubricant Formulation on Aeration Control for Next Generation Passenger Car Motor Oils
Lori Crom, Matthias Eggenstein, Robert Mainwaring, Carl Stow, Neil Elsby, Shell, London, United Kingdom; Mark Jackson, Matt Irving, Infineum, Abingdon, United Kingdom

Oil aeration is worrisome because it can inhibit lubrication in critical contacts, compromise the actuation of hardware components, reduce heat transfer, and accelerate oil oxidation. The amount of air in an oil represents the balance of entrainment and release. Air entrainment is not desirable and is affected by several factors such as high engine speed, reduced oil volume, and low oil viscosity. Release is desirable and is affected by several factors such as low oil viscosity, high temperature, and effective antifoam. Some of these sensitivities conflict, making strong performance with low viscosity oils challenging. We will discuss operational and formulation factors that impact low viscosity oil aeration. The impact of relevant formulation changes and scrutinizing bench methods to pre-screen oils for engine testing will be shared. Results enabled development of a next generation passenger car engine oil, with long oil drain interval and full compatibility with hybrid application.

11:30 am - 12 pm
3812176: The Performance of Diesel Engine Oil With an Ashless Anti-wear Additive Under Actual Driving Conditions.
Yasunori Shimizu, Moritsugu Kasai, Idemitsu Kosan Co.,Ltd, Chiba, Japan

In order to comply with emission standards for vehicles, after-treatment devices such as oxidation catalysts and DPF are installed. It has, however, been reported that metals (ash) in engine oil clog the filter and deteriorate the DPF performance. From this background, low ash engine oils have been studied. While ZDDP has been historically used as an anti-wear additive in engine oil, zinc also accumulates in the DPF as ash. From this point of view, the authors have developed a diesel engine oil containing an ashless anti-wear additive instead of ZDDP. After confirming its valve train wear protection in engine bench tests, the authors widely conducted field tests using the developed engine oil and it was confirmed that the oil showed good oil properties during the tests.

Rolling Element Bearings V

Session Chair: Alexander Fletcher, AFRL/RQTM, Wright Patterson Air Force Base, OH
Session Vice Chair: Kushagra Singh, Purdue University, West Lafayette, IN

8 - 8:30 am
3807966: Analyzing the Electrical Transmission Behavior of Rolling Element Bearings
Maximilian Hausmann, Philipp Liehr, Eckhard Kirchner, Technical University of Darmstadt, Darmstadt, Germany

In order to meet requirements for the digitalization of mechanical engineering, current research shows a trend towards the sensory use of electrical properties of machine elements. Especially, the electrical capacitance of rolling element bearings can be used to derive its operating condition. In order to acquire sensor data in-situ in a rotating mechanical system, the sensor signal must be transmitted to an evaluation unit outside of the system. The transmission via the existing mechanical structure offers a potential solution. Using frequency response analysis, the electrical transfer function of radial rolling element bearings is analyzed in different working points and lubrication conditions for the first time. The effects of speed, axial and radial load, lubricant temperature as well as the type of lubricant, in this case grease, oil and graphite, are analyzed. With this, significant influencing variables on the electrical signal transmission behavior can be derived and described.

8:30 - 9 am
3808347: Lubrication Condition Monitoring of Radially Loaded Ball Bearings by Electrical Impedance Method
Taisuke Maruyama, Shunsuke Iwase, Masayuki Maeda, NSK Ltd., Fujisawa, Kanagawa, Japan; Ken Nakano, Yokohama National University, Yokohama, Kanagawa, Japan

In the previous study, the electrical impedance method has been developed, which measures the thickness and breakdown ratio of oil films simultaneously by applying an alternating voltage to the contact area. However, this method can only monitor lubrication conditions in ball bearings under axial load, which means that all contact areas are uniform. In this study, the electrical method has been improved so that it is also applicable to radially loaded ball bearings.

9 - 9:30 am
3812184: Differences Between the Cathodic and Energetic WEC Fatigue in the View of Bearings in Electric Applications
Daniel Merk, Jörg Franke, Jörg Loos, Schaeffler Technologies, Schweinfurt, Bavaria, Germany

Beside the Hertzian contact stresses, so-called additional loads, like electrical currents, can act on rolling element bearings. If these additional loads exceed a critical limit, they potentially lead to premature bearing failures, provoked by White Etching Cracks (WEC). The influence of the "lubricant chemistry", or the lubricants in General is therefore strongly depending on the type of additional load. In specific cases, this lubricant influence can vary from "minor" to "dominant". The same fact is valid for the influence of the electrical polarity or the degree of mixed friction. The presentation describes the cathodic and energetic WEC and why the influences are strongly depending on the specific operating conditions.

9:30 - 10 am
3808483: Influence of Electrical Current on Rolling Contact Fatigue
Ling Wang, nCATS, Southampton, United Kingdom

The life of rolling element bearings (REBs) under electrification especially in machinery that are subject to high voltages, has shown to be significantly reduced. With rapid growth of electric vehicles (EVs), responding to the global target of zero carbon emissions, the concerns on REB life in EVs is also increasing. To understand the influence of electrification on rolling contact fatigue (RCF), experiments have been conducted on a TE74 twin-roller machine for oil-lubricated rolling contact under a range of conditions while a DC voltage is applied. The test results show that the electric current has induced micro-pitting wear on the roller surface. Electrical charging-discharging events across the oil-lubricating film have been observed and a correlation between the magnitude of discharge current and the average

area of micro-pitting is seen. The results also show that the average size of micro-pitting is influenced by the level of discharge current at the roller contact interface.

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

10:30 - 11 am
3812896: Detection of Micropitting Evolution Using Acoustic Emission and Electrostatic Sensing Techniques
Zaihao Tian, Shuncai Wang, Robert Wood, University of Southampton, Southampton, United Kingdom; Daniel Merk, Schaeffler Technologies, Schweinfurt, Bavaria, Germany

Rolling bearings perform under most operating conditions without any problems, but there are certain conditions where micropitting appears. Considerable work has been conducted on investigating drivers of micropitting based on post-test inspections. However, due to its fast process, micropitting evolution has been poorly captured by online sensing. This work aims to achieve detection of micropitting evolution using acoustic emission (AE) and electrostatic (ES) sensing techniques. A twin-disc tribometer was used to perform rolling contact fatigue tests. Latest results showed how micropits were produced and various wear patterns were identified. Sensor data indicated the AE sensing was sensitive to asperity contact conditions and micropitting propagation, and the ES sensing was capable of detecting tribofilms and micropits. The combination of both measurement techniques allows a general understanding about the root cause, as well as the propagation phase of micropits.

11 - 11:30 am
3834175: Damage and Failure in Rolling-Sliding Lubricated Contacts Subjected to Transverse Vibrations
David Uribe Saenz De Camara, Amir Kadiric, Imperial College London, London, United Kingdom; Armando Felix-Quiñonez, SKF Research & Technology Development, Houten, Netherlands

In a number of practical bearing applications, the rolling-sliding contacts between rolling elements and raceways are subjected to transverse vibrations. We have previously shown that such vibrations can increase the likelihood and the extent of surface damage, particularly micropitting. This talk attempts to provide further insight into the mechanisms behind the observed damage by studying the effect of transverse vibrations on lubrication conditions as well as their impact on the rate of accumulation of asperity stress cycles. The study employs a triple-disc contact fatigue rig which has been modified to incorporate an electrodynamic modal shaker to impose transverse vibrations over a wide range of strokes and frequencies. The lubrication conditions are monitored in parallel to damage development using an electrical capacitance method. The results are presented to illustrate the effect of transverse stroke length, frequency and sliding speed on contact damage and oil film thickness.

11:30 am - 12 pm
3812130: Rolling Element Bearing Defect Detection and Monitoring
John Yu, Baker Hughes, Marietta, GA

Vibration was measured with several accelerometers on the input shaft of an extruder using an on-line remote monitoring system. Though the vibration amplitudes were below the acceptable limit for over a year period, damages on two rolling element bearings were believed to have occurred based on observed vibration signatures. Vibration frequencies and amplitudes were monitored via both normal and demodulated spectra. One damage appeared to be on the inner race of a bearing, and the other on the outer race of a second bearing. An outage was well scheduled based on vibration signatures and readings from both normal and demodulated spectra, along with plant operational needs. Inspection results matches diagnosed inner and outer race damages and extent. Lessons are learned on how vibrations from normal and demodulated spectra should be looked upon to make a correct decision of timing of bearing replacement. Vibration signatures versus damage severity are also discussed.

Herbert S. Cheng Memorial Symposium: Challenges in Lubrication and Tribology Modeling

Session Chair: TBD
Session Vice Chair: TBD

This symposium invites presentations to honor Prof. H. S. Cheng, discussing achievements in more than four decades of the Patir-Cheng average flow model and challenges in modeling lubrication and tribology facing the future technology developments.

8 - 8:30 am
3833491: Unsteady Multiscale Simulation of Lubricated Rough Surfaces
Noel Brunetiere, Arthur Francisco, Institut Pprime, Futuroscope Chasseneuil cedex, France

When dealing with lubrication of rough surfaces, averaging methods such as homogenization or flow factors suffer from a lack of accuracy when the surfaces are nominally parallel while deterministic approaches are limited to the simulation of small areas. It is now known that multiscale methods can overcome both limitations. A fine mesh named bottom scale mesh is used to obtain an accurate pressure distribution. To reduce computation burden, this mesh is split in several sub-domains connected through a top scale mesh ensuring global mass conservation. In many lubrication problems, the situation is transient and it is important to extent these multiscale methods to time-varying problem. In this work, the development of a transient multiscale approach is presented. Several examples of application such as squeeze problems and lubrication of two rough surfaces are presented.

8:30 - 9 am
3833864: Explicit Flow-Continuity-Enforced Elastohydrodynamic Lubrication Analyses with a Mass Conservation Algorithm
Shuangbiao Liu, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Starvation may occur in a lubricated interface globally and locally around asperities, and cavitation may appear around divergent spaces at different scales. Various modified Reynolds equations with mass conservation algorithms have been developed to deal with starvation/cavitation. However, numerical flow-continuity examinations have been neglected in most lubrication analyses, and actual levels of flow-continuity of numerical solutions have not been demonstrated. This work explicitly evaluates flow values, along the velocity direction, passing a single mesh width as well as the total width of a computation domain. This work reveals the importance of low-pressure regions (dimensionless pressure < 1%) to flow continuity, and film-reformation boundaries of starvation/cavitation zones. Hybrid relaxation factors are utilized with the unity assigned to the low-pressure regions. This numerical solver is further applied to study the lubrication of dimpled surfaces.

9 - 9:30 am
3854905: Strength from Weakness: Dynamicity in Biotribological Interfaces
W. Gregory Sawyer, Research Institute of Industrial Science and Technology, Gainesville, FL

Dynamic hydrogel networks are a central feature of biological systems - soft, living, active matter. For example, wet epithelial surfaces form the largest interface in biological systems and are protected by the continuous production and maintenance a functionally graded dynamic aqueous gel, mucous. These gels are formed from a wide array of heavily glycosylated proteins (mucins and glycoproteins) and use “flickering” supramolecular and dynamic-covalent intermolecular interactions as crosslinkers. Mucous is responsible for key cell-protective and barrier functions including hydration, lubrication, and solid contaminant removal.

9:30 - 10 am – Open Slot

10 - 10:30 am - Break

Materials Tribology V

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3813123: Synthesis and Sliding Behavior of Bearing Steel / MAX-Phase Composites
Stephen Berkebile, Nikhil Murthy, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Caleb Matzke, Shawn Ruggiero, Emily Dahlke, Abdulrahman Aldossary, Surojit Gupta, University of North Dakota, Grand Forks, ND

Mechanical interfaces lubricated with low viscosity fuels require materials that can resist damage with little aid from a lubricating fluid film. We hypothesize that MAX phases (layered, hexagonal carbides) incorporated into steel reduce wear of the steel by increasing hardness. Powder metallurgy 100Cr6 steel and composite (100Cr6 steel – 5 vol% Cr2AlC) samples were densified in an unpressurized furnace using argon atmosphere at 1400 oC for 30 minutes, then heat treated at 840 oC for 23 minutes in air with water quench. We determined the microstructure of steel/MAX-phase composites and effects on wear and coefficient of friction when lubricated by fuels of varying chemistries (ethanol, jet fuel) compared to dry sliding. The addition of Cr2AlC was observed to increase the hardness of the steel through unique structural formations during heat treating that originated from the Cr2AlC particles. We will discuss the tribological effects of this transformation in the various fuels.

8:30 - 9 am
3831212: In-situ Methods to Study Scuffing Failures of Self-Mated Steels in Real-Time-Part I: Experimental Details
Farida Ahmed Koly, Arnab Bhattacharjee, David Burris, University of Delaware, Newark, DE; Nikhil Murthy, Stephen Berkebile, DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD; Ben Gould, Oyelayo Ajayi, Maria Cinta Lorenzo Martin, Argonne National Laboratory, Argonne, IL

Scuffing, a type of wear found in highly stressed or poorly lubricated contacts, is characterized by severe plastic deformation of the near surface material. As with other tribological phenomena, scuffing has proven difficult to study directly due to a lack of access to the contact interface. We developed a novel instrument to study scuffing failures within lubricated, self-mated steel contacts in-situ using X-rays in transmission. We discuss the instrument design approach and preliminary scuffing experiments to demonstrate reliable achievement of scuffing. These experiments used fuel-lubricated 52100 and 1045 steels at moderate (cm/s) sliding speeds in reciprocating contacts. Our preliminary synchrotron experiments focused X-rays within the contact area (to a depth of ~ 20 μm) and collected full powder diffraction rings throughout each test. We will review these experiments briefly here, but detailed analysis of these diffraction data will be reserved for Part II.

9 - 9:30 am
3818526: In-situ Methods to Study Scuffing Failures of Self-Mated Steels in Real-Time. Part II: Initial XRD Analysis
Maria Cinta Lorenzo Martin, Dawid Bachnacki, Trenton Culverhouse, Zachary Jernigan, Jun-Sang Park, Oyelayo Ajayi, Benjamin Gould, Argonne National Laboratory, Argonne, IL; Farida Koly, Arnab Bhattacharjee, David Burris, University of Delaware, Newark, DE; Nikhil Murthy, Scott Walck, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Scuffing, a type of wear found in highly stressed or poorly lubricated contacts, is characterized by severe plastic deformation of the near surface material. As with other tribological phenomena, scuffing has proven difficult to study directly due to a lack of access to the contact interface. This part-II talk presents initial analysis of real-time characterization of scuffing failure of lubricated steel in a reciprocating contact using high-energy high-speed synchrotron X-ray diffractometry. We conducted in-situ experiments, where XRD from the contact interface was continuously acquired during scuffing tests, and ex-situ experiments, consisting of 1-micron step XRD depth profile taken before and after scuffing tests to evaluate structural changes up to 150 microns depth from the contact. Initial results showed changes in the lattice parameter, peak intensity and peak width of existing crystallographic planes rather than the emergence of any new crystal phases or transformations.

9:30 - 10 am
3812298: Influence of Dislocation Mobility on the Tribo-oxidation of Single Crystalline Copper
Ines Blatter, Julia Rau, Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Baden-Württemberg, Germany; Baptiste Gault, Max Planck Institute for Iron Research, Düsseldorf, Germany; Lisa Belkacemi, Leibniz-Institute for Materials Oriented Technologies (IWT), Bremen, Germany

Metallic surfaces subjected to tribological loading often suffer from accelerated oxidation, which can significantly influence the resulting friction and wear behavior. Therefore, it is important to better understand the underlying mechanisms in order to engineer materials with better friction and wear properties. By running experiments with varying cycle numbers on a copper-sapphire model system, we were able to monitor the sequence of stages in the microstructural evolution and oxide formation. As previous research suggested that dislocations act as high-diffusivity pathways, two experimental setups were chosen that allowed for either high or low dislocation mobility. It was shown that this strongly influences the oxidation behavior. Atom probe tomography (APT) was performed to identify possible diffusion pathways. In the long term, understanding the underlying and fundamental mechanisms of tribooxidation will enable the targeted development of friction- and wear-optimized surfaces.

10 - 10:30 am - Break

10:30 - 11 am
3801462: Study of Cryogenic Friction and Wear Characteristics of Invar 36 Alloy Against Si_3N_4 Ceramic Balls
Bin Wang, Yanbao Guo, Zheng Zhang, Deguo Wang, China University of Petroleum (Beijing), Beijing, China

A pin-on-disk cryogenic tribotester was designed and constructed for studing cryogenic tribological behavior of Si_3N_4 ceramic balls against Invar 36 alloy under dry condition, and the test temperature ranges from 293 K to 77 K. The sliding friction and wear experiments under four different loads and temperatures were carried out on the tribotester. The results indicated that the Invar 36 alloy showed better tribological characteristics at all test parameters compared with G95cr18 alloy. Both friction coefficient and wear rate dropped with the decreasing temperature. From 293 K to 195 K, the wear mechanism of Invar 36 alloy material is mainly abrasive wear. However, lower contact stress and surface temperature rise at 77 K, and approximately weakened the abrasive wear, showing an extremely low wear rate. The aforementioned is significant for improving the study of tribological characteristics of materials under cryogenic condition.

11 - 11:30 am
3812729: Investigate Wear Transition of CoCrMo Alloys after the Heat Treatment
Jiahui Qi, The University of Sheffield, Sheffield, United Kingdom

This study reports that the wear rate of the heat-treated CoCrMo alloy shows a sudden transition of more than 5-fold when the load/contact pressure increases from 45N (3.6GPa) to 50N (3.7GPa). Heat treatment was used to change the structure of the commercially available CoCrMo from the initial face-centred cubic (γ-fcc) with a small amount of hexagonal close-packed (ε-hcp) to predominantly hcp ε-phase with dispersed nanoscale precipitates of σ-phase. PeakForce QNM was used to quantitatively map the local mechanical properties of the surface at the nanoscale. High-resolution transmission electron microscopy (HRTEM), scanning transmission electron microscope (STEM), energy-dispersive X-ray spectroscopy (EDX), and precession electron diffraction (PED) integrated with the TEM is used to characterize the structure and chemical composition of the worn surface and tribofilm. The possible reason for the wear transition was discussed.

11:30 am - 12 pm
3843109: Mesoscale Modelling of High Temperature Deformation Mechanisms in Refractory High Entropy Alloys
Morgan Jones, Irene Beyerlein, University of California Santa Barbara, Santa Barbara, CA; Nicolas Argibay, Ames Laboratory, Ames, IA

In sectors such as aerospace, automotive, and power generation, a great deal of effort is dedicated to developing high-performance alloys that can withstand increasingly harsh operating conditions. Refractory high entropy alloys (RHEAs) are, in general, noted for their superior mechanical properties. Their remarkable phase stability, insensitivity to thermal history, and solution strengthening mechanisms makes them an ideal candidate to replace components made from traditional Ni-based superalloys.

Unfortunately, the deformation mechanisms of RHEAs at high temperatures are not well understood, and the possible compositional combinations of new RHEAs are nearly limitless. Computational techniques can be employed to inform the design of next-generation superalloys. We present results of dislocation dynamical processes in RHEAs over a range of high temperature conditions using a mesoscale, energy based model. Cross-slip, energetic landscape, and edge vs. screw mobility are discussed.

5E 102C

Tribochemistry II

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3832309: Atomic-Scale Wear Inside Diamond–Quartz Contacts
Jagjeevan Bhamra, James Ewen, Carlos Latorre, Daniele Dini, Imperial College London, London, United Kingdom; John Bomidi, Marc Bird, Baker Hughes, The Woodlands, TX

Diamond surfaces wear when sliding against silicon oxides, despite them being much softer materials. Here, we use nonequilibrium molecular dynamics (NEMD) simulations with a reactive force field for studying the wear of hemispherical single-crystal diamond tips sliding on α-quartz surfaces under a wide range of temperatures and loads. Diamond wear on α-quartz is initiated by the formation of C-O interfacial bonds, which is followed by C-C cleavage, and ultimately CO_2 formation. At low loads, the wear rate of the diamond tip increases exponentially with both temperature and normal stress, consistent with stress-augmented thermally activated (SATA) wear models. At high loads, the NEMD simulation data deviate from the SATA model and the wear rate becomes less sensitive to the normal stress. The wear rate data over the entire load range can be accurately described using the single-asperity multibond wear model depicting the process of wear as interfacial bond formation and breaking.

8:30 - 9 am
3833419: Analysis of Boundary Lubrication of DLC Using Molecular Dynamics Simulation
Hitoshi Washizu, HIrotoshi Akiyama, Rio Nakae, Yosuke Hamano, Koshiro Torimoto, Yudai Tanaka, Ryuichi Okamoto, University of Hyogo, Kobe, Japan

Improving lubrication using DLC coating is still in progress. If tribo-catalytic materials such as zirconia as the counter body of the friction, ultra low fricition such as Friction Fade Out (FFO) phenomena is observed in hydrogen with alcohol gas environment. Recently, specific adsorption of additives in oil to the DLC is reported.
Our approach is to use molecular dynamics (MD) simulation with reactive force field to understand these phenomena. Since the experimental phenomena contain complex and sequential chemical reaction part, we use MD in some phenomena divided from the whole sequence. For example, adsorption and reaction of alcohol molecules on zirconia is analyzed by MD. Then polymerization of the molecules is discussed using radical organic species. In each step, we found important aspect of each chemical reaction step. The importance of zirconia is found replacing DLC substrate by Ni metal. The specific adsorption of additives to the DLC surface is also discussed.

9 - 9:30 am
3812901: Microscale Tribochemistry of Diamond-like Carbon Coatings: How the Run-in to Low Friction is Affected by Sliding Distance and Contact Size
Brian Borovsky, Ana Colliton, Hind Flaih, Eskil Irgens, Lucas Kramarczuk, Griffin Rauber, Zachary Van Fossan, Jordan Vickers, St. Olaf College, Northfield, MN; Seokhoon Jang, Seong Kim, Pennsylvania State University, University Park, PA; Zhenbin Gong, Junyan Zhang, Lanzhou Institute of Chemical Physics, Lanzhou, China

We use an indenter probe to press a microscopic stainless steel sphere onto a hydrogenated diamond-like carbon (H-DLC) coating that forms the surface of a quartz crystal microbalance (QCM). By resonating the QCM in its fundamental shear mode, we induce sliding friction at the interface, with track lengths in the nanometer range and frequencies near 5 MHz. The QCM performs friction measurements while the normal load is fixed at values between 5 μN and 1 mN. We demonstrate that these measurements can be

sustained even when a secondary lateral motion is superimposed using a piezo stage, with a track length of 20 μm and frequency of 10 Hz. Our results show that adding microscale sliding causes a substantial reduction in friction detected by the QCM. We associate this reduction with the “running-in” behavior of H-DLC and its shear plane chemistry. We explore relationships between the sliding distance, contact size, and the tribochemistry of the transition to low friction sliding.

9:30 - 10:00 am
3805937: The Analytical Study of Friction Reduction in Iinstrumented Single-cylinder Block
Yue Guan, Jules Galipaud, Frédéric Dubreuil, Maria-Isabel De Barros Bouchet, Ecole Centrale de Lyon, Écully, France; Johnny Dufils, Etienne Macron, IREIS/HEF GOURPE, Andrézieux-Bouthéon, France; Fabrice Dassenoy, LTDS/ECL, Ecully, France

Diamond-carbon like (DLC) coating has been widely used for improving friction reduction in engines. However, the interactions between DLC and commercially available fully formulated engine oils are still unclear. Here, a commercially available 5W30 lubricant was employed for ring-on-disk sliding tests in DLC self-mated and DLC/steel mixed configuration. Different parameters as sliding velocity and contact pressure were tuned to investigate their impact on the tribological behavior. Post-tests, the wear track was fully characterized by SEM/EDS, AFM, XPS and FIB-TEM/EDS to interpret the relation between tribological performances and tribofilm’s chemical nature and structure. The results show a decrease of CoF as the contact pressure increased in mixed/boundary lubrication regime for steel/DLC pair. This behavior could be related to the increase in calcium carbonate amount in tribofilm as the function of contact pressure, at the expense of iron oxide.

10 – 10:30 am - **Break**

10:30 - 11 am – **Presentation TBD**
John Curry, Sandia National Laboratory, Albuquerque, NM

11 – 11:30 am
3811899: Molecular Structure and Environment Dependence of Shear-driven Chemical Reactions
Yu-Sheng Li, Seokhoon Jang, Seong Kim, The Pennsylvania State University, State College, PA; Fakhrul Hasan Bhuiyan, Ashlie Martini, University of California Merced, Merced, CA

Tribochemistry deals with dynamic interfacial processes that lead to formation of beneficial tribofilms. For a better mechanistic understanding, we studied the tribopolymerization of C6 molecules with different internal ring strain energy on stainless steel in N_2, O_2, and H_2. In N_2 and H_2, strain-free cyclohexane showed the lowest reactivity among the three tested. A similar trend in the reaction yield of three precursors was found in reactive molecular dynamics simulations. Reaction yield produced in H_2 was lower than in N_2. When tribofilms were analyzed with Raman, spectral features of diamond-like carbon (DLC) were observed. However, these features originated not from the tribofilm formed in situ during shearing, but from photochemical degradation of tribofilm induced by high-energy laser. Based on IR analysis, tribofilms were organic materials containing oxygenated groups. These results suggested surface oxygen was a reactant, which was also supported by the findings in simulation.

11:30 am – 12 pm
3831621: Durability of Materials for Nanoelectromechanical Switches Studied by Scanning Probe Microscopy
Cangyu Qu, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Nanoelectromechanical systems (NEMS) switches, a candidate for next-generation electronics for their negligible leakage and low operation voltage, suffer from poor reliability featured by various failure modes during cyclic operation. In this work, the durability of electrical contact materials is studied by scanning probe microscopy (SPM) under NEMS switch-like conditions, with the goal of understanding the tribo-electro-mechanical mechanisms leading to failure. We use an SPM-based methodology for high-throughput assessment of candidate contact materials, with a Pt/Pt interface studied as a prototypical demonstration. The evolution of interfacial properties is measured for millions to billions of contact cycles. The accumulation of insulating tribopolymers resulting from applied stress and bias to adsorbed airborne contaminants is investigated. Measurement on the tribopolymer growth rate and its dependence on contact stress supports a stress-assisted thermal activation model.

Contact Mechanics I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3831690: Understanding the Role of Contact Interfaces on Tribo-electrification in Triboelectric Nanogenerators
Charchit Kumar, Jack Perris, Satyaranjan Bairagi, Nikolaj Gadegaard, Daniel M. Mulvihill, University of Glasgow, Glasgow, United Kingdom; Yang Xu, Hefei University of Technology, Hefei, China

Triboelectric nanogenerators are an emerging technology to harvest electricity from mechanical energy, based on triboelectrification and electrostatic induction effects. In recent years, a large amount of research has been done in the field of TENGs, however the fundamental contact mechanics of TENGs is not clear yet. This work presents a systematic contact mechanics investigation on a simple and robust TENG device. Controlled roughness instances were numerically created and developed using 3D printing and replica-moulding procedure. Surface characterization results confirmed the accuracy of developed tribo-layers. A linear electrodynamic rig was modified to perform electro-mechanical tests, based on the contact-separation mode. Triboelectric and contact area measurements were carried out to investigate the influence of applied load and frequency. Electrical output results were correlated with surface topographies and were discussed regarding contact signatures and strain localization.

8:30 - 9 am
3812297: A New Approach for Calculating the Contact Heat Transfer Coefficient Based on Real Component Surfaces
Patrick Wingertszahn, Stefan Thielen, Oliver Koch, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

The temperature profile between two adjacent components is of great importance in many technical applications. Therefore, the calculation of the thermal contact resistance is an essential element for the simulation of the heat transfer when two bodies are in contact, with or without an interlayer. According to the current state of the art, this important input parameter for thermal simulations is determined in experiments. Due to the large number of dependencies, these are very time consuming. In this approach, the heat exchange between two rough bodies in contact is calculated by iteratively solving the heat conduction problem with a multigrid method. Real component surfaces are considered to calculate the temperature distribution. The following parameters were investigated for their influence: surface roughness, contact pressure, temperature level and temperature difference. This model allows a fast prediction of these parameters by measuring the contact surfaces of both bodies.

9 - 9:30 am
3808042: Tribological Issues in the Wheel-rail Interaction: Background and Experiences.
Angelo Mazzu', University of Brescia, Brescia, BS, Italy

The wheel-rail system is subjected to a complex interaction of several damage phenomena, even in competition with each other. In clean and dry environment, the most frequent phenomena are ratcheting and wear, especially in sliding condition such as in curve or braking, which result in the formation of surface cracks.
In presence of fluid contaminant, such as rain or snow, rolling contact fatigue often prevails, because the surface cracks are filled by the fluid, which is pressurized at every load pass and promotes their propagation.
Solid contaminants, such as sand, induce severe abrasive wear, leading to excessive modification of the wheel-rail contact patch and low duration. Thermal loads, occurring in shoe braking operation or in excessive sliding, can lead to heating cycles which alternate the material microstructure up to the formation of white etching layers (WEL). The experimental and computational experience of the University of Brescia in the study of these phenomena is presented.

9:30 - 10 am
3810658: Identification and Analysis of Some New Influencing Parameters on the Surface Damage of Rolling Elements Bearings by a CEL Model
Amakoe Ahyee, Daniel Nelias, Thibaut Chaise, Arnaud Duval, INSA DE LYON, Lyon, Villeurbanne, France

In this paper, an investigation is carried out on the passage and crushing of particles between the rolling elements and the rings. During operation it very often happens that particles from various sources pass into the contact between the rings and the rolling elements bearings. This results in the formation of dents which can cause damage. To model this phenomenon, some authors have adopted finite element modeling [1-2]. Recently in 2019 a CEL model developed by Bonetto et al [2], was able to reproduce and analyze the crushing of particles on the surfaces. Thus they identified some first-order parameters that influence the geometry of dents such as: debris size, Hertzian pressure, friction coefficient, material properties, and relative sliding between the surfaces. A parametric study conducted with an upgraded CEL model has allowed us to identify some new first-order parameters such as: particle shape, particle location in the contact, and the presence of a critical sliding rate.

10 - 10:30 am - Break

10:30 - 11 am
3816862: Investigating the Contact Area Reduction over a Nearly Complete Rough Surface Spectrum
Robert Jackson, Auburn University, Auburn, AL; Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

This study investigates the predictions of the real contact area for elastic and elastic-plastic rough surfaces using a ‘nearly complete’ surface spectrum for a real surface using a multiscale and statistical model framework. The spectrum employed characterizes the surface down to the nanoscale. The results show that even the smallest scales can have a significant influence on the contact area, especially when the contact is elastic. However, when the contact is elastic-plastic, the influence of smaller scales can be limited depending on the structure of the surface’s spectrum. If the spectrum shows a self-similar trend at some scales, than the pressure tends to saturate at those scales. This work also explores the inclusion of scale dependent yield strength, since it will vary with the scale of the asperities.

11 - 11:30 am
3847781: Contact Mechanics of the Patterned Surfaces Generated by Spinodal Decomposition and Amplified Instability
Wonhyeok Lee, Melih Eriten, University of Wisconsin-Madison, Madison, WI

Recent techniques employing dynamic evolution of microstructures (spinodal decomposition) and instabilities amplified via centrifugal acceleration offer viable and cheaper alternative ways to micromanufacture functional patterned surfaces. When interfacing those patterned surfaces with other components and under self-contact scenarios, geometric variability can cause stress concentration and abrupt failure around the contact. We investigate numerically the real area of contact, contact pressures and stress concentration factors of patterned surfaces formed by spinodal decomposition and amplified instabilities. We first generate patterned surfaces in congruence with actual surfaces created by those processing techniques. Then, we conduct normal-contact analyses of those surfaces via boundary element method under nominal mean pressures ranging from (0.001-1)E*, where E* is the contact modulus. To account for the influence of the processing parameters, we also perform a parametric study.

11:30 am - 12 pm
3847744: A Numerical Model for Simulating the Transient Frictional Viscoelastic Sliding Contact
Dongze Wang, Ali Ghanbarzadeh, Greg de Boer, Institute of Functional Surfaces, Leeds, United Kingdom

The problem of sliding contact has always been an area of interest to determine the behaviour of viscoelastic materials in practice. Considering that there exists little literature reporting the effects of the partial slip regime on the later sliding contact solutions, a frictional viscoelastic sliding contact model is developed in the study, where transient solutions showing the whole evolution from partial slip to gross slip are available. Results show that though the partial slip regime causes a trivial change in normal pressure distribution (e.g. lower peak pressure), it delays the time required by viscoelastic surfaces to reach their steady state. This suggests that the frictionless assumption (no dry friction), which is adopted in most numerical and theoretical models, could induce quantitative differences when analyzing sliding contacts of viscoelastic materials. Qualitative errors may even be encountered when the observation time

is too small to capture the actual steady state.

5G 103B

Tribotesting I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3831949: Physicochemical and Tribological Comparison of Bio- and Halogen-based Ionic Liquids
Md Hafizur Rahman, Tatianna Macias, Manoranjan Misra, Pradeep Menezes, University of Nevada, Reno, NV; Ting Liu, Ashlie Martini, University of California-Merced, Merced, CA; Manish Patel, ExxonMobil, Austin, TX

Phosphonium-based ionic liquids (P-RTILs) have received significant attention recently for lubrication applications due to their physiochemical and tribological properties. Bio-derived P-RTILs are of particular interest for environmental sustainability. In this investigation, we characterized and compared the physicochemical and tribological properties of bio-based trihexyltetradecylphosphonium saccharinate [P-Sacc] and halogen-based trihexyltetradecylphosphonium bis(trifluoromethylsulfonyl)amide [P-NTF2] ionic liquids between 10-120°C to understand their thermal stability, wettability, rheology, as well as lubrication and corrosion mechanisms at steel sliding interfaces. [P-Sacc] has comparable thermal stability, higher viscosity, and higher density than [P66614][NTF2]. The higher viscosity and stronger cohesion of [P-Sacc] contributed to its ability to form an effective adsorption film that reduced friction and wear more than the halogen-based IL across the range of temperatures.

8:30 - 9 am
3816669: Experimental Analysis of Pasting of Brushed DC Motors
Roman Dzhafarov, Daniel Braun, Stephan Diez, Joerg Kopitzke, BMW AG, Munich, Germany

Modern automobiles are equipped with many components in which DC motors are used. A possible failure mechanism in case of brushed DC motors can be so-called pasting. While operating of DC motor some carbon brush debris accumulates in the commutator's insulating air gaps. It clogs the slots with conductive carbon paste resulting in a loss of insulation resistance between the commutator segments. This phenomena affects the motors efficiency and finally triggers the failure of the electric motor. The significant influencing parameters of this process are humidity, load regimes and the composition of the carbon brushes. The aim of this work is to derive the scientific understanding of the physical and contact mechanical phenomena behind the process of pasting as well as to show the interactions between the commutator, carbon and the used lubricants by different environmental conditions.

9 - 9:30 am
3805962: Another Approach to ‘Tribotesting’: Enabling AI
Dirk Drees, Lais Lopes, Falex Tribology, Rotselaar, Vlaams Brabant, Belgium; Emmanouil Georgiou, Hellenic Air-Force Academy, Dekelia Air Force Base, Athens, Greece

AI applications are in the news, so also in our field of tribology, eyes are turning to this powerful technique; how can we discover new insights? The limitation today is the lack of enough relevant and reliable data to train AI systems. Wear resistance particularly, is a parameter with large variability, so relevant data requires typically long tests and many repeats. Our approach to generate data at affordable cost, is using multi-station wear testers. This causes a paradigm shift in tribology: we no longer use sophisticated ‘tribometers’ to analyze a single test, but want to generate statistical data and use automatic data collection and analysis. We are showing our concept of data collection and the prototype parallel wear device with its first results.

9:30 - 10 am
3812432: Measuring Lubricant Viscosity Under Shearing In-Situ Using Ultrasound
Gladys Peretti, Rob Dwyer-Joyce, The University of Sheffield, Sheffield, United Kingdom; Nathalie Bouscharain, Fabrice Ville, Insa Lyon, Lyon, France; Fabio Tatzgern, Nicole Dörr, AC2T research GmbH, Wiener Neustadt, Austria

Sliding machine parts can lead to elevated temperatures, extreme pressures, and high shear rates. Shearing a lubricant modifies its properties, such as viscosity, which is a critical parameter to ensure proper lubrication and operation. Ultrasound has been used to measure lubricant film thickness, but this technology is relatively new for viscosity measurements. Therefore, the aim of the study is to determine lubricant viscosity under shearing using ultrasonic transducers. A signal processing approach is established to determine oil viscosity based on reflected ultrasonic signals. The results of ultrasonic measurements are compared with those obtained with a rheometer. Beside shearing, the impact of several parameters on viscosity is also discussed: base oil chemistry, fresh and used lubricants, temperature, lubrication gap.

10 - 10:30 am - Break

10:30 - 11 am
3817410: A Simulated Test Methodology for Screening of Friction, Wear, and Extreme Pressure Properties of Hydraulic Oils
Rajendra Mahapatra, Indian Oil Corporation Ltd. R&D Centre, Faridabad, Haryana, India

Lubricating oil in hydraulic systems performs dual functions of lubrication & transmission of power. Oil contains necessary additives to ensure AW characteristics, proper viscosity to maintain adequate sealing & lubrication. It is difficult to simulate the AW characteristics of a vane pump in a bench top tribometer. This paper describes a simulation of the frictional, wear and EP characteristics of hydraulic fluids using a SRV machine by analysing friction coefficient, wear scar, and analysis of tribo-pair. The load carrying capacity having indicative of EP characteristics was also studied using a SRV load stage test. To validate the SRV results, performance testing on an Eaton 35VQ25 vane pump test as per ASTMD6973 was carried out on the test fluids. The studies indicate a correlation of the pump test performance with the frictional, wear and EP characteristics. A simulated test methodology for quick screening of friction, wear, and EP properties of hydraulic oils has been developed.

11 - 11:30 am
3806602: Measuring the Damping Capacity of Oils
Kenneth Budinski, Bud Labs, Rochester, NY

There are at least a dozen ASTM standards for measuring and comparing the friction responses of different oils in specific test rig tribosystems. However, these tests do not address the retarding force on a crankshaft sloshing through an oil sump. This is attritious friction. It is the retarding force or damping on a solid moving through a fluid such as oil. The damping capacity test uses a swinging pendulum made from a metal rod set into motion and the end is immersed to a given depth in the test fluid. The relative decay of the pendulum motion in the test fluid is the test metric. Tests were conducted on four commercial oils with the same listed viscosity at temperatures from 7C to 100C. In all cases, there were significant attritious friction differences between supposedly the “same” oil. This is a new “fluid friction” test, and work to date suggests that it simulates energy losses caused by fluid retardation, better than viscosity tests.

11:30 am - 12 pm
3813143: Effect of Environment on Fuel Lubricity Standards
Stephen Berkebile, Monica Ferrera, Briana Segal, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Fuel lubricity has a large impact on system wear in mixed and boundary lubrication conditions found in high pressure fuel pumps, however lubricity standards do not simulate fuel pump environments nor reproduce observed pump damage. ASTM Standard D5001 Ball-on-Cylinder Lubricity Evaluator (BOCLE) is used for evaluating lubricity of aviation turbine fuels, and ASTM D6079 High-Frequency Reciprocating Rig (HFRR) is used for diesel fuels. Scuffing Load BOCLE (SLBOCLE) measures scuffing failure in severe conditions in diesel fuels. All are conducted in air rather than the low-oxygen environment found in fuel pumps. We compared the three standards in both air and an oxygen-starved nitrogen gas environment for over ten fuels. We observed differences in wear and fuel ranking due to the presence/absence of oxygen on fuel lubricity measurements for all fuels. We compare the three testing

methods and discuss the reasons for the differences based on microscopy and spectroscopy of the wear scars.

5H 103C

Commercial Marketing Forum V

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am - **Placeholder**

8:30 - 9 am - **Placeholder**

9 - 9:30 am - **Advanced Chemical Concepts, Inc.**

9:30 - 10 am - **The Lubrizol Corporation**

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

5I 104A

Electric Vehicles V

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am
3832068: Novel Sustainable Low-viscosity Synthetic Base Fluids for E-Mobility
Ramesh Navaratnam, Michael Liang, Patech Fine Chemicals, Dublin, OH

To meet the operational efficiencies of Hybrid (HEV) and Electric Vehicles (EV) technologies the transmission e-fluid requirement has moved toward low-viscosity fluids. Transmission e-fluids used in HEV, and EV are also in direct contact with different electrical components of the motor like battery, transmission gear, and integrated electric motors. This introduces new challenges of requiring excellent electrical and thermal properties of e-fluids to prevent the risk of electric short circuit and overheating. However, conventional low-viscosity base fluids have poor lubricity performance that reduce reliability and performance. In this study, we will demonstrate the benefits of synthetic esters to provide better heat transfer and di-electric properties than other base stock. In understanding these mechanisms, we were able to develop esters specifically for higher heat conductivity, low viscosity with excellent lubricity, and eco-friendly to achieve the goal of sustainability as well.

8:30 - 9 am
3810965: Sustainable E-Fluid Concepts for Electric Motor Cooling and Gearbox Lubrication
Christopher Dobrowolski, Shell Global Solutions, Hamburg, Germany

With the automotive world looking to quickly electrify, lubricant manufacturers are designing fluids that can best protect those highly integrated electric powertrains. E-motor friendly and efficient lubricant solutions are lower in sulfur and have lower viscosity. The next challenge is to provide lower CO_2 intensive products to decarbonize not only emissions but also the actual components used for producing and running cars, like the lubricant. In order to balance the technical properties and requirements with available and more sustainable components and base oils, Shell has generated a study to assess key aspects of those next generation formulations for transmission fluids. The study aims to generate and assess data for understanding performance aspects like efficiency and the potential to formulate low viscous fluid solutions, oxidation stability, material compatibility and CO_2 footprint.

9 - 9:30 am
3830293: Extrinsic Sustainability Benefits of Esters Suitable for Use in Electric Vehicle Gear and Battery Cooling Systems.
Gareth Moody, Bethan Warren, Chris Clayson, Cargill, Goole, United Kingdom

Fluid technology for electric vehicles is developing at a rapid rate with fluids which can aid range extension and fast charging being of particular significance. This presentation will give an overview of the intrinsic sustainability benefits of using esters as part of the formulation as well as a comprehensive review of the extrinsic benefits (reducing CO_2 in use) covering aspects such as efficiency boosts, thermal capabilities and material compatibility as well as introducing a new, very low viscosity base fluid suitable for both gear lubricant and direct battery cooling applications.

9:30 - 10 am
3812488: Study on the Impact of Dedicated Electric Drive Fluid Properties on Total Efficiency of Drive Unit
Pedro Cawich, Masato Yokomizo, Scott Rajala, Idemitsu Lubricants America Corp., Wixom, MI; Hiroyuki Tatsumi, Idemitsu Kosan Co., Ltd., Ichihara-shi, Chiba, Japan

Recently with increased concerns and regulations for the environment, it has become critical to reduce energy loss in many fields. Hence, many OEMs have invested heavily in developing new electric motors with innovative designs. Common ATFs keep being the preferred fluids for these new motors although new and more severe requirements are needed. New electric motors require for improved cooling performance by the oil to increase total efficiency which common ATFs cannot provide. Reducing the viscosity and improving the thermal conductivity of the oil can be effective ways to improve cooling performance but their effects on total efficiency have not been clarified. In this study, the impact of viscosity and thermal conductivity on total efficiency were investigated using a formulation designed for an electric drive unit.

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

10:30 - 11 am
3804913: Polyalkylene Glycols as Base Oils and Co-base oils for Gear Oils in Electric Vehicle Drivetrains
Steffen Glaenzer, Stephanie Cole, Clariant Corporation, Mount Holly, NC

The market penetration of electric vehicles is a major global trend resulting from regulations intended to reduce greenhouse gas emissions. OEMs, suppliers, and researchers are looking for base oils that meet new e-fluid needs, different from lubricants used in internal combustion engine vehicles. So far, few systematic studies benchmark crucial properties of e-fluid base oils. This paper will compare the base oil properties of polyalphaolefins and various polyalkylene glycol solutions, covering the following topics: 1) energy efficiency, 2) cooling performance, 3) electrical properties, 4) wear, 5) solubility, and 4) sustainability. In summary, friction can be reduced to superlubricity (coefficient of friction below 0.01), and heat transfer efficiency can be increased up to 40%. Depending on the type of polyglycol, it can be used as co-base oil/additive or as base oil. In addition, polyglycols offer the possibility to formulate hazard-label-free and readily biodegradable fluids.

11 - 11:30 am
3813071: Fine Tuning the Structure of Esters to Optimize Their Properties as e-COOLANTS
Siegfried Lucazeau, NYCO, Paris, France

Fluids and lubricants used in electrified vehicles need specific features - in particular in the case of direct cooling (battery, engine or e-axle fluids). Synthetic esters do show several benefits in such applications. They give access to ultra low viscosity whilst keeping a higher level of fire safety than other base fluids. They also show very good thermal conductivity levels, an improved resistance to oxidation, and a remarkable ability to reduce traction. However, esters also show some limitations that have to be considered. Synthetic esters are flexible, tunable compounds; a detailed understanding of the relationship between chemical structure and properties allows us to design the optimum fluids and find the best tradeoff between sometimes conflicting features. Practical examples of balancing properties of esters lead to improved elastomer compatibility of a given fluid, as well as optimized traction reduction, whilst maintaining excellent heat dissipation and fire safety features.

11:30 am - 12 pm
3831897: Shear Stable Ester Thickeners - EVs and Beyond
David Gillespie, Kevin Duncan, Cargill, Snaith, East Yorkshire, United Kingdom

Protecting gears from wear can be achieved using high viscosity thickening additives, traditionally based on petrochemical ingredients. Equivalent formulations based on renewable resources are desirable to enhance the environmental profile of finished gear oils. High molecular weight (Mw) esters can be used as alternative thickeners, with benefits of improved film formation and thickening efficiency. High Mw thickeners tend to exhibit poor shear stability and this generally scales with Mw. Formulating gear oil transmission fluids for electric vehicles therefore offers a particular challenge, where gear rotational speeds are expected to exceed 30k rpm. Design of experiments methodology is used to accelerate product development and find an optimal balance between thickening efficiency and shear stability. This analysis is then used to develop a shear stable, efficient thickener, with an excellent sustainability profile that will enhance the performance of gear and transmission fluids.

5L 201B

Surface Engineering I

Session Chair: TBD
Session Vice Chair: TBD

Session Starts at 8:30 am

8:30 - 9 am
3812617: Tribological Behavior of Textured Surfaces Produced by Laser Powder Bed Fusion
Tobias Martin, Q. Jane Wang, Jian Cao, Northwestern University, Evanston, IL; Stephen Berkebile, DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Surface texture impacts the tribological behavior of mechanical components in boundary and mixed lubrication. Currently, many additively manufactured parts undergo expensive and time-consuming post processing to meet surface roughness requirements. If tribologically beneficial surface textures are designed so the texturing and additive manufacturing processes can be combined, parts thus made can be used in their as-built condition. Then production cost can be reduced, and a prolonged life of these parts can be expected. This work focuses on the directional dependence of friction and wear on the textures of as-built additively manufactured surfaces. Reciprocating tribotests are performed on the top surfaces of samples produced by laser powder bed fusion with the sliding direction parallel, perpendicular, and angled to the laser scanning direction. Friction and wear are evaluated with respect to the location in the track formed during experiment and correlated to velocity variation.

9 - 9:30 am
3833013: Development and Performance Evaluation of Novel Surface Polishing Technique for Additively Manufactured Components
Kommineni Uday Venkat Kiran, Sougata Roy, University of North Dakota, Grand Forks, ND; Brady Kimbrel, NASA Marshall Space Flight Center, Huntsville, AL

A novel and sustainable dry electro-Mechanochemical (DEMC) surface finishing technique was devised, which uses dry electrolyte media to improve the surface quality of additively manufactured metallic parts. DEMC uses the synergetic influence of mechanical and electrochemical functions of the polishing to reduce the surface roughness of AM. The process parameters, such as voltage and polishing time variation on the material removal rate, surface morphology, and surface roughness, were analyzed by comparing experimental and characterization results. Sample surface morphologies were analyzed using OM, non-contact surface profilometry, and SEM analysis. Sample surface chemical compositions were detected using EDS spectroscopy. Amplitude, spatial, and hybrid surface roughness parameters were investigated before and after polishing process. The reduced surface finish of metal AM components using this technique validates its capability to post-process metal AM components.

9:30 - 10 am
3833893: Friction and Deformation of Additively Manufactured Micro/Nano-Hierarchical Structures with Different Structural Stiffness
Mahyar Afshar Mohajer, Min Zou, University of Arkansas, Fayetteville, AR; Xingwei Yang, Rong Long, University of Colorado Boulder, Boulder, CO

Textures consisting of micro/nano-hierarchical structures are critical to realizing surfaces with functionalities such as superhydrophobicity. Understanding the tribology of such structures is of great importance. In this study, a small-scale additive manufacturing method known as two-photon lithography (TPL) was utilized to fabricate micro/nano-hierarchical structures (nanohair-covered micropillars). The accuracy and resolution of TPL enabled control over the stiffness of the structures by varying the nanohair length, and micropillar tapering angle. In-situ SEM tribological testing of individual micro/nano-structures provided direct observation of the effect of structural stiffness control on the onset of sliding motion, changes in the friction force, linearity of the relationship between the friction force and the applied normal load, and the interaction of the structures along different length scales.

10 - 10:30 am - Break

10:30 - 11 am
3833052: A Comparative Analysis in Tribo-Mechanical Behavior of Cold Rolled and Additively Manufactured Nickel Titanium Alloy
Hyunsuk Choi, Sougata Roy, University of North Dakota, Grand Forks, ND

Nitinol, an alloy made of Ni and Ti, has two special characteristics: shape memory and superelasticity. Due to its capacity to withstand significant elastic strains and superior mechanical properties compared to martensitic NiTi, austenitic NiTi alloys with superelastic behavior was studied for load-bearing applications. The microstructural characteristics and tribo-mechanical behavior of Nitinol fabricated via laser-wire directed energy deposition with superelastic NiTi wire was investigated and the results were compared against that of cold rolled Nitinol. A set of systematic experiments including microstructure, hardness, porosity measurement, and thermal analysis via DSC were conducted. Reciprocating sliding tests using a ball-on-flat type contacts, were performed in unlubricated conditions against steel balls at room temperature to 200°C. Decrease in friction coefficient with increasing operating temperature was observed in both additively manufactured and cold rolled Nitinol.

11 - 11:30 am
3848291: Additively Manufactured Inconel 625 subjected to Shot Peening and Laser Peening Processes: Microstructural and Elevated Temperature Fretting Wear Analyses
Ali Beheshti, Manisha Tripathy, George Mason University, Sterling, VA; Keivan Davami, The University of Alabama, Tuscaloosa, AL; Lloyd Hackel, Curtiss Wright Surface Technology, Livermore, CA

Inconel 625 with excellent mechanical properties is highly used in harsh environments as joints, seals, valves, etc. With the rapid growth of the metal additive manufacturing industry, it becomes necessary to rigorously study the additively manufactured (AM) components trying to achieve comparable or even superior properties with reference to their conventional counterparts. This study showcases a detailed microstructural and surface property comparison between AM and traditionally manufactured Inconel 625 subjected to shot peening (SP) and Laser Peening (LP) processes. Surface morphology and mechanical properties as well as advanced characterization techniques like XRD, EBSD, and TEM were employed to collate the changes due to the different types of peening processes. In addition, the high temperature fretting wear properties of AM Inconel 625 and its wrought counterpart is evaluated at high temperatures up to 700ºC.

11:30 am - 12 pm
3833036: Exploring the Wear Resistance of Additively Manufactured Al Parts for Future Lunar Exploration Via Custom Developed Testing Strategies
Pial Das, Sougata Roy, University of North Dakota, Grand Forks, ND; Nicholas Dyrstad-Cincotta, Junior Nasah, Institute of Energy Studies, Grand Forks, ND

Erosion by high-speed abrasive particles is a major form of material degradation in numerous systems such as spacecraft, especially during landing on the moon or other planets. Additively manufactured aluminum alloy parts have several advantages over traditionally produced components, i.e., superior mechanical properties, and enhanced wear resistance. Reinforcement using select ceramics gives even higher strength, better wear behavior and higher density to Al matrix over conventional Al alloy by grain

refinement and reducing dislocation movement. Unfortunately, most of the research has been done in the direction of the strength of the MMC while the erosion performance of those materials at extraterrestrial environment has not been extensively explored. In our recent work, we studied erosion performance of laser DED produced specimens under a simulated lunar environment and tested against lunar dust simulant particles impinging at high velocity, and varied temperature ranges.

5M 202A

Grease I

Session Chair: TBD
Session Vice Chair: TBD

8 - 8:30 am – **Open Slot**

8:30 - 9 am
3803372: Role of the Grease Components on the Overall Frictional Response of a Greased Contact Subjected to Low-sliding Velocity Conditions
Francesco Massi, Ilaria Ghezzi, Davide Tonazzi, Sapienza University of Rome, Rome, Italy; Cédric Le Coeur, Michael Rovere, Jeremy Chorier, SOMFY SAS, Cluses, France; Yves Berthier, Université de Lyon, INSA-Lyon, CNRS, Villeurbanne, France

Despite the use of lubricants has been promoted to reduce friction and guarantee an adequate life of components, lubricated contacts are not exempt from unstable vibrations, such as stick-slip. The presence of a lubricant introduces another parameter, which greatly influences the frictional contact response. In case of grease lubrication, the complex rheology of the grease, function of its different components (thickener, additives and oil), covers a key role by driving the frictional response as a function of the sliding velocity. Aiming to understand the role played by the different lubricant components, different types of lubrication conditions have been tested, corresponding to dry contact, oil lubrication and greased contact (with and without additives), both with and without Diamond-Like-Carbon solid lubricant. The results highlighted the relevant role of the thickener and additives that drive the overall frictional response of the greased contact pair under investigation.

9 - 9:30 am
3814543: Unraveling the Role of Particle-Particle Contacts on Microscopic, Rheological and Tribological Characteristics of Nanoenhanced Greases
Jackson Uhryn, Leonardo Martin-Alarcon, Babak Soltannia, Aleksandra Govedarica, Milana Trifkovic, Philip Egberts, University of Calgary, Calgary, Alberta, Canada

Improving tribological properties and reducing the environmental impact of greases is of utmost importance. Nanoenhanced lubricants have been gaining popularity due to improved tribological performance. However, the physical mechanisms responsible in these complex systems is poorly understood. By using a model grease system consisting of organically modified nanoclay particles dispersed in base oil, we establish a link between the microstructure, rheological, and tribological properties. Further functionalization of clay platelets with oleic acid (OA) links particle-particle interaction, brittleness of network structure, network dynamics at high shear rates, and its effect on friction results. Imaging of these systems provides novel insights into the effect of OA on particle and steel interactions, friction, and rheology. Preliminary works on nanocellulose fiber systems, which have an alternative structure and stronger interaction than nanoclays, have shown similar promising results.

9:30 - 10 am
3817326: Structural Changes of Thickener and Rheological Properties of Lubricating Greases under Shear Flow
Takashi Noda, Kentaro Sonoda, NSK Ltd., Fujisawa, Japan; Yuki Takayama, Hitoshi Washizu, University of Hyogo, Hyogo, Japan; Shigeo Kuwamoto, Hyogo Science and Technology Association, Hyogo, Japan

Grease is a colloidal dispersion of fibrous structures mixed with oil, and is known to exhibit complex properties in response to external actions. Although the behavior of the thickener structure, such as the orientation and breakdown of molecular micelles, is considered to be deeply involved in shear-thinning

process, the mechanism is not clear. In this study, shear-induced mechanical structural changes of thickeners can be observed by means of an ultra-small-angle X-ray scattering measurement and coarse-grained small-angle scattering simulation. By examining the relation between microstructural behavior and apparent viscosity of greases based on the subtracted scattering patterns, microscale grease behavior such as alignment and collapse of the thickener structure came out.

10 - 10:30 am - Break

10:30 - 11 am
3831963: The Matrix Revisited: Exploration of Additive Choice with Different Thickener Types
Joseph Kaperick, Afton Chemical Corporation, Richmond, VA

The predominant matrix of choice for grease manufacturers has been lithium for several decades now. However, its position as the default for cost-effective, multipurpose grease formulations is beginning to show signs of weakening. The increasing imbalance in the supply/demand position of LiOH has inspired many grease manufacturers to evaluate alternate thickener types as options for a variety of applications. Unlike most lubricating oil formulations, additive interaction with the grease thickener matrix is a critical element that needs to be carefully considered to create an optimized grease formulation in an efficient and cost-effective manner. This paper looks at the impact of grease thickener type on additive selection by presenting the results of several studies and discussing theoretical aspects of the interactions in question.

11 - 11:30 am
3834151: Ionic Materials in Greases: Influence on Lubrication and Electric Conductivity
Sergei Glavatskih, KTH Royal Institute of Tribology, Stockholm, Sweden

The use of ionic materials, such as ionic liquids, in lubricating greases opens up new possibilities for tuning grease formulations for electric machinery and increasing lubrication efficiency. Ionic materials also bring new properties into lubricant design process that enable additional functionality. Their ionic nature facilitates ion-surface interactions promoting rapid growth of the friction and wear reducing boundary films. It is shown how architecture of non-halogenated ionic materials added to the greases influences their lubrication performance in the sliding and rolling contacts. Different thickeners are considered. Surfaces were analyzed by TOF-SIMS and other techniques. An approach to characterize conductivity of greases using electrical impedance spectroscoy is also considered.

11:30 am - 12 pm
3848545: OBCaS Grease Green One and Customized One
Guillaume Notheaux, SEQENS, Porcheville, France

Benefits of OverBased Calcium Sulfonate (OBCaS) greases are well known in the industry and their manufacturing well established. However, a specific process called “one-step process” is less known. Synthesizing directly OBCaS thickener under calcite form provides flexibility in choosing base fluid and ease of upgrade. Selecting 100% of the oil part contained in the final grease during the process, enables to offer many possibilities. For example -biodegradable OBCaS greases & easy oxidation improvement while keeping performances, biodegradability & label free; -Solutions to replace completely Group I oils in the final grease; -Improve behavior under cold environment, thanks to new carriers; -Improve corrosion preventive under dynamic wet conditions, thanks to different co-acid and additives. A review of all possibilities & updated, with example, will be presented.

5N 202B

Nanotribology V

Session Chair: Gokay Adabasi, University of California, Merced, Merced, CA
Session Vice Chair: TBD

8 - 8:30 am
3819587: Understanding the Corrosion and Wear at Nanoscale Interface Using Machine Learning Technique
Ran Zhang, Saugat Tripathi, Ashutosh Pitkar, Miao Wang, Zhijiang Ye, Miami University, Oxford, OH; Yufei Wang, Hang Ren, University of Texas, Austin, Austin, TX

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

8:30 - 9 am
3833797: Frictional Behavior of Surfaces Textured with Various Core-shell Nanostructures
Colin Phelan, Charles Miller, Josue Goss, Min Zou, University of Arkansas, Fayetteville, AR; Robert Fleming, Arkansas State University, Jonesboro, AR; Christopher Rincon, Ronghua Wei, Southwest Research Institute, San Antonio, TX

The frictional behavior of aluminum (Al)/amorphous silicon (a-Si) and Al/diamond-like carbon (DLC) core-shell nanostructure textured surfaces (CSNTS) was studied using nanoindenters. The indenter tip size, applied normal load, material type, deformation, and texture uniformity were found to have substantial effects on the frictional behavior. For both samples, the highest coefficient of friction (COF) occurred at the lowest normal load tested due to high adhesion forces. At low contact pressures, the Al/DLC CSNTS displayed a lower COF than the Al/a-Si CSNTS due to the superior tribological properties of DLC compared to a-Si. However, at higher contact pressures, the Al/a-Si CSNTS exhibited a lower COF as a result of better deformation-resistant properties of a-Si compared to DLC. The taller Al/a-Si core-shell nanostructures (CSNs) of the non-uniform Al/a-Si CSNTS interlocked with the indenter tip and deformed more severely than uniform CSNs, thereby leading to higher friction forces.

9 - 9:30 am
3817233: Effect of Oxidation of Metal Surface on Additive Adsorption and Friction Property
Lin Sun, Tomoko Hirayama, Naoki Yamashita, Kyoto University, Kyoto-shi, Kyoto, Japan; Hironobu Nakanishi, Kobe Steel, Ltd, Kobe, Japan

To understand the friction characteristics of sliding surfaces, it is necessary to investigate the adsorption property of lubricant additives onto the sliding surfaces. The adsorption property depends not only on the type of metals and additives but also on the condition of the sliding surface. Particularly, previous studies showed that the oxidization of metal surfaces significantly affects the adsorption property of additives, resulting in the change of friction characteristics. In this study, the nanotribological tests of metal surface in lubricant were conducted by using an atomic force microscope. To investigate the effect of surface oxidation to the friction characteristics, the top surface was previously worn by point-probe cantilever, and the nascent surface was exposed in lubricant. After that, the lubricant with additive was dropped respectively and the friction test was conducted in each area to check whether the friction properties differed due to the surface oxidization.

9:30 - 10 am
3811486: Molecular Friction Models for Molecular Adsorbates
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

Atomic-scale nanoscale friction models, based on ideas from Tomlinson and Prandtl, use simple periodic sliding potentials to model the velocity and temperature dependences of the friction force, for example, as measured in an atomic force microscope. However, this approach is not well suited to describing the friction of adsorbed molecular overlayers, for example, self-assembled monolayers (SAMs). We use a simple model interaction potential between the tip and the outer surface of the organic substrate to develop analytical models for molecular friction. In particular, this potential can be coupled to the molecular tilt to provide an analytical model for the chain-length dependence of SAM friction that is in good agreement with experiment.

10 - 10:30 am - Break

10:30 - 11 am
3810952: Tribological Behaviour of Graphene Quantum Dots as Novel Additives for Green Lubrication
Irfan Nadeem, Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

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

11 - 11:30 am
3833794: Probing the Mechanical Properties of Soot to Understand the Tribology of Contaminated Diesel Engine Oils
Alaaeddin Al Sheikh Omar, Institute of Functional Surfaces (iFS), Leeds , West Yorkshire, United Kingdom

The study has evaluated the role of modification in the crystal structure of soot in affecting the performance of engine oils [1-3]. Carbon black particles (CBPs) were used to simulate the real soot in the engine. Fully Formulated Oil containing CBPs was aged in the lab. The oils and CBPs were chemically investigated using FTIR, ICP, EDX and XRD. In-situ nano-compression tests for fresh and aged CBPs with different sizes were studied using SEM nanoindention. Nano-compression tests for single particle showed that aged CBPs had a higher deformation load to break the particle compared to fresh CBPs. The displacement load to deform the particles were increased to approximately double compared to fresh CBPs. This study demonstrates modification in the crystal structure, and how the ageing oil and interactions with additives can influence the turbostratic structure of soot, mechanical properties of particles and hence the tribological performance.

6A 101A

Lubrication Fundamentals VI: Innovative Test Methods

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3813027: Boundary Lubrication in an Inert Atmosphere - a New Route to Sustainability
Hugh Spikes, Jie Zhang, Janet Wong, Tribology Group, Imperial College London, London, United Kingdom

The recent availability of nitrogen concentrators that filter O_2 from an air flow to provide an almost pure N_2 stream may make it feasible to blanket closed lubrication systems in inert gas, with obvious benefits to lubricant life and allowable operating temperature. However, this requires lubricant formulations that can provide low friction and protection against wear, scuffing and rolling contact fatigue in zero or very low oxygen atmospheres. Here we compare the lubricating properties of base oils and lubricant additive blends in a nitrogen atmosphere with their response in air. In nitrogen, the base oils very rapidly form protective carbon films on rubbed surfaces, resulting in much lower friction and wear than seen in air. It is found that some lubricant additives behave quite differently in the two atmospheres and the origins of these differences are explored and interpreted in terms of both carbon film formation and the presence or absence of iron oxide on the rubbing surfaces.

2 - 2:30 pm
3833863: Differential Topography – on the Challenges of Three-dimensional Characterization of Tribofilms
Nicole Dörr, Viktoria Seidl, Georg Vorlaufer, Serhiy Budnyk, AC2T research GmbH, Wiener Neustadt, Austria

The chemical composition of tribofilms from zinc dialkyl dithiophosphate (ZDDP) has been verified by numerous studies. The growth of such tribofilms can be monitored cycle by cycle using atomic force microscopy. This work discusses a methodology for the three-dimensional (3D) characterization of tribofilms to get insight into the lateral distribution of tribofilm thickness based on 3D optical microscopy images. Therefore, wear scars were produced with an engine oil in an oscillating ball-on-disk contact. The workflow for data analysis comprises techniques well-known from computer vision like image preprocessing and template matching. Topography data sets taken before and after the removal of the tribofilm were compared and aligned to each other using an iterative point cloud matching process. Results were quantified and visualized in terms of film thickness distribution.

2:30 - 3 pm
3830022: Achieving Macroscale Superlubricity in Non-polar Oil by Sacrificial Carbon Nanotube Coating
Chanaka Kumara, Michael Lance, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Achieving superlubricity is an efficient way of reducing friction and improving energy efficiency. We achieved macroscale superlubricity using sacrificial carbon nanotube coating under ambient environmental conditions. Notably, a coefficient of friction of 0.001-0.007 was achieved when a CNT-coated stainless-steel disk sliding against a M2 tool steel disk in boundary lubrication using only a drop of Polyalphaolefins base oil. Raman spectroscopy and electron microscopy analysis showed a formation of graphene/ graphene oxide-based tribofilm on both contact surfaces. Further, sustainable superlubricity was achieved up to 10 km or 11 days of continuous sliding. This superlubricity CNT coating is potentially applicable to solve a wide range of friction and wear issues.

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

3:30 - 4 pm
3813470: Lubricating Properties of Volatile and Gaseous Fuels
Hugh Spikes, Jie Zhang, Tribology Group, Imperial College, London, United Kingdom; Matthew Smeeth, Clive Hamer, PCS Instruments, London, United Kingdom

There is growing interest in the use of highly volatile and even gaseous fuels to replace conventional gasoline and diesel in crankcase engines. Volatile hydrocarbons can burn cleaner and have lower proportionate CO_2 emissions than higher molecular weight hydrocarbon fuels, while carbon-free gaseous fuels may eliminate CO_2 emissions altogether. Just like gasoline and diesel these fuels must be pumped and injected into the combustion chamber and must thus possess sufficient lubricity to prevent wear and minimise friction of pump and injector systems. This presentation describes the use of a new, sealed high frequency reciprocating rig to measure both friction and wear properties of a range of volatile and gaseous fuels. Because it is a sealed system it is also able to study the lubricating ability of conventional gasoline and diesel and their blends with bio-components at higher temperatures and pressures than is currently possible.

4 - 4:30 pm
3834006: Evolution of Surface Roughness and Correlation with Friction Using In-situ Profilometry
Debdutt Patro, Sravan Josyula, Fabio Alemanno, Ducom Instruments, Groningen, Netherlands; Deepak Veeregowda, Ducom Instruments (EUROPE) B.V., Groningen, Netherlands

Friction, wear and scuffing of starved tribological contacts are often related to the changes in surface topopraphy and chemistry of tribofilms. In this study, a 3D interferometer was integrated with a tribometer to capture the evolving surface topography. Friction, surface roughness, wear and film thickness evolution were recorded as a function of time using force sensors, electrical contact resistance and a 3D interferometer integrated with the tribometer. Lubricants with different anti-wear property were tested under linear reciprocation motion. The tests were intermittently stopped, ball and disc imaged and testing continued without disturbing the configuration. Under some conditions of load and temperature, failure of the lubricant film was observed with significant changes in surface topography. The transitions in friction and wear would be connected with the surface roughness to obtain new insights into lubricant behaviour.

4:30 - 5 pm
3839578: Inevitable Deviations in Surface Profile and System Vibration Determine Tribological Behavior
Yulong Li, Nikolay Garabedian, Johannes Schneider, Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Germany

A surface profile, in most cases, is characterized via roughness and waviness parameters, which are considered simple and informative scalar quantities. Such quantitative indicators have to be used during the surface finishing process, as reaching a completely flat surface is impractical, if at all possible. Similarly, manufacturing surfaces with the exact same surface topography is almost unachievable in practice, and consequently, inevitable deviations always exist (within a prescribed acceptable range). The mounting process and the mechanical vibration from the tribometer further compound to the complexity of the tribological interface. In this contribution, the surface profile, interface-induced oscillations, and mechanical vibrations were measured in a pin-on-disk tribometer. It was found that there is a non-obvious interplay of surface and system properties, which, when taken together, strongly correlate with friction and can be used to predict the locations of highest wear.

5 - 5:30 pm
3803597: Investigation of Emission Characteristics and Lubricant Properties in a Hydrogen Internal Combustion Engine.
Modestino De Feo, Aramco Overseas, Rueil-Malmaison, France, France

Hydrogen with a low-carbon footprint has the potential to facilitate significant reduction in energy-related CO_2 emissions and to contribute to limiting global temperature rise to 2°C. Because of the H_2 combustion properties, a dedicated lubricant would be desirable to offer to this technology the reliability and performance it demands.
The objective of this study is to support the development of heavy-duty H_2 Internal Combustion Engine (ICE) by identifying the levers to be optimized to meet the main requirements linked to this specific application. Solid and gaseous emissions from a bench engine using several engine oil formulations have been characterized, and there the oils' tendency to cause the phenomenon of pre-ignition have been monitored. Moreover, an endurance test has been performed in order to verify the ability of the lubricant to handle water accumulation and prevent wear and deposit formation.

6B 101B

Rolling Element Bearings VI

Session Chair: Daulton Isaac, AFRI Turbine Engine Division, Wright Patterson Air Force Base, OH
Session Vice Chair: Kushagra Singh, Purdue University, West Lafayette, IN

1:30 - 2 pm
3812999: Numerical Analysis for Tapered Roller Bearing in Relation to Roller Profile Based on Running-In Method
Renshui Cao, Yonggang Meng, Tsinghua University, Beijing, China

Tapered Roller bearings (TRB) are widely used under large radial and axial loads at heavy-duty operations, such as gas turbine engines, axle boxes of bogies, etc. One of the technical problems in TRBs is the existence of sharp spikes of the contact pressure in the vicinity of the two ends of the tapered rollers. The quasi-static model and the mixed lubrication model are established to analyze the influences of different axial profiles on a single tapered roller and on the whole tapered roller bearings. The results show that the optimized profile, based on the numerical running-in method, has immense advantages in terms of the asperity contact pressure uniformity and the elimination of end effect of stress concentration not only for a single tapered roller but also for the whole tapered roller bearings. In addition, effects of other factors on asperity contact pressure distributions are discussed, including radial load (Fr), rotation speed (N), and standard deviation of roughness (Rq).

2 - 2:30 pm
3819320: Efficient Residual Stress Quantification in M50NiL Bearing Steel
Daulton Isaac, Mathew Kirsch, AFRL Turbine Engine Division, Wright Patterson Air Force Base, OH; Teresa Wong, Adrian DeWald, Hill Engineering, LLC, Rancho Cordova, CA

In this work, efforts to apply advanced stress release methods of residual stress measurement, namely slitting and slotting, to a bearing steel are presented. The advantages of both techniques can be seen in low error estimates, higher stress-depth resolution, and faster acquisition time. The test article chosen was a flat disk of M50NiL, a widely used case-carburized bearing steel. XRD measurements from two sources were also obtained on the same part in an attempt to interrogate the repeatability of that method. Good agreement was obtained between all the measurements made as well as with previously published data. The investigation was continued by executing slotting measurements on bearing rings made from M50NiL. XRD was also performed on these same parts. The similarities and contrasts between the results of the two methods are discussed as well as the challenges in applying the slotting method to curved surfaces of a bearing steel.

2:30 - 3 pm
3810628: Prediction of Rotation of a Shrink-fitted Cup of a Tapered Roller Bearing Under Thermal Loading
Victor Pinardon, Sébastien Morterolle, Daniel Nelias, INSA Lyon, Villeurbanne, France; Timothée Gentieu, Safran, Vélizy-Villacoublay, France

In some tapered roller bearing mountings, it is usual to shrink fit the cup of the bearing into the housing. However, high transient thermal loads can lead to a decrease in clamping when the cup and its housing do not have the same thermal expansion coefficients. Under these conditions, the cup may start to rotate in the housing due to the torque transmitted by the bearing. This rotation could strongly affect the bearing performance. This study aims at predicting the risk of cup rotation by comparing the operating torque of the tapered roller bearing and the loss of clamping between the cup and the housing. The bearing torque is calculated with an analytical model of the bearing. The evolution of the shrink-fit torque is computed with a transient thermomechanical model. Particular attention is paid to the application of a significant mechanical loading as when the inner ring experiences misalignment.

3 - 3:30 pm - Break

3:30 - 4 pm
3808525: A Generalised Machine Learning Model for Bearing Fault Diagnosis
Ling Wang, Amirmasoud Kiakojouri, nCATS, Southampton, United Kingdom; Honor Powrie, GE Aviation, Southampton, United Kingdom; Patric Mirring, Schaeffler Technologies, Herzogenaurach, Germany

Intelligent fault diagnosis for rolling element bearings (REBs) using machine learning (ML) techniques can significantly increase reliability of industrial assets. One of the main issues has been the lack of training data and most importantly the ability of ML models to be used for applications without specific training data, i.e., generalization capability. This study develops ML models using input features obtained from a novel hybrid method, combining cepstrum pre-whitening and full-band enveloping. The results show that a two-stage ML model, trained by data from the I2BS project, can successfully classify bearing faults present in a number of literature databases, including the Case Western Reserve University data, without further training. The bearing types and operating conditions in literature databases are completely different from those in the training data, thus presents a generalised ML model with the potential to be used to monitor bearings for a wide range of applications.

4 - 4:30 pm
3799664: Performance Evaluation and Life Estimation of Cryogenic Ball Bearing from Accelerated Life Test Results
Yeongdo Lee, Wonil Kwak, Korea Institute of Science and Technology, Seoul, Republic of Korea

Cryogenic ball bearing is an important rolling element of cryogenic pumps such as LNG pumps, and rocket turbopumps. In order to ensure stability of cryogenic pumps, performance of cryogenic ball bearing that used for then must be guaranteed. Performance of ball bearing includes load capacity, dynamic stability, reliability, durability. In this research, cryogenic ball bearing test rig was presented and with this tet rig, accelerated life test of cryogenic ball bearing was performed to evaluate performance and life estimation of bearing. The tests were performed until bearing fault occur. In order to accelerate degradation of bearing and to estimate L10 life, load was chosen as an accelerated stress factor. At two

levels of severe stress condition, test was conducted, Performance was evaluated with friction torque measured from test bearing and cage whirling orbit according to stress level. And we analyzed L10 life of ball bearing at each stress level

4:30 - 5 pm
3813109: Accelerated Life Time for Cryogenic Ball Bearing: Evaluation and Discussion of Tribological Phenomena with the Various Internal Clearance Design
Yongbok Lee, Wonil Kwak, Yeongdo Lee, Korea Institute of Science and Technology, Seoul, Republic of Korea

The reliability of cryogenic bearings is closely related to pump stable operation and life expectancy shall be ensured to ensure the life of the LNG pump required in the industrial field. This study develops a test evaluation instrument that can evaluate the reliability of cryogenic bearings by simulating the operating environment of the submerged LNG pump, and presents a method of evaluating the reliability and lifetime of bearings for cryogenic environments based on experimental research. The cryogenic bearings under extreme load conditions rather than pump operating conditions were experimented with to predict their lifetime under the pump operating conditions. The fault detection was identified through variable dynamic signals such as cage whirling orbit, bearing friction torque, the temperature of the test bearing outer race, motor current value, and the frequency analysis of sound level meter and acoustic emission were used to identify defects among the bearing elements.

5 - 5:30 pm
3812159: Diagnosis of Grease Condition using Dielectric Spectroscopy
Shunsuke Iwase, Taisuke Maruyama, NSK Ltd., Fujisawa, Kanagawa, Japan; Satoru Maegawa, Fumihiro Itoigawa, Nagoya Institute of Technology, Nagoya, Japan

In rolling bearings, poor lubrication causes damage such as fatigue and seizure. One of the causes of lubrication failure is physical and chemical degradation of grease, but the detailed mechanism is not known. Dielectric spectroscopy is a promising method to determine the physical and chemical states of lubrication in rolling bearings. In this study, dielectric spectroscopy of grease was measured using a parallel plate electrode. Five parameters were derived by applying a set of theoretical equations to quantify the dielectric properties of grease. These parameters were found to change depending on the internal state of the grease such as thermal degradation, which means that lubricant condition monitoring could be performed without collecting grease from the practical bearings by applying AC voltage between the electrode, which are the ring and the ball.

6C 102A

Synthetic Lubricants and Hydraulics I

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

1:30 - 2 pm
3812992: Liquid Amides – Novel, High Performance Base Oils
Claire Ward, Cargill, Goole, East Yorkshire, United Kingdom

This paper examines a tertiary liquid amide which has been structurally designed for use as a novel, high performance Group V base oil in industrial and automotive applications. The hydrolytic and oxidative stability benefits of the new liquid amide base oil could offer enhanced product performance and lifetime over some conventional esters in challenging high temperature environments with the potential for water ingress. These stability benefits are showcased in fully formulated oils for a number of industrial applications. Inherent corrosion inhibition properties of the amide and reduced oxidative degradation deposits could also help to extend the service life of this base oil and some of the mechanical components it comes into contact with. The intrinsic differences in amide and ester polarity also expand the solubility properties of this new base oil, helping to create stable formulations with some challenging components in PAO and GTL based systems.

2 - 2:30 pm
3812460: Synthetic Esters with The Advent of Electric Vehicles (EV) Era: Electric Power Factor & Heat Capacity, Structure – Property – Performance Relationships
Hoon Kim, Michael Creamer, Doug Placek, Zschimmer-Schwarz US, Gordon, GA

With the advent of EV era technical focus of lubricant industry is in shifting from engine oil to ATF/driveline lubricants, and likewise from hydrodynamic lubrication to EHL/mixed lubrication in tribology. Since most electric cars run on compact battery with high energy density under high-speed, high-load and high-temperature environment, EV lubricants require desirable electrical properties, low traction, better stability, and better thermal control. Along this line, in this presentation we report our latest investigation on useful structure-property-performance relationships of various synthetic esters in terms of the effect of their chemical and viscometrical properties on thermal control and the electrical stability performances.

2:30 - 3 pm
3834140: Ionic Lubricant Design Considerations
Sergei Glavatskih, KTH Royal Institute of Tribology, Stockholm, Sweden

The lubricant design process requires availability of a wide range of molecular building blocks. Ionic liquids, materials composed entirely of ions but liquid under the conditions used, significantly expand the range of available species. As lubricant additives, ionic liquids are expected to primarily follow the surface adsorption mechanism for friction reduction. However, this process is strongly affected by the oil or grease type used to prepare an ionic lubricant. To show the differences we compare phosphonium ionic liquids with orthoborate and phosphate anions in terms of their interfacial film formation, both physisorbed and sacrificial from chemical breakdown, in sliding and rolling contacts. Analysis of the obtained results reveals how contact conditions and ionic liquid carrier chemistry influence lubricating functionality of the ionic lubricant.

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

3:30 - 4 pm
3832052: Sustainability - “Energy savings are just an oil change away”
Brian Hess, Evonik Oil Additives USA, Inc., Horsham, PA; Denis Sepoetro, Evonik Operations GmbH, Darmstadt, Germany

As climate change is one of today’s biggest challenges, energy savings have become a primary target for equipment manufacturers and end users. Life Cycle Assessments (LCA) of energy efficient lubricants compared to currently established fluids quantify the effects an oil change can have on the carbon emissions along the entire life cycle of any machinery. Besides identifying the hotspots in the life cycle, strategies to reduce the Product Carbon Footprint (PCF) of the lubricant itself will be highlighted. The results demonstrate that switching to a high-performance lubricant significantly improves the sustainability performance of stationary and mobile hydraulic equipment, compressors, and industrial gearboxes. Furthermore, a lubricant upgrade is one of the most cost-effective and easiest measures to implement.

4 - 4:30 pm
3833575: Technical and Scientific Perspective From Using Polyglycol on a Composition of Compressor Lubricants
Eduardo Lima, Dow Chemical Brazil, São Paulo, Brazil

The perspective in seven dimensions attributed to Polyglycol being a differentiated technology of high performance for compressor system in fully formulated lubricants. In this presentation, perspectives from the Polyglycol synthesis process to the technical attributes related to this application will be explored.

4:30 - 5 pm
3819310: Testing Results of a Novel Bio-based Oil-soluble PAG Base Fluid and its Comparative Analysis to Conventional Oil-soluble PAGs.
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Polyalkylene glycol (PAG) lubricants have shown great promise and results as lubricants for many years and in many metalworking applications and offer many performance benefits. PAGs are polyether molecules that can vary in size and viscosity and generally are polar base fluids that provide affinity to metal surfaces generating suitable film strength properties for metal working applications. Common PAGs are produced from non-renewable resources which can impact end users who are striving toward better

sustainable practices. At Biosynthetic Technologies, we have developed a renewable and bio-based oil-soluble PAG with exceptionally high bio-content and hydrolytic stability. We will discuss the physical and performance testing results of Biosynthetic's novel oil-soluble PAG and compare to commercially available oil-soluble PAGs on the market.

5 - 5:30 pm
3829733: An Investigation of Varnish Formation and Removal in a High Pressure Piston Pump
Shriya Kalijaveedu, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI; Nathan Knotts, Zefu Zhang, Chevron Lubricants, Products & Technology, Richmond, CA

Prevention and remediation of hydraulic system varnish is important to equipment users because varnish can cause valve malfunction, heat exchanger fouling and shorten fluid life. In this investigation the tendency of fluids to form deposits was evaluated using the JCMAS P 045 High Pressure Pump test. Fluids that had low and high varnish-forming potential were compared. A modular plate and frame heat exchange was used to facilitate the inspection and analysis of deposits. Fluids with high-varnish forming tendency deposited oxidation debris on heat exchanger and reservoir surfaces. Analysis of the debris revealed high concentrations of additive elements. A varnish removing additive was blended into the fluid and its effectiveness was evaluated at 50°C and 80°C. The system was drained and disassembled for inspection. The cleaner was found be effective at removing deposits at both temperatures. These findings provide insights in how to extend the life of hydraulic fluids and equipment.

5:30 - 6 pm - **Synthetic Lubricants and Hydraulics Business Meeting**

6D 102B

Materials Tribology VI

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3859389: An Investigation into Wear of a Metal-metal Interface in a Jet Engine
Mary Makowiec, Elizabeth Miller, Michael Fox, Pratt & Whitney, East Hartford, CT

Exit guide vanes are positioned at the aft end of the low pressure compressor in a jet engine. These vanes direct the flow of air leaving the compressor to promote maximum efficiency. A recent evaluation of an engine-run part was performed to analyze and characterize the wear occurring on the support tabs of the outer diameter shroud of an exit guide vane. This presentation will discuss the outcomes of the analysis, including types of wear observed on the surface and characterization techniques used to evaluate the wear, including white light interferometry, scanning electron microscopy and elemental analysis, and x-ray photo spectroscopy.

2 - 2:30 pm
3812631: Formation of Wear-Protective Tribofilms on Different Steel Surfaces During Lubricated Sliding
Arman Khan, Tobias Martin, Jannat Ahmed, Shuangbiao Liu, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Alloying elements in steels impact friction and wear behavior. We performed reciprocating tribotests on 52100 ball on steel flats with different compositions, heat-treated to similar hardness and microstructure, with polyalphaolefin and n-dodecane as lubricants. There are significant variations of friction coefficient among these alloys. Steels containing high concentrations of Cr, Mo, V, or Cu/Ni produced reduced wear than 52100 or plain carbon steels; D2 steel, containing 11.5 wt.% Cr, is the most wear resistant. The wear resistance correlates with the formation efficiency of carbon-containing films at the surfaces. This correlation holds for higher hardness steels and n-dodecane, a low viscosity lubricant. Molecular dynamics simulation on Cr_2O_3 demonstrated catalytic ability to form carbon-containing oligomeric films from hydrocarbons. Cr-containing alloys and coatings derive their wear resistance in part from in-situ formation of wear-protective tribofilms at contacting asperities.

2:30 - 3 pm
3812205: Holistic Measurement of the Friction Behavior of Wet Disk Clutches
Patrick Strobl, Georg Johann Meingaßner, Katharina Voelkel, Hermann Pflaum, Karsten Stahl, Technical University of Munich, Garching near Munich, Germany

Safe and efficient torque transmission in wet disk clutch systems requires high coefficients of friction. To achieve good controllability and high comfort, a positive slope of the coefficient of friction over sliding velocity is ensured by a reasonable formulation of the lubricant and choice of friction pairing. This results in low transmittable torque at very low sliding speeds. Thus, the occurrence of undesirable micro slip in dynamic operation modes must be considered for the design of safety-relevant clutch systems. This work presents a methodology for the holistic measurement of the friction behavior of wet disk clutches. It is suitable for numerous applications and supports a sound understanding of frictional properties in the range of sliding velocities occurring in brake shifts, through slip operation down to static torque transmission. Experimental determination of the holistic friction behavior is key to the development of optimized design guidelines for clutch systems.

3 - 3:30 pm - Break

3:30 - 4 pm
3834192: Slip Induced Solid Lubrication And Friction Reduction on Polymeric Substrates
Pallav Jani, Saad Khan, Lilian Hsiao, North Carolina State University, Raleigh, NC

Erucamide (ER), a fatty amide, is widely used in packaging films, hygiene fabrics as well as anti-biofouling elastomeric coatings to impart a slippery surface. ER is an amphiphilic friction modifier that preferentially adsorbs on or migrates to the contact surfaces to provide boundary lubrication. While ER migration in polymeric matrices is well understood, a comprehensive understanding of the slip properties under different operating conditions and materials encountered in the various applications and their impact on the friction reduction is lacking. Utilizing Bowden and Tabor's theory, we identify adhesion and load-controlled friction stress dissipation modes of ER boundary films on a range of polymer-polymer contacts under varying contact pressures and substrate moduli. We find that the friction reduction potential of ER is governed by the dissipation mode in operation, and this can have implications in terms of designing or identifying solid lubricants for a specific application.

4 - 4:30 pm
3832307: SLiPP+ Fiber Fabric: Flexible Ultra-low Friction and Wear Material by Mimicking Articular Cartilage
Hong Liu, Lanzhou Jiaotong University, Lanzhou, China

Articular cartilage is a thin layer of specialized connective tissue to provide a smooth, lubricated surface for low friction and facilitates the transmission of loads to the underlying subchondral bone. It shows a porous structure with chondrocytes and organized collagen fibrils. With an eye to heeding the lessons of nature, SLiPP (Self-lubrication Oil Impregnated porous polymer) material is combined with fiber fabric(Glass, Carbon) to produce a porous fibrous composite. Different polymers, such as Polyphenylene sulfide (PPS) and Phenolic resin, are successfully employed to fabric SLiPP materials to significantly decrease its cost. Moreover, fiber fabric such as Glass and Carbon is used to produce the SLiPP+ Glass/Carbon material. These SLiPP+ materials show outstanding tribological and mechanical properties while they also demonstrate the flexibility of fiber material, which can be widely used as the low friction material.

4:30 - 5 pm
3834379: Tribological Performance Evaluation and Enhancement of Bio-Lubricants by using Nano Additives and Ionic Liquids
Muhammad Bhutta, National University of Sciences & Technology (NUST), Islamabad, Capital, Pakistan

The environmental concerns associated with artificially formulated engine oils have forced a shift towards alternative lubricants. Base oil is produced by means of refining crude oil. In this research work 3 Bio-Lubricants, namely, Waste Cooking Oil, Cotton Saeed Oil and Ratanjot Oil have been prepared through Transesterification and their performance have been evaluated against Polyalphaolefin (PAO) using ASTM 4172 Four Ball Testing. PAOs are extensively used in automotive fluids as well as hydraulic, gear and bearing oils, working in extremely cold climates or hot applications. Bio-Lubricants performance has been enhanced by using a combination Ionic Liquid and Nano-Additives. Results show a decrease in coefficient of friction by increasing load in in case of using Bio-Lubricants. Ratanjot Oil has shown

comparative good performance when compared to PAO.

5 - 5:30 pm
3811472: Effect of Composition on Friction in Pine Loblloly Biomass Material
Maria Cinta Lorenzo Martin, Oyelayo Ajayi, George Fenske, Argonne National Laboratory, Argonne, IL; Jordan Klinger, Yidong Xia, INL, Idaho Falls, ID; Troy Semelsberger, Ricardo Navar, LANL, New Mexico, 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 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. In this paper, the effect of the composition of pine loblolly particles in terms of anatomical fraction of bark, needle, stem and whole on friction behavior was evaluated by the new test method.

5:30 - 6 pm – **Materials Tribology Business Meeting**

6E 102C

Tribochemistry III

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3807754: Encapsulation of Halogen-Free Boron-Based Ionic Liquids within Polymer Microshells
Filippo Mangolini, Jieming Yan, Kenechukwu Moneke, The University of Texas at Austin, Austin, TX

Even though ionic liquids (ILs) are attractive for lubrication purposes owing to their unique properties (e.g., high thermal stability) and good tribological properties, their limited solubility in hydrocarbon fluids has hindered their employment in oil formulations. Here, we develop two methodologies, based on mini-emulsion polymerization and solvent evaporation, for encapsulating halogen-free, boron-based ILs (hf-BILs) within polymer shells with the aim of introducing these ILs in base oils in a concentration that exceeds their solubility limit. Macroscale tribological tests performed using synthetic oil containing encapsulated hf-BILs together with ex situ X-ray photoelectron spectroscopy measurements indicate that the mechanically-induced rupture of the polymer shells at sliding interfaces results in the release of the encapsulated ILs, whose surface adsorption reduces friction and wear. The new methodology paves the way towards the implementation of ILs in lubricant formulations.

2 - 2:30 pm
3834000: Differences in ZDDP and Ionic Liquid Based Tribofilms
Florian Pape, Gerhard Poll, Leibniz University Hanover, Garbsen, Lower Saxony, Germany

To protect bearings against wear, additives in lubricants play an important role. ZDDP plays a very important role as an additive that forms a protective phosphate glass layer under load. A recent development is the use of phosphonium-based ionic liquids, which can also form phosphate-containing layers. In order to compare the layers formed, the formation of phosphate-containing layers under tribological contact was studied on samples of 100Cr6 rolling bearing steel in a rotating Anton Paar MCR with tribometer setup. In this test, the temperature was varied from 20°C to over 100°C. Finally, tests were also carried out on the FE8 test rig and the frictional torques and the layers formed were examined to draw conclusions about suitability.

2:30 - 3 pm
3833990: Mechanochemical Synergy Between Metal Oxide Nanocrystals and Surface-active Molecules at Lubricated Contacts: An In-situ Atomic Force Microscopy Study
Pranjal Nautiyal, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA; Robert Wiacek, Pixelligent Technologies LLC, Baltimore, MD

Metal oxide nanocrystals are promising lubricant additives for harsh environments because of their ability to form protective tribofilms under elevated stresses at sliding contacts. We examine the tribochemical interactions between nanocrystals and reactive sulfur/phosphorus-containing anti-wear additives used in lubricants. We used atomic force microscopy to interrogate the nanoscale growth kinetics of tribofilms in situ for oils formulated with mixtures of ZrO_2 nanocrystals and three distinct classes of S/P additives: zinc dialkyldithiophosphate, phosphoric acid ester, and phosphate ester. For all three, a combination of nanocrystals and molecular additives gave faster tribofilm growth rates compared to the individual constituents. We hypothesize this synergy stems from simultaneous activation of stress-assisted sintering of nanocrystals and the mechanochemical reaction of surface-active S/P molecules. Depth-resolved chemical characterization elucidates tribofilm growth mechanisms.

3 - 3:30 pm - Break

3:30 - 4 pm
3833100: Molecular Mechanisms of Tribochemical Reactions: Reactive Molecular Dynamics Simulations of Cyclic Organic Molecules
Fakhrul Hasan Bhuiyan, Ashlie Martini, University of California, Merced, Merced, CA; Yu-Sheng Li, Seong Kim, The Pennsylvania State University, State College, PA

Tribochemical reactions determine the performance of lubricant additives that form friction and wear-reducing tribofilms. However, mechanistic understanding of these reactions is still limited because the mechanochemical response of reactant species is a complex function of many variables. Here, we studied tribochemical reactions of simple cyclic organic molecules to isolate the effect of chemical structure on reaction yield and pathway. Results identified shear stress as the key driver of association reactions under tribological conditions. The trend of reaction yield in simulations was consistent with shear-driven polymerization yield in ball-on-flat sliding experiments. Analyzing the simulated oxidative chemisorption showed the effect of the chemical features of a reactant on its sensitivity to mechanochemical activation. Lastly, the most common association reaction pathways were identified, and a bond-by-bond analysis revealed the role of shear stress in mechanochemical activation.

4 - 4:30 pm
3811471: Understanding the Effect of Forces on Tribochemical Reaction Rates
Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

The effect of applied stress σ on the rates of tribochemical reactions is described using the Bell model, where the rate varies as $\exp(\sigma\Delta V^{\ddagger}/k_BT)$, where $\Delta V^{\ddagger}$ is the activation volume. Strategies for measuring reaction pathways are illustrated using the gas-phase lubrication of copper by dimethyl disulfide (DMDS) where the rate of reaction of on a Cu(100) single crystal substrate is measured by exerting the force using an atomic force microscopy tip. The stress-dependent rates of these model systems are accurately measured using an atomic force microscopy tip and this enables models to be developed that can accurately reproduce the experimental data and the strategies for accomplishing this will be discussed in detail.

4:30 - 5 pm
3833820: How are Chemical Reactions Activated in Tribological Interfaces?
Seong Kim, Pennsylvania State University, University Park, PA; Ashlie Martini, University of California, Merced, CA

In recent studies of tribochemistry, a “mechanically-assisted thermal-activation” model is often used for mechanistic understanding. Conceptually, this model assumes the existence of a thermally-activated process with high activation energy and that the net effect of mechanical energy delivered by interfacial shear action is to lower this thermal activation energy. From the semi-log plot of tribochemical reaction rate or yield versus applied load or shear stress, the so-called “activation volume” can be determined. The magnitude of this activation volume can be quantified readily in both experimental and computational studies [Tribology Letters (2021) 69:150]. However, the physical meaning of its magnitude is still debatable. In this talk, we’ll address the question if the activation energy of the hypothetical thermal

reaction can really be determined. If yes, how such reaction pathways can be identified? If not, what does the activation volume really mean?

6F 103A

Contact Mechanics II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3833768: Macro-scale Characterisation of the Contact Between Ski and Snow.
Kalle Kalliorinne, Andreas Almqvist, Luleå University of Technology, Luleå, Sweden

In cross-country skiing, the time difference between a race winner and the person coming second is typically very small. Since much of the energy is spent on overcoming friction, a relatively small decrease can have a significant impact on the race results. One step towards understanding the frictional mechanisms between the ski and the snow is to characterise the tribological interface. The present method involves an ANN (Artificial neural network) and BEM (Boundary element method) based contact mechanics simulation method. Using this approach, the contact-mechanical response between the ski and the snow counter surface can be characterised at several scales. The results suggest that different skis will be optimal for minimising the frictional forces under different snow conditions.

2 - 2:30 pm
3810729: Effects of Mechanical Stimulation on Reconstructed Skin at Different Levels of Maturity
Na Qiao, Ecole centrale de Lyon, Ecully, France

Skin aging has always been an issue of great concern. Therefore, it is reasonable to explore the differential effects of mechanical stimulation on young and old skin samples. In this study, reconstructed skin tissues (young and old) were subjected to two types of mechanical stimulations: the indentation using a dynamic bioreactor and the shear wave generated by air using the device developed by our group. In indentation stimulus, all reconstructed tissues were compressed in the X and Y axis, with older skin being more compressed than younger skin. Collagen content in the young group increased, whereas in the old group decreased. However, after shear wave stimulation, young and old skins are extended in both directions. In addition, the degree of deformation of old skin is higher than that of young skin. The change trends of collagen content were the same as that of indentation stimulation.

2:30 - 3 pm
3812991: Impact of Plantar Pressure Variations on the Ski-snow Contact During the Double Poling Cycle in Cross-country Skiing
Gustav Hindér, Kalle Kalliorinne, Joakim Sandberg, Andreas Almqvist, Hans-Christer Holmberg, Roland Larsson, Luleå University of Technology, Luleå, Sweden

Cross-country ski related sports offer the most medals during the Winter Olympics Games. Double poling (DP) is one of the most frequently used sub-techniques and has been studied thoroughly, but never in connection with numerical simulations of the ski-snow contact. The present study aims to investigate the impact of the variations in plantar pressure distribution (PPD) during the DP cycle on the ski-snow contact. PPD was recorded during the DP cycle and used as input data to a ski-snow contact mechanics solver. An incorporated artificial neural network predicts the shape of the ski, and the solver outputs the contact area and the pressure distribution of the ski-snow interface for a given PPD, throughout the DP cycle. The results show that the variations of the PPD have a significant impact on the ski-snow contact. Improving the DP technique and selecting appropriate skis for the given snow conditions are therefore key factors affecting the performance during the DP cycle.

3 - 3:30 pm - Break

3:30 - 4 pm
3810971: An Application of Hydrodynamic Lubrication Theory to Automotive Windscreen Wipers
Bradley Graham, James Knowles, Georgios Mavros, Loughborough University, Leicester, United Kingdom

The primary function of automotive windscreen wipers is to remove excess fluid and debris from automotive windscreens. Their effective operation is imperative for both the driver and ADAS systems to secure an unobstructed view of the road. Cleaning performance is strongly related to film thickness, but the latter also influences friction which in turn affects the wiper's vibration behaviour. There is hence a need to be able to predict the thickness of the residual film to assess any impacts it may have on the ADAS systems and drivers view. This work combines a dynamic model of the wiper with hydrodynamic lubrication theory to calculate the residual fluid film thickness and transient friction coefficients. The results of this work agree well with known friction coefficient ranges of lubricated automotive wipers, with the friction coefficients ranging $\mu \approx 0.1 \rightarrow 0.6$. Additionally, the estimated residual film thickness is found to be as thick as 10^(-5)m.

4 - 4:30 pm
3815309: Coupling Effect of Boundary Tribofilm and Hydrodynamic Film
Bao Jin, Yongyong He, Tsinghua University, Beijing, China

Reducing the friction and wear of dynamic interfaces has been a constant endeavor in the field of sustainability. Lubricants with two dimensional atomic materials are operative frameworks proposed as promising candidates. However, a quantitative characterization of the film formation and their coupling behaviors in the finite domain is lacking. Here, we report the coupling effect of tribofilms and hydrodynamic films regulated by typical representatives of two-dimensional material family (graphene, hBN, MoS_2, and WS_2). The anti-wear properties of the interfaces are attributed to the behavior of the tribofilm, whereas the anti-friction properties of the interfaces are attributed to the viscosity behavior of the hydrodynamic film. This study provides an understanding of the intrinsic coupling mechanism of a tribofilm and a hydrodynamic film and a possible strategy for the design of interfacial lubricating systems.

4:30 - 5 pm
3812168: Relationship Between Hertzian Contact Pressure and Raman Band Shift: the Case of an Alumina-glass Pair.
Karl Delbé, Jean-Yves Paris, Malik Yahiaoui, École Nationale d'Ingénieurs de Tarbes, Tarbes Cedex, France

Optimising the performance of materials requires the characterisation of residual stresses at the design stage. Raman spectroscopy offers access to these residual stresses at the micrometre scale. In this case, the relationship between the Raman mode shift and the pressure has to be known. We propose a new method that involves a Hertzian contact to obtain this relationship. Several Raman spectra are recorded into the contact between an alumina ball against a glass plane. Hertz's theory accurately describes the pressure profile as a function of position for elastic materials. We then deduce the correlation between the pressure profile and the spectral profile. We obtain results in good agreement with the literature for the Eg modes of alumina at 417 cm-1, at 2.07 cm-1/GPa. In the case of glass, we refine the measurement of the Q3 mode shift at 1096 cm-1 at a shift of 4.31 cm-1/GPa. This work opens up promising prospects for investigations in tribology.

5 - 5:30 pm
3834272: Flows Around a Contacting Asperity Modeled in the Micro and Nanometer Scales
Nicole Dorcy, Henry Soewardiman, Shuangbiao Liu, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

Asperity contacts commonly experience mixed lubrication conditions. It is important to understand how flow behaves when contacts reduce in size to the point that molecular forces become the dominant factor over bulk fluid dynamics. This work studies a fully flooded wedge in which a flat surface moves at a constant velocity relative to a fixed incline, focusing on the event in which the flow meets the corner of the wedge. Three scales are investigated by implementing three computational methods : computational fluid dynamics, elastohydrodynamic lubrication modeling via the Reynolds equation, and molecular dynamics simulations. The molecular dynamics approach aids mixed lubrication modeling by providing quantification of wall slip and details of the flows at asperity tips.

Tribotesting II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3810635: Friction and Lubrication with Dry Powdered Soaps Used in Wire Drawing
Marie-Louise Schlichting, Marc Masen, Janet Wong, Amir Kadiric, Imperial College London, London, United Kingdom; Stijn De Pauw, Hendrik Van Hoecke, Marc Derdeyn, NV Bekaert SA, Ingelmunster, Belgium

Wire drawing is a process to produce steel wires that are used in a wide range of applications, from car tires to champagne corks. During wire drawing, the wire is pulled through a series of conical dies to reduce its cross-sectional area. This process uses vast amounts of energy and involves complex tribological conditions including high pressures, high speeds and dry powdered soaps as lubricant. High frictional forces at the wire-die interface are not only detrimental to the quality of the wire but also increase the energy consumption. Improving the wire-drawing process could entail significant economic and environmental benefits. Yet, the tribological conditions in wire drawing are barely studied. This work uses laboratory tests to study the frictional behaviour of WC-steel contacts lubricated with dry powdered soaps, together with direct observations of the produced lubricating films. Presented results reveal new insights into the tribological interactions in the wire-die contact.

2 - 2:30 pm
3813312: Reducing Agglomeration of Gas-Phase Synthesized Graphene in Group IV PAO Base Oil to Enhance Anti-Wear Performace
Gordon Krauss, ; Albert Dato, Harvey Mudd College, Claremont, CA; Huijie Li, Harvey Mudd College, Brea, CA; Matthew Siniawski, Loyola Marymount University, Los Angeles, CA

Gas-Phase Synthesized Graphene or GSG has been shown to reduce wear during pin-on-disc testing when used in small concentrations as an anti-wear additive in Group IV PAO base oil. However, the GSG tends to agglomerate over time negatively impacting the anti-wear benefits. Prior studies examined demulsifier additives in conjunction with GSG with the exception that they would prevent the interference of small quantities of water which were believed to drive the agglomeration. This was not found to be effective. In this study, several dispersant additives were tested on PAO containing 0.1%wt. GSG, effectively reducing observed agglomeration of the GSG additive. This presentation describes image processing techniques applied to quantify agglomeration and POD wear test results for the oil with these additives. The data shows different effects of dispersant agents in terms of degree of agglomeration of GSG and on pin (ball) wear volume observed.

2:30 - 3 pm
3830800: Image Processing Test Development to Quantify Separation of Gas-Phase Synthesized Graphene from Base Oils and Predict Anti-Wear Effectiveness
Gordon Krauss, Albert Dato, Harvey Mudd College, Claremont, CA; Huijie Li, Harvey Mudd College, Brea, CA; Matthew Siniawski, Loyola Marymount University, Los Angeles, CA

The effectiveness of Gas-Phase Synthesized Graphene or GSG as an anti-wear additive decreases with time as it agglomerates and separates from the base oils. The factors controlling agglomeration are not fully understood, however an important aspect of studying this separation of GSG from the base oil and additives is quantification of the degree of agglomeration. This is complicated by the resulting dark color of the oil mixed with GSG and the size of the agglomerates. As a result, many traditional methods of quantification such as turbidity are ineffective. Micrographs of GSG containing oil with different concentrations of a dispersant additive are evaluated using a Python based image processing system. The size distribution of agglomerates and degree of separation is quantified and compared with pin-on-disc wear test data. This image processing tool may be effective in predicting the anti-wear behavior of GSG and possibly other nano-material containing lubricant additives.

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

3:30 - 4 pm
3833989: Tribological Properties of the Cold Spray Deposited Cermet Coatings
Subin Jose, Pradeep Menezes, Ashish Kasar, University of Nevada, Reno, Reno, NV

The successful development of the multi-component cermet system is often difficult to achieve via conventional manufacturing routes. The cold spray deposition process can deposit ceramic materials with deformable metals to provide better deposition efficiency and superior coating characteristics. In this study, a mixture of Copper (Cu), Silver (Ag), Alumina (Al_2O_3), and Amorphous Boron (B) is successfully cold spray deposited on an Aluminum substrate (Al6061) to achieve cermet coatings. The microstructural and tribological studies of these coatings were tested at different temperatures. The influence of particle size on the deposition performance of cold spray coating is also carefully investigated.

4 - 4:30 pm
3824194: Soot Wear in Heavy-duty Diesel Engine Oils
Thomas Kirkby, Tom Reddyhoff, Imperial College London, London, United Kingdom; Joshua Smith, Jacqueline Berryman, Infineum UK Ltd., Milton Hill, Abingdon, United Kingdom; Mark Fowell, Volvo Group Trucks Technology, Göteborg, Sweden

Soot levels in engine oils have increased due to longer service intervals and the drive to reduce emissions. This can lead to problematic wear of components especially in heavy-duty diesel engines. Lubricant and original equipment manufacturers (OEMs) use different tests and industry standards to quantify oil related durability of engines. However, our research using lab-based tribometer testing shows divergence in tribological performance between different types of test lubricant. Hence, we use test samples including field test engine oils, OEM dyno engine test oils, industry standard dyno test oils, and carbon black laden fresh oils. Certain oil samples seem to favour an oil degradation dominated wear mechanism while others favour a soot induced wear mechanism, even when apparent soot levels are equal. To demonstrate this and enhance understanding of soot interactions, we present High Frequency Reciprocating Rig friction and wear data correlated with measured lubricant properties.

4:30 - 5 pm
3831910: Accelerated Endurance Testing of Lubricants Using High-speed KRL Shear
Deepak Veeregowda, Fabio Alemanno, Ducom Instruments (EUROPE) B.V., Groningen, Netherlands; Debdutt Patro, Sravan Josyula, Ducom Instruments, Bangalore, India

The KRL shear stability test is one of the most severe test to evaluate permanent viscosity loss of lubricants due to the high EHD stresses and long duration shearing. In this report, we explore the effect of speed on shear stability of lubricants. A standalone KRL shear stability with inline friction torque measurement module was used. Reference fluid, RL209, was sheared for 20 h and 100 h at 1475 rpm. In addition, RL209, was also sheared at 2450 rpm for 20 hrs and 60 h. The coefficient of friction for all the tests were ~ 0.003 indicating an EHD lubrication regime for both standard and high speed tests. The 60 hour accelerated test showed 30% higher permanent viscosity loss compared to a 100 hour standard test even though both accumulated ~ 8.8 million cycles indicating a shear rate dependence. Overall, acceleration of the KRL test to higher speeds reduced the test time by 40% while still providing reliable permanent viscosity loss data for a reference oil.

5 - 5:30 pm
3831927: Twin Disc Evaluation of Wheel Flange Lubricants and Top of Rail Friction Modifiers
Deepak Veeregowda, Fabio Alemanno, Ducom Instruments (EUROPE) B.V., Groningen, Netherlands; Debdutt Patro, Sravan Josyula, Ducom Instruments, Bangalore, India

Wheel flange (WF) lubricants are designed to reduce friction to low levels (CoF < 0.15) whereas top of rail (ToR) friction modifiers are designed for intermediate friction (0.15 < CoF < 0.35) so as not to affect safety factors like braking distance. In this study we evaluate both WF and ToR lubricants as per the BS EN 15427-2 standard. A twin disc tribometer with independent speed control and crowned on flat disc configuration was used. Fixed quantity of lubricant was applied to the discs before the test and loads selected to achieve a contact stress of ~ 1 GPa. Testing for both WF and ToR lubricants were conducted at fixed % slip and duration to obtain friction and retentivity characteristics. To obtain the creepage curves, tests were conducted with different speeds of the discs with % slip varying between 0.1 and 25%. The results for both WF and TOR lubricants would be compared and factors affecting precision presented.

6H 103C

Commercial Marketing Forum VI

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm - **Placeholder**

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

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

6I 104A

Electric Vehicles VI

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3804553: The Effect of Esters on the Tribological Performance of Electric Vehicle (EV) Transmission Lubricants.
Johann Watson, Ardian Morina, Farnaz Motamen Salehi, Shahriar Kosarieh, University of Leeds, Leeds, West Yorkshire, United Kingdom; Gareth Moody, David Gillespie, Cargill, Snaith, East Yorkshire, United Kingdom

With the increased adoption of EVs and the new challenges they present, it is important to develop dedicated high performance EV lubricants. This study aims to experimentally evaluate the effectiveness of two esters as additives on the tribological performance of a fully formulated lubricant in conditions relevant to EVs. The effect of viscosity and polarity on traction has been studied using the MTM programmed for timed, Stribeck, and traction steps in the mixed and EHL regimes, simulating starting and running conditions in an EV transmission system. Wear has been analysed with optical profilometry and imaging. Tribofilms chemical structure has been analysed with the complimentary spectroscopy techniques Raman/SIMS/XPS. The results show improved stability and traction, with decreased wear when using esters. The tribological performance in relation to lubricant chemistry, testing conditions, and tribofilm structure will be discussed to explain the performance of esters in EV lubricants.

2 - 2:30 pm
3832111: Shelf-stable hBN-based Additive as Sulfur-free Anti-wear and Efficiency Booster for Low Viscosity E-driveline Fluid Applications
Peter Moore, Stephan Wieber, Dmitriy Shakhvorostov, Andreas Hees, Evonik Oil Additives, Horsham, PA

Solid lubricant materials have been documented in literature to have extraordinary tribological properties including very low friction in both boundary and mixed regime, anti-wear properties and pitting prevention. Additionally, solid lubricants such as hBN don’t contain sulfur or phosphorous and aren’t electrically conductive. Therefore, they fulfill crucial prerequisites for additives for use in EV applications with direct contact to copper and electrical componentry. A shelf-stable additive based on hBN has been developed as an anti-wear and efficiency booster in the low-speed high-torque regime that enables the formulation of sulfur-free and low viscosity e-drive formulations without compromise on copper corrosion and electrical conductivity. In this presentation performance data of the shelf-stable hBN-based additive in base oil and in formulated e-drive fluids will be presented compared to state-of-the art chemistry.

2:30 - 3 pm
3812753: Promising Aspects of Nanolubricants Use for EVs, a Critical Review
Waleed Ahmed Abdalglil Mustafa, Fabrice Dassenoy, LTDS/ECL, Ecully, France

Throughout the years, there has been steady progress in improving the performance of lubricants dedicated toward internal combustion engine (ICEs) vehicles. These improvements depend on utilizing functional additives that rely on tribo-chemical actions under the tribo-contact. However, new challenges are imposed on these conventional lubricants due to the rapid introduction of electric vehicles (EVs) to the market. Lubricants for EVs require standardized breakage voltage and conductivity properties in correlation to optimum tribological performance under high rpm, thermal management benchmarks, and corrosion resistance. Nanolubricants with nanoparticle additives can be more advantageous in tackling these obstacles when compared to the previous additives. This study critically reviews the latest studies on nanolubricants and how they meet EVs' operative needs. Findings from this work can be used as guidelines for applying nanolubricants in EVs and highlight research gaps in the theme.

3 - 3:30 pm - Break

3:30 - 4 pm
3833573: The Effect of Friction Modifiers Under Ultra Low Viscosity Engine Oils
Kenji Yamamoto, Kouichi Takano, Shinji Iino, ADEKA Corporation, Tokyo, Japan

Electrified ICE equipped vehicles are considered to be important to reduce the CO2 emission for coming decades. Since HEV are operated under low temperature more frequently, the effect of ultra-low viscosity engine oil for FEI would be more significant. Ultra low viscosity engine oils such as 0W-8 are introduced to Asian market in 2019 with JASO GLV-1, and these viscosity grades are under discussion for implementing ILSAC specification as well. The effect of friction modifiers with those ultra-low viscosity engine oils are significantly higher than with conventional viscosity grades because of their more frequent contact of surfaces. In this study, friction reduction performances of several friction modifiers with 0W-8 and 0W-20 formulated with GF-6 additive technology are evaluated under bench tests and motored engine friction tests. As a result of study, MoDTC exhibited significant friction reduction performance compared to other FM technologies especially with 0W-8 viscosity grade.

4 - 4:30 pm
3818318: The Response of Phosphonium Ionic Liquids (ILs) in Lubricating Greases with Respect to Various Tribological Contacts
William Stibbs, Eamonn Conrad, Derek Voice, Jean-Noel Tourvielle, Solvay, Niagara Falls, Ontario, Canada; Mehdi Fathi-Najafi, Jinxia Li, NYNAS, Nynashamn, Sweden

There are many challenges facing today’s electric vehicle (EV) manufacturers. When selecting EV lubricants and greases, companies often rely on iterative improvements to formulations designed for internal combustion engines. These lubrication systems present challenges and fail to substantially improve system efficiency. Vehicles running with conventional or modified lubricants in EV lose as much as 30% of efficiency due to losses directly associated with lubrication. This presentation demonstrates the responses of phosphonium ionic liquids as metal free/ashless additives to deliver AW/EP properties and thermal/electrical conductivity improvements, beneficial to this application with specific focus on lubricating greases.

4:30 - 5 pm
3815330: Influence of Additive/Ionic Liquid Concentration on the Electrical and Tribological Properties of an ATF
Alejandro García Tuero, Noelia Rivera Rellán, Alfonso Fernández González, José Luis Viesca Rodríguez, Antolín Estaeban Hernández Battez, University of Oviedo, Gijón, Asturias, Spain

Some electric vehicles have the electric motor inside the transmission housing, and in contact with the automatic transmission fluid (ATF). This ATF must fulfil special requirements, such as electrical compatibility, in order to avoid current leakage or possible discharges due a buildup of charges. This work studies how the concentration of additives, including a phosphonium-based ionic liquid (IL), can impact on the electrical (conductivity, resistivity, permittivity, dielectric dissipation factor, and breakdown voltage) and tribological properties of an ATF. The results show that friction and wear reduction occurs by adding the IL, and the electrical conductivity was increased, although it remained being dissipative. The dielectric properties dropped to around 1 kV in the IL-containing samples, so further measurements need to be made. The increase in the additive concentration improved tribological properties, and maintained the

electrical compatibility of the samples.

5 - 5:30 pm
3810591: Investigation on Gear and Bearing Protection with Lower Viscosity Lubricants for Electric Vehicles
Hiroyuki Tatsumi, Kazushige Matsubara, Yasuhito Nakahara, Daisuke Takekawa, Keiichi Narita, Idemitsu Kosan Co., Ltd., Ichihara-shi, Chiba, Japan

From the viewpoint of reducing environmental impact, electric vehicles are becoming increasingly popular. Lubricants are also required to have suitable performances for them, and we have previously reported that lower viscosity lubricants are effective for motor cooling performance. However, reducing the viscosity causes a decrease in the protection performance of mechanical components, so it is necessary to maintain and improve them with lubricant additives. In this study, we investigated in detail the protection performance of gears and bearings in lower viscosity lubricant oil for electric vehicles. As a result, it was found that optimizing the phosphorus-based extreme pressure agent can protect the friction surfaces and improve both anti-scuffing and anti-fatigue performances. In addition, the study of the effect of friction properties showed that lubricants with reduced friction coefficients tended to improve the gear fatigue life.

5:30 - 6 pm
3834101: Combining Durability and Efficiency for Electric Vehicle Transmission Fluids
Thorsten David, Castrol, Hamburg, Germany

Range anxiety remains one of the fundamental issues when convincing customers to switch from ICE-powered cars to electric vehicles and thus the efficiency of the drivetrain remains crucial. As efficiency benefits are mainly achieved through lower viscosity fluids it is important to put an emphasis on the durability of such EV Transmission Fluids. In this presentation it shall be demonstrated how EV Transmission Fluids can further improve the drivetrain efficiency whilst providing a high level of hardware protection. This includes durability testing on rigs as well as on transmission level.

6 - 6:30 pm - **Electric Vehicles and Engine and Drive Train Business Meeting**

6K 201A

Tribology of Biomaterials I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2:00 pm
3834223: In Situ Measurements of Syringe- Stoppers Contact Interfaces in Deep Cold Storage for Shipment and Storage of Biologics
Adam DeLong, Kylie Van Meter, Catherine Fidd, Brandon Krick, Florida State University, Tallahassee, FL; Nestor Rodriguez, Guilllaume Lehee, Grace Lin, Ludovic Gil, BD Medical-Pharmaceutical Systems, Pont de Claix, France

New drug technologies, like mRNA-based COVID vaccines, require cold storage, ranging from -40°C to < -80°C to ensure stability. During cold storage, prefilled syringes - comprised of a glass or polymer barrels, rubber stopper, and a lubricant - undergo thermal, mechanical, and physical changes that can affect the integrity of the seal. The focus of this study is to understand the effects of the freeze-thaw cycle experienced by these prefilled syringes. A custom cryostat has been created to thermally cycle prefilled syringes comprised of a glass and polymer syringes with a silicone oil lubricated butyl rubber stopper and filled with deionized water. An adaptive optics system was employed to measure the contact and position of the syringe barrel-lubricant-stopper interface in situ, as a function of temperature. The results show how cyclical freezing and thawing affect the complex behavior of the prefilled syringe system.

2 - 2:30 pm
3832949: Relationship Between Friction Coefficient and Permeability of Physically and Chemically Crosslinked Hydrogels
Nusrat Chowdhury, University of Illinois Urbana-Champaign, Urbana, IL

Hydrogel preserves their shape because of the crosslinking of polymer chains. The transport parameters, like permeability, are significantly influenced by the hydrogel concentration or pressure gradients that move the fluid through the polymer mesh. A flow pressure-controlled permeameter was developed to determine the permeability of hydrogels like pAAm, and PVA at various polymer concentrations and compare the permeability variation due to chemical and physical crosslinking. The sliding test would help understand the relationship between variation in permeability and friction coefficient. The aim is to find the relation between chemically and physically crosslinked hydrogel surface properties difference for varying concentrations and an attempt to link it to structural properties like permeability. In addition, these hydrogels were layered at these varying concentrations with a thickness of 0.2mm layers to see whether the contact mechanics change by structured layers affect friction.

2:30 - 3 pm
3810826: Sliding Friction Through Dislocation Glide in Shape Complementary Soft Interfaces
Jasreen Kaur, Lehigh University, Bethlehem, PA

Friction behaves differently at different scales, we study friction at the microscale using shape complementary polymeric structures. These bio-inspired structures are used to enhance friction selectivity which has applications ranging from rubber processing in tire manufacturing to object handling in soft robotics. PDMS is patterned with fibrillar microstructures to create the samples. A custom-built tribometer is used to measure friction between the two complementary samples. The two samples when brought in contact with each other spontaneously produce an array of dislocations depending on the misorientation and lattice spacing between the two samples. These dislocations are micron-scale replicas of dislocations produced on atomic scale. The two samples when subjected to relative sliding motion do so by the interfacial glide of dislocation structures. We also conduct finite element analyses to study how individual fibrils interact with each other.

3 - 3:30 pm - Break

3:30 - 4 pm
3832706: Dynamic Viscoelasticity Measurement of Hydrated Polymer Brush Film in Narrowing Shear Gap
Fengchang Lin, Shintaro Itoh, Kenji Fukuzawa, Naoki Azuma, Hedong Zhang, Nagoya University, Nagoya, Aichi, Japan

2-Methacryloyloxyethyl phosphorylcholine (MPC) polymer brush is known as a promising coating material for artificial joints due to its excellent lubricity. Friction coefficient of the MPC polymer brush film showed dependence on the shear gap. This is presumably because polymer brushes' mechanical properties (viscoelasticity) changed in different shear gap. However, it is difficult to measure viscoelasticity's shear gap dependence due to the very small film thickness. In previous studies, we have developed a fiber wobbling method (FWM), which can measure the shear gap dependence of dynamic shear viscoelasticity of nanometer-thick liquid films. In this study, we improved FWM and measured the dynamic shear viscoelasticity of hydrated MPC polymer brush film in a narrowing shear gap. The shear gap dependent dynamic shear viscoelasticity is considered to be resulted from a dehydrating process of the MPC polymer brush film during compression.

4 - 4:30 pm
3832182: The Role of Gradient Layer on Depth-dependent Adhesion in Hydrogel Using AFM Nano-indentation
Md Mahmudul Hasan, Alison Dunn, University of Illinois at Urbana-Champaign, Urbana, IL

The gradient softer outer layer, found in many biological systems or synthetic crosslinked hydrogels, plays a crucial role in their interaction with the countersurfaces. Our previous research showed that a gradient layer controls the contact mechanics at the submicron scale (the scale close to the layer thickness). We hypothesize that the water redistribution in loose chains will lead to adhesion behaviors that may also play a role in the biological function. In this study, we have measured the indentation adhesion of polyacrylamide (pAam) hydrogel at different indentation depths (from 50nm to 1200nm) using a colloidal probe Atomic Force Microscopy (AFM). Our results showed that at shallow indentation depth,

the adhesion is much stronger due to the easier chain pull out, driven by increased fluid-transport near the contact, from the softer gradient layer when the probe retracts. These results allow a more accurate understanding of depth-dependent adhesion in a gradient layer surface.

4:30 - 5 pm
3834053: Study of Biological Interfaces - Fron Cartilages to Personal Care Products
Kartik Pondicherry, Paul Staudinger, Julius Heinrich, Anton Paar GmbH, Graz, Austria; Mayank Warshney, Anton Paar India, Gurugram, India

In the recent years, there has been an increased interest in the study of biotribological interfaces as well as personal care products ranging from lipsticks to deodorants to condoms and personal lubricants. As each case is more or less unique, the test setup as well as the test methodology need to be adapted to cater to the real-life application. In the current work, the authors present case studies from various applications wherein focus is laid on the test and method development, including the challenges one faces in the process. In most of the studies, it was found that the choice of material used as a surrogate for the real-life biological surface place a very critical role. The authors also present a specific case from food tribology wherein a model was created to correlate tribological data with that obtained from a human sensory panel.

5 - 5:30 pm
3834204: Characterization of Mechanical Properties of Solvent-Cast 3D-Printed Peptide-polymer Scaffolds for Osteochondral Tissue Regeneration
Santiago Lazarte, Tomas Babuska, Catherine Fidd, Brandon Krick, Florida State University, Tallahassee, FL; Tyler French, Diana Hammerstone, John Tolbert, Andrew Kitson, ; Lesley Chow, Lehigh University, Bethlehem, PA

Interactions between cells and biomaterials are essential to regenerating functional tissue. Cells are affected by the chemical, mechanical and other biological cues from their microenvironment. These cues can be functionally embedded in 3d-printed scaffolds for directing mesenchymal stromal cell (MSC) differentiation to spatially direct tissue regeneration. In many tissue regeneration applications, including the osteo-chondral (bone-cartilage) system, the mechanical properties of the scaffold must be tuned to perform a physiological function (i.e. support load) while the new tissue is generated. This work explores how differences in the architectures of solvent-cast 3D printed peptide-polymer scaffolds as well as polymer conjugate concentration will affect their mechanical properties. In this work, we explore different metrics for characterizing the mechanical properties of the scaffolds, mainly through microindentation.

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

6L 201B

Surface Engineering II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3832278: Tribological and Tribo-corrosion Mechanisms of Al7075-T6 alloy by Ultrasonic Nanocrystal Surface Modification
Auezhan Amanov, Young-Sik Pyun, Sun Moon University, Asan, Republic of Korea; Domenico Furfari, Airbus Operations GmbH, Hamburg, Germany

It has been a great challenge to employ effective, simple, and economical surface engineering technologies to control the tribological properties of materials. The objective of this study is to investigate the effect of ultrasonic nanocrystal surface modification (UNSM) technology on tribological and also tribo-corrosion properties of Al 7075-T6 alloy. Microstructural evolution together with surface properties (roughness, hardness, residual stress, XRD pattern, EBSD) before and after UNSM treatment were discussed. Both tribological and tribo-corrosion properties of the UNSM-treated Al 7075-T6 alloy were better than the untreated one. Wear and corrosion mechanisms were discussed to shed light on the effectiveness of UNSM technology. It is expected that the aerospace industry may be benefited from the

features of UNSM technology, such as an increase in strength, residual stress, wear resistance, and corrosion resistance of Al 7075-T6 alloy.

2 - 2:30 pm
3809868: A Multiscale Modeling System for Surface Texturing a Radial Pump Plunger to Improve Tribological Performance
Henry Soewardiman, David Pickins, Yip-Wah Chung, Q. Jane Wang, Northwestern University, Evanston, IL; Blake Johnson, Nikhil Murthy, Stephen Berkebile, US Army DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

The plunger-bore interface of a fuel pump is critical for the efficient delivery of high-pressure fuel. This interface has a clearance of at most a few microns and is subjected to misaligned plunger motion, prompting scuffing under marginal lubrication conditions. Proper textures on these components may help enhance lubrication, decrease friction, and control lubricant leakage, thus increasing the pump's lifespan. Presented here is a multiscale modeling system of the pump, which couples system-scale simulations and an interface analysis, aiming to develop a robust and efficient plunger-bore interface. The system models identify structural and fluid conditions of the full fuel pump, while the interface model explores critical rubbing conditions and the effects of surface texturing on the interface performance. A surface design scheme is proposed, promising textures are selected, and their performances are evaluated.

2:30 - 3 pm
3815718: Interaction Between Lubricants and Surface Texture Under EHL Conditions
Mohd Syafiq Abd Aziz, Tom Reddyhoff, Jie Zhang, Imperial College London, London, England, United Kingdom; Mohd Syafiq Abd Aziz, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia

Applying surface texture to the surfaces of sliding components can be a powerful way to improve tribological performance, for instance reducing friction or wear. As a result there has been considerable research effort expended on textured surface, often focusing on the effect of geometric texture parameters. However, there have been far fewer studies into the effect of lubricant composition on surface texture performance. To address this, we present recent research in which the friction reducing performance of surface textured components are compared to the of a non-texture reference for a range of commercial and model lubricant formulations. As well as showing how lubricants can be optimised for texture contact, results show how specific additives interact with texture features and thus shed light on the mechanisms that are occurring.

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

3:30 - 4 pm
3814721: Adjustment of the Properties of Frictional Hysteresis Loops in Metallic Contacts by Surface Engineering
Mirco Jonkeren, Katharina Brinkmann, Matthias Wangenheim, Leibniz University of Hannover, Garbsen, Germany; Paolo Giudici, ML ENGRAVING srl, Onore, Italy; Anastasia Dianova, Marta Brizuela, TECNALIA, Basque Research and Technology Alliance (BRTA), Donostia-San Sebastián, Spain

Frictional contacts with cyclic relative motion exhibit frictional hysteresis loops if the frictional force is plotted against the relative displacement. The area within the hysteresis loop is a measure of the frictional energy dissipated per oscillation period. It is utilized as frictional damping in metallic contacts e.g. in turbine blade applications to handle critical vibration phenomena. In this work we investigate the possibility of modifying the shape of the hysteresis loop by laser surface texturing and coating of the metallic contact partners. The goal is to adjust static and dynamic coefficients of friction separately and to modify the velocity dependence of the dynamic coefficient of friction. The results of an experimental campaign with 20 different surface textures and coatings with respect to cyclic relative motion are presented, showing an increase of the frictional energy dissipation of up to 35%.

4 - 4:30 pm
3813005: Combining Concentrated Polymer Brushes and Laser Surface Texturing to Achieve Durable Superlubricity
Sorin-Cristian Vladescu, King's College London, London, United Kingdom; Chiharu Tadokoro, Takuo Nagamine, Saitama University, Saitama, Sakura, Japan; Mayu Miyazaki, Ken Nakano, Yokohama National University, Yokohama, Japan; Tom Reddyhoff, Imperial College London, London, United Kingdom; Shinya Sasaki, Tokyo University of Science, Tokyo, Japan; Yoshinobu Tsujii, Kyoto University,

Kyoto, Japan

Concentrated polymer brushes (CPBs) have recently attracted significant scientific attention due to their ability to achieve superlubricity (i.e., coefficients of friction below 0.01), promising a new means of reducing energy losses in mechanical systems. However, their durability remains a limiting factor. To study CPB wear mechanisms, we grafted CPBs atop a novel picosecond-laser-etched matrix of micron-sized dimples. We employed a custom-built optical test apparatus to investigate the inter-dependencies between CPBs and laser-produced surface texture (LST), assessing for the first time the friction, film thickness, and wear behavior in situ and simultaneously. At low sliding speeds, combined CPB–LST reduces the friction coefficient to 0.0006, while increasing CPB durability by up to 34%. The imaging results shed light on mechanisms of lateral support offered by micro-features and failure propagation impacting CPB wear resistance.

4:30 - 5 pm
3812590: Increasing Tire Tread Ice Traction by Superhydrophobic Laser Texture
Matthias Wangenheim, Michael Hindemith, Leibniz University of Hannover, Hannover, Germany

The lack of traction on ice, in particular on glaze ice is one of the main causes of dangerous driving situations and traffic accidents on winterly roads. While on dry, rough surfaces the most relevant rubber friction mechanisms hysteresis (deformation) friction and adhesion dominate the friction contact these mechanisms are impeded on ice close to the melting point. On the one hand these ice surfaces tend to be relatively smooth and on the other hand they are covered by a liquid water level of a few up to many molecule layers causing coefficients of friction lower than 0.1. In the course of this work we textured a winter tire tread surface with a superhydrophobic pattern by picosecond laser ablation. Our hypothesis was that the liquid water layer would be repelled from the contact by the superhydrophobic rubber surface resulting in a quasi-dry rubber-ice contact. Experiments resulted in a coefficient of friction of up to 0.8 which is a very promising success of this approach.

5 - 5:30 pm - **Surface Engineering Business Meeting**

6M 202A

Grease II

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3814128: Shear Properties of Various Greases in Micrometer-Order Gap
Hanul Chun, Tomoko Hirayama, Naoki Yamashita, Kyoto University, Kyoto-shi, Nishikyo-ku, Kyoto-fu, Japan

Grease lubrication is widely applied to sliding parts under severe condition in bearings that support EV motor shafts and wind turbine shafts, for examples. Therefore, understanding the behavior of grease in micrometer-order gap is imperative to improve the lubrication performance more efficiently. However, the researches on grease in micrometer-order gap are still few because a typical rheometer can only provide shear properties of samples in submillimeter-order gap. In this study, the shear properties of several kinds of greases with various thickener structures inside were measured by the original viscometer, which is able to measure the shear properties with maintaining a micrometer-order gap supported by an aerostatic bearing.

2 - 2:30 pm
3833718: Impact of Thermo-Mechanical Aging of Grease During Churning on Grease Properties and Life
Sathwik Chatra K R, SKF, Houten, Netherlands; Jude Osara, University of Twente, Enschede, Enschede, Netherlands; Piet Lugt, SKF Research and Technology Development, Houten, Netherlands

In grease-lubricated rolling bearings, grease ages during the churning phase due to high shear and temperature caused by macroscopic flow. In this study, we explore two different models to quantify the

energy dissipated in the grease during churning by utilizing the temperature profile. One model estimates the imposed temperature-corrected energy density and the other estimates the heat transfer entropy density. Both models show good correlations with the measured degradation parameter yield stress and with measured grease life.

2:30 - 3 pm
3815401: Effects of Shear Aging on Oil-separation Properties of Lubricating Greases
Femke Hogenberk, Jude Osara, Dirk Van Den Ende, University of Twente, Enschede, Overijssel, Netherlands; Piet Lugt, SKF, Houten, Utrecht, Netherlands

Controlled release of base oil from lubricating greases, referred to as bleeding, is fundamental to the lubrication of rolling bearings. Over time, the thickener structure of the grease will degrade, while the oil content is reduced due to the bleeding. Consequently, the bleed rate, i.e., the rate at which oil is released, may change. The effect of aging on bleed rate is studied for five types of greases. Grease samples are subjected to shear aging using a grease worker, equipped with a load cell to capture the imposed energy density. No significant change in bleed rate is observed for the studied range of imposed energy densities, even though softening of the grease after aging is observed. A permeability model is used to explain these observations. Moreover, a comparison with data from rolling bearing tests shows that higher imposed energy densities are required to obtain significant changes in bleed rate.

3 - 3:30 pm - Break

3:30 - 4 pm
3823866: Bevel Gear Grease - a Sustainability Case Study.
Johan Leckner, Axel Christiernsson Int. AB, Nol, Sweden

This paper summarizes two recent studies which together highlight both the importance and the complexity of including in-service performance when assessing the environmental footprint of a lubricant. The first study focuses on the development of a new grease for nutrunner bevel gears. Here we show that the durability and energy efficiency of both the gear and the grease can be significantly enhanced when modern grease formulation solutions are applied. The second study compares the grease formulations using two different LCA approaches that highlight the importance of a more holistic, cradle-to-grave approach, incorporating data from bench and field tests, versus a more limited cradle-to-gate approach. In essence, the core message of this paper is that the performance of lubricated machine elements can have a very significant impact on sustainability assessments and that a grease providing better performance can, even if it requires more resources to produce, be the superior solution.

4 - 4:30 pm
3830847: Benchtop Tribological Characterization of Electric Motor Greases for Hybrid Bearings
Abhishek Kumar, Jose Vasquez-Reyes, Ashlie Martini, University of California Merced, Merced, CA; Christina Cheung, Thomas Murray, Anoop Kumar, Chevron Corporation, Richmond, CA

Electric motors (EM) can require that greases operate in demanding conditions, such as high temperature, and with non-ferrous materials. Evaluating grease formulations for these conditions therefore requires modifications of standard benchtop tests. This study involved tribological characterization of EM greases using four-ball and ball-on-disk tests with materials and conditions modified to better reflect current and emerging applications, including electric vehicles. The hybrid bearing configuration was mimicked by testing with silicon nitride and 52100 steel tribopairs. The market-available and new grease formulations studied had mineral or synthetic base oil, and polyurea or lithium thickener. The friction traces, wear response, energy dissipation, and estimated film thickness were analyzed to enable comparison of the tribological properties of these greases specifically for EM applications.

4:30 - 5 pm – Open Slot

5 - 5:30 pm - Grease Business Meeting

Wear I

Session Chair: TBD
Session Vice Chair: TBD

1:30 - 2 pm
3803642: Adjusting for Running-in: Extension of the Archard Wear Equation
Michael Varenberg, John Crane, Inc., Morton Grove, IL

The Archard equation is widely employed to predict wear in engineering practice, but its use is usually restricted to the cases of sufficiently long wear duration, so the transient running-in behavior can be neglected with respect to the steady-state wear. To address this problem, here the steady state wear equation is extended into the running-in regime based on the bearing ratio curve representing the initial surface topography. This approach is verified using a unidirectional dry sliding of steel against PTFE and the extended equation is shown to be able to predict service life or to obtain wear coefficients regardless of the test duration if the initial surface topography is defined. It is also found that the bearing ratio curve can be efficiently approximated using the logistic function calibrated by four standard surface roughness parameters. This approximation proves to be more accurate than the widely used Gaussian normal distribution function.

2 - 2:30 pm
3803822: An Advanced Numerical Model for Wear
Jamal Choudhry, Andreas Almqvist, Roland Larsson, Luleå University of Technology, Luleå, Sweden

Wear is a complex phenomenon that may depend on several factors such as, surface roughness, material properties and operating conditions. Classical wear laws, such as Archard's wear law, rely on using a single wear coefficient to predict wear. This may raise issues since the wear coefficient may not be constant but depend on the many complexities that were just mentioned. For this reason, there is a need to develop a numerical wear model that accounts for all these complexities and accurately predict wear. In present work, an advanced numerical method is used to predict the wear of interacting asperities on the micro-scale contact region of the surfaces.
The numerical model uses an advanced particle method to discretise the asperities and predict the large plastic deformations up to fracture. It is shown that this advanced model can be used to calibrate and obtain a more sophisticated wear coefficient in Archard's wear law, used in classical BEM calculations.

2:30 - 3 pm
3806376: Wear Behavior of Metallic Part Repaired by an Additive Manufacturing Process
Théo Zurcher, Eric Charkaluk, Laboratoire de Mécanique des Solides-Ecole Polytechnique, Palaiseau, France; Vincent Fridrici, Bruno Berthel, Laboratoire de Tribologie et Dynamique des Systèmes-Ecole Centrale de Lyon, Lyon, France; Benoit Dodin, Société Nationale des Chemins de fer Français, Saint-Denis, France

Additive manufacturing processes and more specifically the Laser Metal Deposition process belong to a new family of processes which are standing out in the past 20 years and offer the possibility to repair worn out metallic parts. This study investigates the wear behavior of metallic parts repaired by this innovative process. Samples were built by using different scanning strategies with different materials (Inconel718 and 316L SS). Regardless of the deposited material, the scanning strategy and the sliding direction do not impact tribological properties. However, tribological parameters (normal force, frequency, temperature...) have a great impact on the observed wear mechanisms. Wear tracks, counter-body faces and wear debris were studied trough several characterization methods. Effects on friction and wear volume were also analyzed and discussed. The results were compared to results for conventionally manufactured materials: the competitiveness of this LMD process is highlighted.

3 - 3:30 pm – **Break**

3:30 - 4 pm
3807117: Tribology Analysis of Additive Manufactured, Nickel-Based Super Alloys
Khosro Shirvani, SUNY Farmingdale, Farmingdale, NY

Nickel-based super alloys such as Inconel 718 (INC 718) can be manufactured through traditional and additive manufacturing (AM) methods. This study compares the tribological characteristics of traditionally manufactured INC 718 to additive manufactured INC 718. This is a significant study as INC 718 is an extremely hard material which results in a high rate of tool wear and expensive tooling parts. Developing an additive manufacturing method for INC 718 will eliminate the machining step, allowing the material to be built directly into the desired part and shape. Wear, weight loss and coefficient of friction were all measured with a pin-on-disc wear tester. By testing various loads, distance and speeds on the pin-on-disc tribometer, we were able to have a comprehensive understanding of mechanical and wear properties of INC 718 manufactured through two different methods leading to a better understanding of the benefits and limitations of the new methods of manufacturing.

4 - 4:30 pm
3810351: Effects of Temperature and Lubricant on Reciprocating Sliding Wear Behavior of HNBR/FKM
Zhangyu Qiao, China University of Petroleum, Beijing, China

As one of the crucial part of downhole tools, the sealing rubber is vulnerable to wear and failure resulting from the harsh working condition. However, the tribological properties of rubber under this downhole sever condition have not been fully studied. Therefore, the tribotest of HNBR/FKM at 100 under different lubrication conditions and temperature was conducted. Wear volumes and worn surface morphology were analyzed in detail. The results show that under non-lubricated environment, the wear volume of HNBR shows a great increase at 100 degree celsius, while the wear volume of FKM presents a decrease trend. The Salamach stripes were found on the wear surface of HNBR, which is a typical feature of abrasive wear. The findings demonstrated the fluorine rubber has excellent wear resistacne under downhole harsh environment.

4:30 - 5 pm
3812212: Computational Modelling of the Antiwear Effect of Zinc Dialkyldithiophosphate Tribofilms in Mixed Mode Lubricated Contact
Robert Anderluh, Hrvoje Jasak, University of Cambridge, Cambridge, Cambridgeshire, United Kingdom

Zinc dialkyldithiophosphate (ZDDP) is still the most commonly used antiwear additive in the field of lubrication. Recent experimental discoveries have improved our understanding of the mechanisms through which ZDDP-induced tribofilms form and protect surfaces of components exposed to sliding contact. The aim of this study is to review the current understanding of those mechanisms and to incorporate that knowledge into a computational model capable of simulating rough-surface elastohydrodynamic lubrication (EHL) contact mechanics problems. The model is developed in OpenFOAM, an open-source code library, most often used in the field of computational fluid dynamics, but capable of tackling many general continuum mechanics problems. Results of the novel model are finally compared to existing experimental measurements.

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