stle
Annual Meeting & Exhibition

May 17 - 20, 2021

Preliminary Program
As of March 2, 2021

2021 Virtual STLE Annual Meeting
All Times Eastern Daylight Time
Preliminary as of 3/02/2021

Monday, May 17, 2021

8:30 am – 10 am – Opening Session and Keynote Address

10 am – 10:30 am – Break & Special Programming

Technical Sessions – 10:30 am - 1 pm
1A – Seals I
1B – Environmentally Friendly Fluids I
1C – Fluid Fill Bearings I
1D – Gears I
1E – Metalworking Fluids I
1F – Nanotribology I
1G – Power Generation and Wind Turbine Tribology I
1H – Commercial Marketing Forum I
1I – Synthetic Lubricants and Hydraulics I

1 pm – 2 pm - Lunch and Luncheon Program TBD

Commercial Exhibits and Student Posters -
10 am – 4 pm

Technical Sessions - 2 pm – 6 pm
2A – Engine & Drive Train Session on Electric Vehicles I
2B – Environmentally Friendly Fluids II
2C –
2D – Materials Tribology I
2E – Metalworking Fluids II
2F – Nanotribology II
2G – Power Generation and Wind Turbine Tribology II
2H –
2I – Commercial Marketing Forum II
2J - Synthetic Lubricants and Hydraulics II

3 – 4 pm - Break and Exhibitor Appreciation Hour

Welcome Reception
6:30 pm– 8 pm

Tuesday, May 18, 2021

8:30 – 10 am – Keynote Address

10 – 10:30 am – Break & Special Programming

Commercial Exhibits and Student Posters -
10 am – 3:30 pm

Technical Sessions – 10:30 am – 1 pm
3A – Condition Monitoring I
3B – Lab to Field: Bridging the Gap Between Bench and Engine: Engine & Drive Train & Lube Fundamentals Joint Session I
3C – Nonferrous Metals I
3D – Materials Tribology II
3E – Metalworking Fluids III
3F – Nanotribology III
3G – Rolling Element Bearing I
3H – Lubrication Fundamentals I: Non-tribological Oil Properties
3I – Commercial Marketing Forum III

1 – 2 pm - Lunch and Luncheon Program TBD

Technical Sessions - 2 pm – 6 pm
4A – Condition Monitoring II
4B – Additive Manufacturing I
4C – Nonferrous Metals II
4D – Materials Tribology III
4E – Metalworking Fluids IV
4F – Nanotribology IV
4G – Rolling Element Bearings II
4H – 2D Materials + Superlubricity: Material Tribology & Nanotribology Joint Session I
4I – Commercial Marketing Forum IV

3 – 3:30 pm - Break & Special Programming

Wednesday, May 19, 2021

8:30 – 10 am – Keynote Address

10 – 10:30 am – Break & Special Programming

Commercial Exhibits and Student Posters -
10 am – 3:30 pm

Technical Sessions – 10:30 am – 1 pm
5A – Biotribology I
5B – 2D Materials + Superlubricity: Material Tribology & Nanotribology Joint Session II
5C – Engine & Drive Train I
5D – Lubrication Fundamentals II: Oil Additives I
5E – Wear I
5F – Tribotesting I
5G – Rolling Element Bearings III
5H – Nonferrous Metals III
5I – Commercial Marketing Forum V

1 – 2pm - Lunch and Luncheon Program TBD

Technical Sessions - 2 pm - 6 pm
6A – Biotribology II
6B – 2D Materials + Superlubricity: Material Tribology & Nanotribology Joint Session II
6C – Engine & Drive Train II
6D – Lubrication Fundamentals III: Oil Additives II
6E – Wear II
6F – Tribotesting II
6G – Rolling Element Bearings IV

6H – Tribochemistry – Materials Tribology & Nanotribology
Joint Session I
6I – Grease I

3 – 3:30 pm - Break and Special Programming

Thursday, May 20, 2021

8:30 – 10 am – Keynote Address

10 – 10:30 am – Break & Special Programming

Commercial Exhibits and Student Posters -
10 am – 3:30 pm

Technical Sessions – 10:30 am – 1 pm
7A - Grease II
7B – Contact Mechanics I
7C – Engine & Drive Train III
7D – Lubrication Fundamentals IV: EHL
7E – Tribochemistry – Materials Tribology & Nanotribology
Joint Session II
7F – Tribotesting III
7G – Rolling Element Bearings V
7H – Surface Engineering I
7I – Gears I

1 – 2 pm Lunch and Luncheon Program

Technical Sessions - 2 pm- 6:00 pm
8A – Grease III
8B – Contact Mechanics II
8C - Engine & Drive Train IV
8D – Lubrication Fundamentals V: Viscosity
8E –Tribochemistry – Materials Tribology & Nanotribology
Joint Session III
8F – Additive Manufacturing II
8G – Rolling Element Bearings VI
8H –Surface Engineering II
8I – Gears II

3 – 3:30pm - Break

Seals I

Session Chair: Bo Tan, University of Kentucky, Lexington, KY
Session Vice Chair: Khalid Malik, Ontario Power Generation, Ajax, Ontario, Canada

10:30 - 11 am
3492008: On Surface Energy and Friction of Hydraulic Rod Seals
Oliver Feuchtmüller, Frank Bauer, Lothar Hörl, Universitat Stuttgart, Stuttgart, Germany

The lubrication condition in the sealing gap of rod seals are of great interest due to its influence on friction, wear and leakage. At outstroke, the fluid film thickness in the sealing gap is in the submicron to nanometer-scale. Wetting behavior at the solid-liquid interface and surface properties influence the tribological behavior in these thin lubrication gaps. In this work, the influence of sealing materials on friction is analyzed experimentally. Sealing materials based on different polymers and different compounds are used. The surface energy of the polymers is determined using sessile drop contact angle measurements. Friction of different rod seals is measured as a function of rod speed and viscosity of the hydraulic oil. The influence of wetting properties and surface energy of the sealing materials on friction is presented.

11 - 11:30 am
3499704: Advanced Sealing Concepts for Redox Flow Batteries
Detlef Jannes, Lothar Hörl, Frank Bauer, University of Stuttgart, Stuttgart, Germany

A redox flow battery (RFB) is a secondary battery with flat cell plates stacked on top of each other. These batteries have great advantages as an energy storage element in terms of flexibility, response, and safety concerns. RFB are potential most suitable for large storage applications as the energy is saved in big electrolyte containers outside of the battery. For large stationary energy storage applications, such as harvesting green energy on Terawatt level, redox flow batteries are a better choice. Aside materials selection, nearly every redox flow battery has a fundamental design with common components. Sealing elements are in between every cell component to avoid leakage of the corrosive electrolyte. Most common sealing elements consist of conventional elastomer profiled rings or gaskets. Aside conventional sealing methods, new advanced sealing methods are introduced for 3 different RFB systems: Hydrogen-Bromine (HBr), Zinc-Air (ZnA) and Organic.

11:30 am - 12 pm
3476014: A Method of Direct Measurement of Mechanical Seal Wear In Pumps and Compressors
Mark Slivinski, Carbide Derivative Technologies, Tucson, AZ

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

12 - 12:30 pm
3497118: Computational Fluid Dynamics Analysis and Experimental Results for the Dynamic Performance of Two Long Smooth Surface Annular Seals Operating with a Liquid in Air Mixture
Jing Yang, Dung Tran, Luis San Andres, Texas A&M University College Station, College Station, TX

Centrifugal compressors in subsea oil production handle wet gases and must operate reliably for many years. Annular seals ensure compressor performance though may affect the system rotordynamic stability. A program produced leakage and force coefficients for balance drum seals supplied with a two-phase flow having a liquid volume fraction reaching 8%, an inlet pressure of 62 bar, a discharge pressure of 31 bar, and a 10 krpm shaft speed. The liquid is a 5 cSt silicone oil that mixes with air. The program included two smooth surface seals: one with diameter D = 89 mm (length L/D = 0.65) and clearance C_r = 0.002 D; and (2) another having D = 115 mm (L/D = 0.75) and C_r = 0.0017 D. The first seal shows its direct stiffness reduces as the liquid content increases, while the other seal shows the opposite. A computational fluid dynamics model and its predictions, the thrust of this paper, unveil the rationale for the distinct dynamic performance characteristics between the two seals.

12:30 - 1 pm - **Seals Business Meeting**

1B Virtual Meeting Room 2

Environmentally Friendly Fluids I

Session Chair: Brajendra Sharma, University of Illinois, Champaign, IL
Session Vice Chair: Selim Erhan, Oil Process Industries, Decatur, IL

10:30 - 11 am
3492300: Global Fluid Trends
Edward Jones, Hangsterfer's Labs. Inc., Mantua, NJ

Environmentally Friendly Fluids are sometimes simple and sometimes very complex formulas and technology. There exist several internationally and industry wide recognized governmental and independent agencies that greatly influence trends in acceptable technology. These agencies and their guidelines will be reviewed in detail along with reasons why certain ingredients have or will become obsolete. The utilization of sustainable lubricant ingredients will also be reviewed and steps that need to be taken now. The presentation will contain information based on USA, Canada, EU, UK, Japan and China governments, and industrial sectors that include the Aerospace, Automotive, Electronic, and Medical sectors. The impact on manufacturing processes, service and maintenance will also be discussed.

11 - 11:30 am
3472961: EU Ecolabel for Lubricants – European Approach to Evaluate EALs
Salvatore Rea, Thomas Klein, Lanxess Solutions US, Inc., Shelton, CT

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

11:30 am - 12 pm
3499043: Sustainability in the Lubricants Industry
Inga Herrmann, VSI Verband Schmierstoff-Industrie e.V., Hamburg, Germany

Sustainability is a key point on the agenda of our lubes industry for the presence and the upcoming decades and strikes at the very core of the lubricants industry. Without a sustainable business model our customers will leave us, the raw materials used in our lubricants would diminish and the resources expended in the manufacture of our products, like energy would also expire. In addition the European Green deal is forcing far greater speed to fix sustainability in economic activity. Therefore developing specific measures that are meaningful, measurable, and transparent and are themselves sustainable is of utmost importance to lubricants producers, their suppliers and distributors. The German VSI is currently working on a sustainability concept for the lubricants industry which will adopt those facts to evaluate a licensed and transparent system.

12 - 12:30 pm
3480821: New Hydrolytic Stability Testing on Biobased Lubricants and Base Fluids
Mark Miller, Biosynthetic Technologies, Indianapolis, IN

There is more and more interest in biobased and biodegradable lubricants in and around the marine environment. The hydrolytic instability of vegetable and ester base oils is well known. Conventional hydrolytic tests do not demonstrate "real world" performance adequately. A new test has been developed that closely simulates the hydrolytic performance of lubricants and base oils in the presence of water and heat. This paper will describe test methodology and demonstrate the results of various biobased lubricants and base oils. The results of the testing is reviewed and supported with the original test data, and compared to standard industry hydrolytic tests.

12:30 - 1 pm
3500611: Bio-Based and Biodegradable Base Oils for Environmentally Acceptable Lubricants (EALs)
Zach Hunt, Tetramer Technologies LLC, Pendleton, SC

This presentation will provide performance data for a new class of high-performance synthetic esters with enhanced stability that are optimally suited as base oils for environmentally acceptable lubricants (EAL). These simple ester base oils are biobased and biodegradable with low pour points, high thermo-oxidative stability, high viscosity indices, and high shear stability. These novel synthetic esters can serve as an EAL base oil for a range of applications including turbines, hydraulic fluids, transmission and gear oils, metalworking fluids, and 2-cycle oils. The surprising properties and underlying molecular architectures of novel synthetic esters will be reviewed, as well as the performance of fully formulated EALs in various applications, including hydroelectric turbine lubricants.

1C Virtual Meeting Room 3

Fluid Film Bearings I

Session Chair: Bruce Fabijonas, Kingsbury, Inc., Philadelphia, PA

10:30 - 11 am
3559597: Influence of Journal Surface Scratch Characteristics on the Performance of a Two-lobe Journal Bearing - Comparison Between Experimental Data and Numerical Results
Anh Vo, Jean Bouyer, Michel Fillon, Universite de Poitiers, Poitiers, Poitou-Charentes, France

Scratches on the shaft surface influence the performance of journal bearings. The effects are already assessed by experiments, this work develops a numerical thermohydrodynamic (THD) code to simulate

the effects. Experimental tests were conducted using the Pprime Institute bearing test rig. The performance of the same two-lobe journal bearing as used in a previous study, lubricated with ISO VG 46 oil, was evaluated. Scratches that vary in depths, widths, positions, and density, are evaluated. The major consequence of the presence of the scratches is a lowest load carrying capacity of the journal bearing: the shaft eccentricity increases, leading to a sensible reduction of the minimum film thickness. Both the pressure and temperature fields are also locally affected by the geometry modification of the lubricant film. THD solutions with various shaft speeds and applied loads, were studied. Results show a good agreement between simulations and experiments for pressure and temperature.

11 - 11:30 am
3519704: Effect of Pad Fixations on the Tribological Performance of Parallel-Surface Fixed-pad Thrust Bearings.
Anastassios Charitopoulos, Michel Fillon, Institut Pprime, CNRS – University of Poitiers –ISAE- ENSMA, Chasseneuil, Nouvelle Aquitain, France; Christos Papadopoulos, Ethniko Metsobio Polytechneio, Zografou, Attica, Greece

It is well established in the literature that one of the main pressure build-up mechanisms of the fixed-pad parallel surface thrust bearing is the creation of a thermal deformation wedge, due to the corresponding deformation of the rotor and stator profiles. Moreover, experiments have shown that the load carrying capacity of such bearings is significantly affected by the type and properties of pad fixation. In the present study a 3D ThermoElastoHydroDynamic (TEHD) model has been generated, and the reference model has been validated against previously obtained experimental results. Different bearing fixation configurations have been investigated, by altering the structural boundary conditions of the model, and the more suitable configuration has been identified and reported. Finally, the latter configuration has been applied to the case of a tapered-land thrust bearing; the corresponding bearing performance has been compared to that of a bearing with typical fixation configuration.

11:30 am - 12 pm
3488092: Experimental Characterization of Hydrodynamic Bearing during Oil Flow Interruption Event
Lorenzo Naldi, Riccardo Ferraro, Baker Hughes Company, Firenze, Italy

Nowadays fluid film Bearings are the standard for turbomachinery industrial applications. Oil fluid bearings have a large purpose in several fields and especially in the Industrial, where final users request to reduce the oil consumption and simplify the lube oil auxiliary system feeds the market competitiveness and push the OEMs to new solutions. Nevertheless, to move on advanced configurations, requires a deep knowledge of the fluid film bearing behavior up to the extreme environment like “oil-off” event. This work shows the authors experience matured on dedicated test campaign to evaluate the behavior of Journal and Thrust bearings in no flow condition; all measurements are reported with special focus on new instrumentation mounted on few thrust pads to measure pad tilting angle and the oil film thickness.

12 - 12:30 pm
3498814: A Study of the Dynamic Properties of the Elastic Supports of an Air Journal Bearing
Ahmed Paridie, Nicoleta Ene, The University of Toledo, Toledo, OH; Florin Dimofte, DiWave Technologies, Cleveland, OH

The purpose of this study is to evaluate the dynamic behavior of elastic elements used to support the air journal bearings of a small turbine engine. Numerical simulations were performed to obtain the response of the elastic supports to different harmonic forces. The stiffness and damping coefficients of the elastic supports were then calculated. The influence of the amplitude and frequency of the harmonic force on the stiffness and damping properties was also analyzed. To validate the numerical results, a test rig for the experimental study of the dynamic response of the elastic elements was designed and built. A shaker is used to apply different harmonic excitations to the elastic elements. The dynamic response of the elastic elements is observed using accelerometers and load cells. The theoretical and experimental results are in good agreement.

12:30 - 1 pm - **Fluid Film Technical Committee Business Meeting**

1D Virtual Meeting Room 4

Gears I

Session Chair: Jeffrey Ewin, NAVAIR, Patuxent River, MD
Session Vice Chair: Weixue Tian, ExxonMobil Research & Engineering, Annandale, NJ

10:30 - 11 am
3484437: Permissible Water Content of Gear Lubricants Regarding the Pitting Performance of Case-Carburized Gears
Nadine Sagraloff, Karsten Stahl, Gear Research Centre (FZG), Technical University of Munich (TUM), Garching, Germany; Christian Engelhardt, Patentanwälte von Bezold, Munich, Germany; Thomas Tobie

In most high power density gear applications, high performance lubricants are required. Contamination of water can alter the performance of lubricants negatively, particularly regarding the pitting resistance. Especially gears in offshore wind turbines are at high risk.
The influence of water contamination on synthetic oils in industrial applications is unknown. A characteristic value and a threshold limit for the amount of water in lubricants would be helpful. In order to gain a better understanding on the effect of water contamination on the pitting performance, experimental investigations on lubricants with different water contents were conducted on FZG-back-to-back gear test rigs with case-carburized gears. As a result, relative humidity was defined as a suitable characteristic to evaluate measured water contents in practical applications. As a recommendation for the practical industrial usage, this paper gives guidelines regarding the relative humidity of lubricating oils.

11 - 11:30 am
3484786: Approach for the Development of an Alternative Classification Method for Gear Oils for High-Loaded Hypoid Gears Comparable to API GL-5
Alexander Drechsel, Josef Pellkofer, Michael Hein, Karsten Stahl, Technische Universitat Munchen, Garching bei München, Germany

In general, it is not possible to determine the influence of the lubricant on the load carrying capacity of gears solely on basis of physical or chemical oil data. For this reason, some practical test methods have been developed to evaluate and classify the load carrying capacity of lubricants. A common used classification of hypoid gear oils are the guidelines of the American Petroleum Institute (API). The properties and performance characteristics of the oil are evaluated in complex axle test bench tests (L37 and L42), taking into account the tooth flank damage occurring on the gears. The tests planned for API GL-5 oils can only be carried out with great effort. Currently it is not possible to perform L37- and L42-tests in Europe due to a lack of missing institutes. By means of extensive experimental and theoretical investigations, an alternative method for the classification of gear oils comparable to API GL-5 is to be developed. The planned approach is presented in this publication

11:30 am - 12 pm
3498786: The Effect of Surface Roughness and the Λ Ratio on the Initiation and Progression of Micropitting Damage
Benjamin Wainwright, Amir Kadiric, Imperial College London, London, United Kingdom

Micropitting is a type of rolling contact fatigue surface damage that occurs in lubricated rolling-sliding contacts as a result of cyclic stresses on the roughness asperity level. With the current trends towards using less viscous lubricants and increasing machine power density, both with the aim of increasing mechanical efficiency, machine components are being run with thinner lubricating films which has led to increased asperity contact and subsequently increased incidence of micropitting damage. However,

despite the increasing frequency of its occurrence, the physical mechanisms behind micropitting are poorly understood and there are currently no established design criteria for its prevention. Tests looking into the effect of surface roughness and the Λ ratio are conducted on a triple-disc contact fatigue rig. The tribological mechanisms responsible for the onset of micropitting damage and possible preventive measures are discussed in relation to the obtained results.

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

1E Virtual Meeting Room 5

Metalworking Fluids I

Session Chair: TBD

10:30 - 11 am
3480913: IW5000, Oil-Free Aqueous AF/AW/EP Additive Based on IF-WS_2 Technology: Extending the Frontiers of Water-Based Lubrication Fluid Technologies
Hoon Kim, George Diloyan, Rui Wu, Vasya Ignatyshyun, Nanotech Industrial Solutions, Avenel, NJ

IF-WS2 particles have been well-known as excellent lubrication agents due to its sub-micron size and unique molecular structure, the so-called molecular onion with three dimensional layers. The layered particles are exfoliated under shear force created by moving parts to form two dimensional tribo-film on intercontact surfaces. Besides the outstanding lubrication, the film also provides a damage-healing function on the micro-cracks. This novel technology can be incorporated into both oil and water based lubricant systems, and the applications are versatile from MQL to well-drilling. Along this line, NIS has developed a new water-based IF-WS2 dispersion, IW5000 as an oil-free aqueous AW/EP additive. In this presentation, the stability and performance of IW5000 will be discussed in terms of centrifugal force resistance and AW/EP. With this innovative aqueous IF-WS2 additive technology, a significant improvement can be achieved in AW/EP performance of various finished lubricant products.

11 - 11:30 am
3482901: Cross-Functional Benefits of Metalworking Fluid Additives
Michael Stapels, Kao Chemicals GmbH, Emmerich, Germany; Clayton Cooper, ANGUS Chemical Co, Buffalo Grove, IL

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

11:30 am - 12 pm
3484653: Improving and Expanding the Applicability of the ASTM D3233 Pin & Vee Block Method for Cutting Fluid Evaluation: Correlation with a Real Cutting Operation
Dirk Drees, Michel De Bilde, Emmanuel Georgiou, Falex Tribology NV, Rotselaar, Belgium

Nowadays, a lot of standard tests are done with procedures and equipment designs from many decades ago. However, equipment has evolved and improved, and so have our insights. Thus, we need to look at

these ‘older’ standard test methods and consider how to update/modify them to obtain more relevant and repeatable information. In this work, we present an expansion to the well-known ASTM D3233A standard, with the aim to create new information that is more relevant to the application engineer. This standard uses the Pin & Vee Block setup to evaluate cutting fluids, but it is always limited to steel-steel contacts and the test results are limited to only the failure load. With our approach, we bring different metallurgies into the equation, and we focus on testing aqueous emulsions, rather than formulated oils. By monitoring the frictional torque throughout the test, significant differences between products can be revealed and correlated with an instrumented cutting (tapping) operation.

12 - 12:30 pm
3493012: New Seal Compatibility Test Method for Metalworking Fluids
Stephan Baumgaertel, VSI Association German Lubricant Industry, Hamburg, Germany

New formulations of metalworking fluids (MWF) are designed for a good performance, but also for a good environmental compatibility as well as low toxicity. Sometimes, modern formulations show a poor seal compatibility resulting in damage or even destruction of plastics and seal material. The German lubricant industry set up a test method for seal compatibility assessment. After first round robin testing, this test method may become a new standardized DIN 51533 method. This method will allow MWF formulators to show that their products are compatible with materials used by OEM.

12:30 - 1 pm
3499803: Consistently Beating the Odds – How to Build Successful Products
Emil Schnellbacher, Formulas & Solutions, LLC, Sterling Heights, MI

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

1F Virtual Meeting Room 6

Nanotribology I

Session Chair: Nikolay Garabedian, University of Delaware, Newark, DE
Session Vice Chair: Prathima Nalam, SUNY University at Buffalo, Buffalo, NY

10:30 am - 11:30 am
INVITED TALK: Polymer Brushes on Gels: Imitating the Lubricious Properties of Cartilage
Nicholas Spencer, ETH Zurich, Zurich, Switzerland

In natural lubrication, a common theme is the use of a soft, water-rich substrate that is covered by a softer layer that is rich in loose macromolecules. Such systems are to be found in our eyes, our articular joints, and in the linings of our blood vessels. In an effort to create materials with similar properties that may have useful applications in interfacing with such systems, or in industrial environments, we have synthesized a range of soft materials onto which arrays of macromolecules have been grafted. By means of a number of newly developed approaches, we are able to establish strongly bonded polymer brushes with compositions of our choice on a variety of hydrogel substrates. We have also explored the way in which brush-covered gels respond to normal loads and shear forces, and arrived at the conclusion that

careful design of devices that incorporate such systems is crucial, if the highly lubricious properties of the brushes and gels are to be used to their best advantage.

11:30 am - 12 pm
3499904: Formulation of Lubricant Additives Using AB Initio Computational Methods
Chiara Gattinoni, Eidgenossische Technische Hochschule Zurich, Zurich, Switzerland

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

12:00 pm - 12:30 pm
3490400: Molecular Dynamics Simulations of Nanofluidics
Mohamed Elewa, Hannes Holey, Karlsruhe Institute of Technology, Karlsruhe, Germany; Lars Pastewka, University of Freiburg, Freiburg, Germany; Peter Gumbsch, Karlsruhe Institute of Technology, Karlsruhe, Germany

The classical framework of hydrodynamic lubrication breaks down when the fluid is highly confined. Numerical solutions for the Reynolds equation typically encode fixed form constitutive laws that are only approximate and do not apply under these conditions. Deviations from “classical” behavior include the limiting shear-stress effect, non-locality of the interfacial stress tensor or velocity slip along the walls. Incorporating microscopic effects into the wall/fluid model is therefore essential for obtaining reliable numerical solutions in particular for highly loaded contacts operating in the boundary lubrication regime. We present non-equilibrium molecular dynamics simulations of pressure driven flow using the ”pump” method with the independent state variable being the thermodynamic force (Norton ensemble) or the thermodynamic flux (Thevenin ensemble). Transport coefficients as well as the stress tensor are obtained for n-alkanes as a function of gap height, shear rate and mass flux.

12:30 - 1 pm
3484404: Rheo-Tribological Analysis of Cellulose Nano-Crystalline (CNC) Aqueous Suspensions
Behzad Zakani, Sohrab Entezami, Dana Grecov, University of British Columbia, Vancouver, British Columbia, Canada

Industrial lubricants are widely introduced to mechanical systems to reduce the wear and energy losses. With the increasing demand for environmental protection, developing eco-friendly lubricants becomes more crucial. Due to their abundance, biodegradability, high thermal stability, non-toxicity and low cost ,cellulose nanocrystals (CNCs) may be an appropriate choice for formulating green lubricants. In this study, the optimum conditions for minimizing the coefficient of friction using CNC aqueous suspensions were investigated. Using a rheo-tribological characterization approach, the effect of structural parameters such as sample concentration and sonication output, as well as normal load, as a tribological parameter, were all analyzed. It was found that under hydrodynamic lubrication, liquid crystalline samples induce lowest co-efficient of friction. On the other hand, under boundary lubrication, the minimum co-efficient of friction occurs for the case of isotropic suspensions.

Power Generation and Wind Energy I

Session Chair: Salvatore Rea, Lanxess Corp, Perkasie, PA

10:30 - 11 am
3483809: Environmentally Acceptable Lubricant (EAL) Novel Esters That Are Extremely Hydrolytic and Oxidation Stable
Ramesh Navaratnam, Patech Fine Chemical, Dublin, OH

EAL as defined by various regulatory agencies is biodegradable, minimally toxic, and not bioaccumulative. Conventional EAL base stocks lack in thermal oxidation and hydrolytic stability has impeded its adaptation in high performance Lubricants in extreme conditions. To meet this challenge, a series of ISO 46 to ISO 3000 novel esters was developed using an advanced molecular modeling technology. These readily biodegradable ester base stocks were vigorously tested for hydrolytic and thermal oxidation stability. To achieve an extreme testing conditions, ASTM D2619 hydrolytic test was extended from 48 hours to 400 hours. Thermal oxidation test conducted using PDSC also showed outstanding results. Seal compatibility and lubricity performance were studied and yielded excellent results. These novel esters are designed to provide extended equipment life in high temperature and humid environment such as in marine transportation and wind turbine.

11 - 11:30 am
3484486: Efficiency and Lifetime Improvement for Wind Turbines by Using Silicon-Based Additive Technology
Stefan Bill, Croda International PLC, Goole, East Yorkshire, United Kingdom

REWITEC® is a part of CRODA Int Plc and develops an innovative silicon-based nano- and micro-particle surface treatment technology. The active particles use lubricants as a carrier and build through adsorption a protective and repairing silicon-based coating in gears or bearings of the wind turbine. In this way it reduces friction, wear, surface roughness and temperature. This talk will look at scientific tribological tests on our newest study about standstill damages of bearings, which can be significantly reduced and repaired through our coating technology. Generally, a 20 to 50% reduction in friction is achieved in running systems like gears and bearings. At the same time, the surface roughness and wear are also significantly reduced. Due to the system modification the surface temperature decreases too. All in all, these effects provide a longer lifetime and higher efficiency of the wind turbine.

11:30 am - 12 pm
3485238: Bio-Based Ionic Liquid Lubricants for Wind Turbine Applications
Md Hafizur Rahman, Pradeep Menezes, University of Nevada Reno, Reno, NV; Manish Patel, NanoTech Industrial Solutions, Lake Charles, LA; Ashlie Martini, University of California Merced, Merced, CA

Wind turbines are usually installed far from the ground and potentially also offshore to exploit uninterrupted wind flow for energy conversion. In these conditions, regular maintenance is difficult. Therefore, scientific investigations are needed to reduce the failure of components such as gearsets used in wind turbines. One of the reasons for failure is high friction and wear of the interacting components. Superior lubrication is essential to combat the friction and wear losses and enhance service life. In this research, bio-derived ionic liquid lubricants were synthesized and tests were conducted to characterize friction and wear performance. Steel-steel tribo-pairs were used to simulate the wind turbine gearset. Results showed lower friction and wear for ionic liquid lubricants compared to natural oils and petroleum-based lubricants. This investigation will contribute to expanding the applicability of bio-derived lubricants and improve the efficiency of drivetrains in wind turbines.

12 - 12:30 pm
3491278: Developing Accelerated Benchtop Testing Methodologies for Grease Lubricated Main Bearing Contacts in Wind Turbines
Benjamin Gould, Nicholaos Demas, Robert Erck, Aaron Greco, Argonne National Laboratory, Lemont, IL

The drivetrain components of wind turbines experience numerous detrimental contact conditions such as excessive slip, stray electrical currents, and torque reversals leading to impact loading. This leads to the formation multiple premature failure modes including micro-pitting, white-etching cracks, smearing, and macro-pitting. The formation of these failures is especially detrimental in the grease-lubricated main bearing, due to the fact that the entire rotor must be removed by a large crane to replace the bearing, thereby resulting significant costs to the turbine owner. This work will focus on replicating these failure modes in an accelerated state using representative wind turbine greases, and contact conditions which can occur up tower. Specifically, accelerated testing methodologies using a three-ring-on-roller contact will be presented to study the effect that electrical current, lubricant formulation, and contact slip have on premature failures in wind turbine greases.

12:30 - 1 pm - **Power Generation Business Meeting**

1H — Virtual Meeting Room 8

Commercial Marketing Forum I

Session Chair: TBD

10:30 - 11 am - **Bruker**

11 - 11:30 am - **Pilot Chemical**

11:30 am – 12 pm - **ExxonMobil Chemical**

12 - 12:30 pm - **Kao Chemicals**

12:30 - 1 pm - **LANXESS**

1I — Virtual Meeting Room 9

Synthetic Lubricants and Hydraulics I

Session Chair: Ryan Fenton, BASF Corp., Tarrytown, NY
Session Vice Chair: Rob Davidson, Afton Chemical, Richmond, VA

10:30 - 11 am
3488536: Novel Base Oil Technologies for Industrial Gear Oils
Justin Langston, Gabriela Fedor, Thomas Schimmel, Evonik Oil Additives, Horsham, PA

Industrial gear oils must protect equipment against wear, micropitting, and oxidation in a wide variety of severe operating conditions. These harsh conditions stipulate the use of higher viscosity grades, most commonly ISO VG 150 to 680. To reach these viscosity targets, and ensure stay-in-grade performance, formulators use shear-stable, high viscosity base stocks in combination with low viscosity base stocks. Additives are then added to provide durability, protect gearbox components, and improve low-temperature performance. In this paper, we will report on the performance of novel high viscosity base

stocks. When included in industrial gear oil formulations, they offer unique advantages in viscosity index, low-temperature performance, and solvency. Furthermore, these formulations are designed to meet the most stringent standards for industrial gear lubrication and therefore meet and or exceed standardized testing for scuffing, micropitting, and oxidation.

11 - 11:30 am
3485682: Could the Latest Oil Technology Give You Cleaner, Longer-Lasting and More Productive Hydraulic Systems?
Sravani Gullapalli, Sameer Sathaye, Shell Global Solutions USA Inc, Houston, TX

Operators are working their hydraulics systems for longer, exerting extra stress on hydraulic oils, including higher operating pressures and temperatures. At the same time, mobile hydraulic systems are becoming more compact. Their smaller oil reservoirs allow less heat dissipation, which means higher oil temperatures. This increases the risk of oxidation and thus sludge and varnish formation. Poor-quality hydraulic fluids are more susceptible to the problem of sludge and varnish as they readily oxidise in the presence of yellow metals, water, and air contamination. In addition, they contain additives that are not thermally stable and decompose at elevated temperatures. This presentation will showcase premium zinc-based hydraulic fluid technology, formulated with gas-to-liquid (GtL) base oils, that demonstrate low sludge forming tendency and excellent wear and oxidation protection.

11:30 am - 12 pm
3480820: New Hydrolytic Stability Testing on Biobased Lubricants and Base Fluids
Marlon Lutz, Biosynthetic Technologies, Indianapolis, IN

Esters are a class of compounds that have performance characteristics and use as a petroleum replacement in lubricant formulations. However, in aquatic applications esters have the tendency to thermally hydrolyze in the presence of water leading to organic acids which catalyzes the subsequent hydrolysis of unreacted esters leading to high total acid number resulting in corrosion of metal working equipment. Estolides are a distinct class of esters that has demonstrated exceptional hydrolytic stability compared to traditional esters. A modified hydrolytic stability test was developed by Biosynthetic Technologies to monitor the extensive stability of estolides versus traditional lubricant esters over a long duration of time under real world applications.</p>

2A — Virtual Meeting Room 1

Engine and Drive Train Session on Electric Vehicles I

Session Chair: Babak Lotfi, ExxonMobil, Houston, TX

2 - 2:30 pm
3480287: Test Rig to Investigate Function and Efficiency of the Speed4E Hyper-High-Speed Electromechanical Powertrain
Lukas Pointner-Gabriel, Hermann Pflaum, Karsten Stahl, Technical University of Munich, Garching, Bavaria, Germany

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

2:30 - 3 pm
3505568: Fluid Cooling Performance Understanding for Electric Drivetrain Applications
Yungwan Kwak, Kun Liu, Afton Chemical Corp, Richmond, VA; Adam Banks, Afton Chemical Ltd, Bracknell, Bracknell Forest, United Kingdom

The penetration of hybrid and electric vehicle technology into automotive powertrain designs is a major trend resulting from global regulations intended to improve vehicle fuel efficiency and reduce emissions of greenhouse gases and other pollutants. High thermal conductivity enables fluids to carry heat away from the electric motor, increasing vehicle efficiency and durability. This talk will cover two topics: 1) cooling performance evaluation of various fluids in an experimental rig, along with comparable results obtained via modeled simulation of that testing, and 2) direct oil cooling versus indirect coolant cooling comparisons for eMotor operating conditions and performance. The first topic is self-explanatory. Three significant aspects were investigated for the second topic: 1) eMotor efficiency maps as a function of shaft speed, 2) temperature comparisons under a fixed operating condition, and 3) achievable continuous power outputs under similar eMotor temperature conditions.

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

4 - 4:30 pm
3483132: Lubricant & Greases Solutions for the Whole Electrical Vehicle Drivetrain Including the Thermal Management of Batteries
Torsten Murr, Shell Global Solutions Germany, Hamburg, Hamburg, Germany

In 2019 more then 1.0 mio pure elec. vehicles have been produced, incl hybrid vehicles the total prod. on of electrical units are above 5 mio. In addition to the typical PasCar appl, electr. systems are being designed for LD-,HD Truck and Off Highway equipment. Even the highest electrical grade of PTs demands lubes solutions; for red.gears and e-axle syst. dedicated trans fluids, for bearings dedicated greases and for batt. cooling dedicated liquids with fluid volume from 0.5 to 4.0 l.In red. gear appl. the fluid does not get in contact with the electric propulsion system & only need to fulfill traditional hardware requirements. The wet E-Motor design, needs to consider chem & electromagnetic interactions of the fluid and the hardware components. For the new fluids new test method and screeners need standardized, i.e. Dielectric Breakdown, resistivity. In the area of Thermal manage. alternative fluids need to be qualified for immersed cooling with test methods describing power density & heat conduct.

4:30 - 5 pm
3485393: Thermal Properties of Group V Base Fluids for Fast Charge Battery Cooling Applications
Bethan Warren, Croda International PLC, Goole, East Yorkshire, United Kingdom

Thermal management in hybrid and electric vehicles becomes ever more important with the ever-changing architectures of modern vehicles. The ability to fast charge a battery is predominantly dependent on safely managing the temperature. Conventional cooling systems are reaching their limits on being able to provide the cooling required for such high charge rates. Immersion cooling appears to be able to offer the thermal management required for these systems. This presentation aims to highlight the ability of a submerged cooling system with group V base fluids, and in particular esters, in addressing the thermal management challenges of fast charging.

5 - 5:30 pm
3517639: Prediction of Power Losses in Electric Vehicle Transmissions
Amir Kadiric, Joseph Shore, Imperial College London, London, United Kingdom

Transmission power losses provide a major contribution to the overall energy loss in an electric vehicle (EV). In relative terms, this contribution is much larger than in an equivalent IC-powered vehicle. Consequently, the ability to predict and minimize transmission losses provides an important avenue for improving the efficiency and thus extending the range of EVs. This paper describes a model for prediction of EV gearbox efficiency including the influence of lubricant properties. The approach utilizes a thermally coupled gear lubrication model to accurately predict gear teeth friction as well as bearing and churning

losses. The model uses experimentally obtained lubricant rheology parameters as input which allows it to discriminate between different lubricant formulations in terms of their effect on the gearbox efficiency. Results are presented to illustrate the key trends in EV transmission losses with a selection of oils and over a range of EV operating conditions.

5:30 - 6 pm
3490846: Ultra-Low Viscosity Synthetic Fluids to Enhance Performance and Durability for Electric Vehicles (EVs)
Babak Lotfi, ExxonMobil, Houston, TX

Evolving regulations and consumer trends motivate automotive industries to lower CO_2 emissions, and pursue electric drivetrain alternatives to the internal combustion engine. Integrated e-modules where lubricant fluid being used for cooling of e-motor and electrical components bring new challenges. Base oil plays a critical role in lubricant properties. In this work energy efficiency, oxidative stability, thermal management, and electrical properties were studied. Results demonstrate superior performance and durability of synthetic fluids Gr IV/V, comparing to Gr II/III base oils for developing EV fluids. Synthetic blends have shown improved oxidative stability which can help with the longer drain interval and also desirable electrical properties over the life of the lubricant. Unexpectedly, a unique PAO structure has shown superior low traction. Lower traction lubricant can result in improving energy efficiency, and potentially extending miles for EVs.

2B Virtual Meeting Room 2

Environmentally Friendly Fluids II

Session Chair: Daniel Garbark, Battelle, Columbus, OH
Session Vice Chair: Brajendra Sharma, University of Illinois, Champaign, IL

2 - 2:30 pm
3480823: Latest in Biosynthetic Base Oils – Evaluating Estolide Performance Characteristics in Expanding Viscosity Ranges
Matthew Kriech, Biosynthetic Technologies, Indianapolis, IN

Estolides are an environmentally acceptable base oil that is referred to as a “biosynthetic”. They are known for their performance characteristics and use as a petroleum replacement in lubricant formulations. The number of estolide products being offered to the market is growing as new viscosities are being offered. We look at how these products compare to each other and to other commercial base oils in the industry. Estolides are very versatile and can be used in several industries and products within the marine, automotive, and industrial markets. Findings from example formulations will show performance benefits of these estolides.

2:30 - 3 pm
3497856: Lubricity Behavior of HVOs
Deepak Halenahally Veeregowda, Angela Maria Tortora, Ducom Instruments, Groningen, Netherlands

Hydrated Vegetable Oils (HVOs) are straight chain paraffinic hydrocarbons without oxygen, sulfur, and aromatics. HVOs without oxygen and sulfur has contributed to poor lubricity. In this study, we used HFRR to investigate friction and wear behavior of neat and additized HVOs, following ISO 12156. Ten test were conducted for each fuel type to determine the statistical significance and precision limits. Additives enhanced lubricity behavior of HVOs and helped HVOs comply with the EN 590 standard (MWSD < 450 µm). Wear topography for neat HVOs showed adhesion and abrasion whereas additized HVOs showed only adhesion. At mild wear conditions the friction coefficient had direct influence on wear, but not at high wear conditions. This relationship between friction and wear can be related to low shear boundary layer

composed of fatty acids and polar carboxyl groups. In conclusion the methyl esters enhance lubricity of HVOs and provide flexibility to control friction within mild wear conditions.

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

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

4:30 - 5 pm
3484497: EALs for Marine Vessel Stern Tubes – Not All Esters Are Equal
Kevin Duncan, Croda International PLC, Goole, East Yorkshire, United Kingdom

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

5 - 5:30 pm
3485148: How Polyalkylene Glycols Save Energy in Industrial Gear Application - A Sustainability Case Study
Tiffany Meyers, Andy Michael, Clariant, Mount Holly, NC

For decades synthetic industrial gear oils gain market share against mineral oil-based gear oils. The main reasons for this trend are the drive towards increased productivity and reduction of total costs. Smaller gear boxes and reduced oil reservoirs on the one hand, coupled with the trend of higher loads and the extension of oil change intervals on the other hand make the utilization of high performing base stocks inevitable. Amongst the group of synthetic gear oils Polyalkylene Glycols (PAGs) offer a unique set of properties originating from their polar structure. Clean operation due to reduced varnish and sludge formation, high resistance against water contamination as well as superior load-carrying and lubrication properties are characteristics of PAGs in gear applications. We have systematically assessed the potential environmental impacts of one particular PAG production vs. its benefits due to lower friction, i.e. energy savings in the use phase in a case study example.

5:30 - 6 pm
3484505: Soy-Based Lubricants: Performance and Sustainability
Robert Brentin, Omni Tech International, Midland, MI

The use of biobased oils in lubrication applications is growing with the increased focus on sustainability, greater market preference for environmentally friendly fluids, and improved performance with advances in vegetable oil base stock and formulation technology. Among vegetable oils, soybean oil is notable for its high lubricity, chemical polarity, high viscosity index, high flash point / low evaporation rate, while being a biodegradable and non-toxic material. These properties make it a preferential candidate for use in passenger car motor oil, two-cycle engine oil, greases, cable lubricants, hydraulic fluids, and metalworking fluids while having an environmentally acceptable footprint. New soybeans with increased oleic acid and lower content of polyunsaturated fatty acids are leading to more effective soy-based lubricants. This presentation will discuss the performance factors that make soybean oil a leading lubricant material in the environmentally friendly fluids category.

6 - 6:30 pm – **Environmentally Friendly Fluids Business Meeting**

Materials Tribology I

Session Chair: TBD

2 - 2:30 pm
3499517: The Effect of Hot Compaction on the Tribological Performance of the PDA+PTFE Nanocomposite Coatings
Sujan Ghosh, Min Zou, Nathaniel Harris, University of Arkansas, Fayetteville, AR; Samuel Beckford, Neda Mahmoudi, SurfTec LLC, Fayetteville, AR

The effect of hot compaction on the tribological behavior of 43 mm-thick polydopamine (PDA) + polytetrafluoroethylene (PTFE) nanocomposite coatings were studied. The mixing of PDA and PTFE helped the coating to adhere better to the stainless-steel substrate and prevented the detachment of the coatings. The compaction reduced the roughness and porosity of the coating by 97% and 98%, respectively. The reduction in roughness helped the compacted coating to exhibit a lower COF than the non-compacted PDA+PTFE coating. The compacted PDA+PTFE coating was 28.6- and 2.6-times more durable than the PTFE alone and the non-compacted PDA+PTFE coating of similar thickness, respectively. The enhanced tribological performance of the compacted PDA+PTFE coating was ascribed to the higher resistance to deformation, lower roughness and porosity, and better adherence to the substrate.

2:30 - 3 pm
3499239: The Effect of Environmental Factors on the Tribological Behavior of PDA/PTFE + Graphite Particles Coating on 60NiTi
Dipankar Choudhury, Min Zou, University of Arkansas, Fayetteville, AR

This study investigates the effect of two environmental factors, relative humidity, and temperatures, on the tribological behaviors of PDA/PTFE + Graphite particle coated 60NiTi. The unidirectional sliding experimental results revealed that the coating wear life reduced severely as the relative humidity increased from 20% to 40% due to coating delamination. Coating wear life at 100^{o}C operating temperature reduced significantly compared to that at 21^{o}C. Interestingly, the elevated temperature enhanced the transfer film at the beginning of the test but decreased the coating's wear-resistance eventually. A suitable operating temperature that optimizes the transfer film and coating mechanical property were determined to provide a durable coating.

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

4 - 4:30 pm
3522263: Effect of Filler Mechanical Properties on Fluoropolymer Composite Wear
Mark Sidebottom, Sifat Ullah, Miami University, Oxford, OH; Nathan Heckman, Brad Boyce, Los Alamos National Labs, Albuquerque, NM; Tomas Babuska, Lehigh University, Bethlehem, PA; Brandon Krick, Florida State University, Tallahassee, FL

Certain Fluoropolymer (PTFE, PFA) –alumina (Al_2O_3) particle composite materials have exhibited a 10,000x improvement in wear rate compared to unfilled fluoropolymers. Protective tribofilms that minimize damage to the fluoropolymer composite and counterface during sliding have been identified as key factor in promoting this improvement. In this work, the tribological properties of a PTFE-α alumina particle composites with different mechanical properties materials were tested against 304 Stainless steel countersurface. The wear rate of the composites was improved between 100-10,000x more than unfilled PTFE. In-situ nanoindentation of the different alumina particles used in the composites revealed very different mechanical properties based on the loading condition. From these results, the effect of the mechanical properties of the filler on the formation of tribofilms and wear behavior of fluoropolymer

composite systems may be determined.

4:30 - 5 pm
3522247: Effect of Counterface and Filler Particle Properties on Wear Performance of Fluoropolymer Composites
Sifat Ullah, Mark Sidebottom, Miami University, Oxford, OH

Certain fluoropolymer composites exhibit 10-100x lower wear rates than other fluoropolymers composites. These composites are called ultralow wear composites. The mechanism for this ultralow wear has been studied over the past 15 years with certain combinations of fluoropolymer composites and metal-countersurfaces. This ultralow wear mechanism has been attributed to/affected by particle properties (e.g. porosity, size, etc.), robust tribofilms, environment, and surface roughness. However, different testing pairs of fluoropolymer composites and metal countersurfaces may reveal different wear behavior. Therefore, combinations of different fluoropolymer matrices, filler particles and/or counter surface materials will be evaluated using linear reciprocating tribometers. Characterization methods (e.g. infrared spectroscopy, optical profilometry, nano-indentation etc.) will be used to evaluate the tribofilms, polymer composites, and counterbody materials.

5 - 5:30 pm
3501523: Ultralow Wear Self-Mated PTFE Composites
Kylie Van Meter, Tomas Babuska, Brandon Krick, Florida State University, Tallahassee, FL; Kasey Campbell, Lehigh University, Bethlehem, PA

Adding fillers such as α- alumina or other engineering polymers such as polyether ether keytone (PEEK) to unfilled polytetrafluoroethylene (PTFE) has been shown to reduce the wear rate of PTFE by more than four orders of magnitude, from 5 x 10^{-4} mm^3/Nm to ~1-5x10^{-8} mm^3/Nm. The significant improvement in the wear rate is attributed to the formation of a tribolfilm that coats both the polymer and countersample. Tribofilms and their composition are largely affected by the substrate material. To investigate potentially lower friction and wear systems, PTFE based polymer blends were tested on both stainless steel countersamples as well as matching polymer blend countersamples in a “self-mated” configuration. Samples of varying polymer concentrations were testing in a controlled humidity environment to directly compare performance. Chemical spectroscopy (FTIR) was used to understand the differences in tribochemistry for polymer-on-steel versus self-mated polymer-on-polymer configurations.

5:30 - 6 pm
3501937: Leveraging Trace Nanofillers to Stabilize and Discretize Already Low Wear Polymer Interfaces
Istiaque Alam, David Burris, University of Delaware, Newark, DE

To date, the potential for nanofillers to radically alter the physical properties of polymers at trace loadings has yet to fully materialize for a range of important material, surface, and interface properties. In this paper, we demonstrate a 40-fold improvement in the wear resistance of an already low wear polymer blend (5 wt% PEEK-PTFE) with an optimal loading of 0.1 wt% alumina nanofiller. Our results show that trace nanofillers activate surface-scale tribochemical processes that stabilize sliding surfaces by effectively crosslinking near-surface polymer chains. In-situ observation of the polymer wear surface revealed that nanoparticles prevented coalescence of the PEEK domains and discretized the real areas of contact. Our hybrid approach allowed us to isolate the effects of trace nanofillers on interfacial wear and identify a minimum effective dose of no more than 0.01 wt%. This study also demonstrates that the size-scale of the contact plays a crucial role in polymer wear.

Metalworking Fluids II

Session Chair: TBD

2 - 2:30 pm
3475838: Foam Control & Formulation Techniques to Minimize Foam in Water Dilutable MWFs
Michael Miller, Univar Solutions, Houston, TX

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

2:30 - 3 pm
3473238: Adenylate Energy Charge – New Tool for Determining Metalworking Fluid Microbial Population's Sublethal Response to Microbicide Treatment
Frederick Passman, Biodeterioration Control Associates, Inc., Princeton, NJ; Peter Küenzi, Blaser Swisslube AG, Hasle-Ruegsau, Bern, Switzerland; Jordan Schmidt, LuminUltra Technologies, Ltd, Fredericton, New Brunswick, Canada

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

3 - 4 pm - **Break**

4 - 4:30 pm
3481361: Reserving Metalworking Formulation Space for the Impossibilities
Harish Potnis, Angus Chemical Company, Mumbai, Mahararashtra, India

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

4:30 - 5:30 pm - **Panel Discussion: Metalworking Hot Topics**

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

2F Virtual Meeting Room 6

Nanotribology II

Session Chair: Mehmet Baykara, UC Merced, Merced, CA

2 - 2:30 pm
3507286: Nanotribology and Nanorheology of Confined Ionic Liquids
Rosa Espinosa-Marzal, Mengwei Han, University of Illinois at Urbana-Champaign, Urbana, IL

Ionic liquids (ILs) have been recognized as potential lubricants because the strongly adsorbed ILs layers on the solid interface are capable of bearing heavy loads and effectively reduce friction. We study the nanoconfined IL films using a nanorheometer-nanotribometer-surface forces apparatus. The thinnest films of the studied ILs (~2-3 nm) are found to be elastic and water is found to alter their viscoelastic behavior. The results from the nanorheological tests are compared to friction measurements. Friction varies with sliding velocity in the range of investigated velocities, and severe stick-slip is observed at the slowest investigated velocities, which correlates with the highest friction; while the presence of water alters the tribological response. By comparing the tribological and nanorheological studies, this work sheds light on the molecular mechanisms that govern IL lubrication.

2:30 - 3 pm
3484465: Eco-Friendly Aqueous EP Additive Based on IF-WS_2 /Polyalkylene Oxides Combi Technology: Structure-Property-Performance Relationship Beyond the Horizon in Lubricant Industry
Hoon Kim, George Diloyan, Rui Wu, Vasya Ignatyshyun, Nanotech Industrial Solutions, Avenel, NJ

Inorganic fullerene like tungsten disulfide particle (IF-WS2) features its nano size with symbolic onion-shaped molecular structure and serves as excellent solid lubricant in many applications from MQL to well-drilling. During lubrication operations, the unique three-dimensionally layered nanoparticles are exfoliated to form two dimensional tribo-film on the intercontact surfaces. Although this novel technology can be readily incorporated into both oil and water based lubricant systems, most of the literatures from the last decade highlight numerous applications mainly for various oil-based systems while only a few for water-based ones. Along this line, in this paper we report our latest research on useful structure-property-performance relationship of various polyalkylene oxide block copolymers in terms of the effect of their molecular weight, polarity, and monomer sequence distribution on the centrifugal force stability and extreme pressure performance of aqueous IF-WS2 dispersions.

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

4 - 4:30 pm
3485187: Reviewing the Performance of Permanently Suspended Nanocarbons in Lubricants.
Aaron Darnell, Lubrication Specialties, Inc., Mount Gilead, OH

Despite the promise of reduced friction and wear, nano particles are not widely used in the lubrication industry. The primary obstacle preventing marketability is the inability to keep nano particles in suspension. In this study, a clear carbon nano particle blend, designed to stay in suspension, was dispersed into a variety of completed engine oils, gear oils and base oils at a rate of 1-5% by weight. Samples were monitored to ensure particles stayed in suspension. HFRR, MTM and Four Ball tester were used to collect wear and coefficient of friction data by utilizing several ASTM methods. Test data revealed 5-18% reduction in friction. Additional fuel mileage and dyno testing also reflect an increase in fuel efficiency from reducing the frictional forces in the engine and resulting in a reduction in carbon emissions.

4:30 - 5 pm
3485307: The Electrical and Tribological Performance of Silver Nanoparticle Laden Lubricants in Comparison to a Conventional Product
Larkin Crilly, Robert Jackson, Samuel Bond, German Mills, Auburn University, Auburn, AL; Suvrat Bhargava, TE Connectivity Ltd Berwyn, Middletown, PA

The reliable operation of electrical contacts and connectors is a cornerstone of electrical systems. These systems are found in a range of environments, from climate controlled to extreme environments (e.g. engines/factories) that can cause material degradation through wear and other mechanisms. These can lead to excessive changes in the electrical contact resistance, causing failure. Lubricants, often used to combat such effects, are usually non-conductive and not suited to electrical applications. Dodecane-based silver nanoparticle colloids have been previously researched due to their potential to reduce wear and changes in electrical contact resistance. Further experiments have been conducted to characterize the friction and wear effects of multiple silver nanolubricants, finding a distinct decrease in friction with higher particle concentration. SEM and EDS were conducted, revealing that nanoparticles were not sintering or embedding on the surface and signs of reduced overall wear.

5 - 5:30 pm
3485451: High Temperature Nanomechanical and Nanotribological Behavior of Sub-5 nm Nitrogen-Doped Carbon Overcoat Films
Ahmad Shakil, Andreas Polycarpou, Texas A&M University College Station, College Station, TX

Elevated temperature tribological properties of ultra-thin nitrogen-doped carbon overcoat (NCOC) protective film for magnetic disks were investigated. NCOC with three different thicknesses (2.5, 3.5, and 4.5 nm) were examined at temperatures up to 300 ^{o}C. The chemical changes were traced by XPS, revealing that the configuration of both carbon and nitrogen elements change partially from sp^3- to sp^2-hybridizations with exposure of NCOC samples to annealing. The friction coefficient, wear rate, and deformation of the NCOC films were measured using nanoscratch/wear experiments. Mechanical experiments verified the operating temperature and thickness dependence of the tribological behavior of the NCOC films. The NCOC samples show that the average wear depth is acceptably small after exposure to annealing, thus offering durable films for high temperature applications. Noteworthy, the permanent reduction in mechanical properties associated with annealing reduces in the presence of N dopants.

5:30 - 6 pm
3498186: PEO-Chameleon as a Potential Protective Coating for High-Temperature Applications
Asghar Shirani, Samir Aouadi, Andrey Voevodin, Diana Berman, University of North Texas, Denton, TX; Aleksey Yerokhin, University of Manchester, Manchester, United Kingdom; Andras Korenyi-Both, Tribologix Inc., Golden, CO

Here we produce an adaptive dual-phase coating on aluminum alloy by modifying the substrate with plasma electrolytic oxidation (PEO) followed by burnishing with graphite-MoS_2-Sb_2O_3 chameleon solid lubricant. The PEO layer offers high hardness and load support while the composite solid lubricant enables low friction sliding over the range of temperature and environment conditions. The coating demonstrated significant improvement in the friction and wear behavior. Coefficient of friction values decreased from 0.2 at the room temperature to 0.02 at 300 °C, which is attributed to defect healing and adaptive behavior of the coating. In-situ Raman spectroscopy analysis revealed high chemical stability of the coating up to 300 °C with neither oxidation nor reduction of the chameleon components observed. Instead, modifications in the tribological behavior originated from release of the lubricious phases to the sliding interface activated by thermal and mechanical stresses.

2G — Virtual Meeting Room 7

Power Generation and Wind Energy II

Session Chair: Salvatore Rea, Lanxess Corp, Perkasie, PA

2 - 2:30 pm
3474239: Salvaging Poorly Stored Turbine Oil
Nnamdi Achebe, Petrosave Integrated Services Ltd., Amuwo-Odofi, Nigeria

Turbine lubricant drums poorly stored outdoor were rusty and severely contaminated with water. All forms of water – Free, Demulsified and Dissolved were present in the oil sample taken. Turbine oils are expensive and that Plant Management hoped for a solution to cut losses. Unique combination of Filtration and select oil analysis tests including RULER and ISO 4406 Cleanliness proved effective in reconditioning severely water contaminated lubricants. Earlier, Free and Emulsified water layers were drained off and elements oven-dried to increase their water absorption capacity. After turning over every drum 5 – 7 times, bright and clear oil sample measuring dissolved water content of <100ppm using the KF method was achieved and within OEM Fresh Oil limit. However, that water can damage oil additives, made it significant to check the remaining anti-oxidant additives. Matched against in-service oil, all recovered drums recorded higher % anti-oxidant and within Target ISO Cleanliness.

2:30 - 3 pm
3491891: K_{sp} and Thermodynamic Considerations Relevant to Effective Varnish-Removal
Matthew Hobbs, Peter Dufresne, EPT, Calgary, Alberta, Canada

Varnish is a result of unmanaged oil breakdown and its deleterious impact on reliability is well-documented. Traditionally defined as an insoluble deposit, varnish exists in soluble and insoluble states. The relative amount of soluble and insoluble varnish in a system and, therefore, its potential for varnishing are controlled by the solubility product K_{sp}. Since K_{sp} depends only on the concentration of dissolved species, particles/deposits have no impact on an oil's varnish potential. Many strategies exist to mitigate the effects of varnishing. Most rely on filtration which removes insoluble that have no impact on oil K_{sp}. Filtration, therefore, fails to meaningfully address varnish problems. Resin-based systems, however, remove soluble varnish. Since they remove the contaminants that influence K_{sp}, thermodynamic first principles allow them to remove all forms of varnish. They can, therefore, be used to effectively manage oil breakdown and varnishing where alternative strategies fail.

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

4 - 5 pm - **Wind Turbine Business Meeting**

2I — Virtual Meeting Room 8

Commercial Marketing Forum II

Session Chair: TBD

2 - 2:30 pm
3566322: Estolides - High Performance Sustainable Base Oils for Lubricant and Metalworking Formulations
Matthew Kriech, Biosynthetic Technologies, Indianapolis, IN; Mark Miller, Ramapo College of New Jersey, Mahwah, NJ

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

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

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

4 - 4:30 pm
3572948: Get Electrified with Evonik – VISCOPLEX® and VISCOBASE® for E-fluids.
Justin Mills, Evonik Oil Additives, Horsham, PA

The vehicle landscape is changing rapidly as many automotive OEMs turn toward electrification to meet tightening emissions standards and consumers' desire for more sustainable solutions. With electrification comes new challenges for formulating lubricants for OEMs and blenders alike. Conventional properties like shear stability and oxidative stability will remain, albeit with tightened limits, and more contemporary properties like compatibility with electrical components, thermal management, and efficiency will come more into focus. To address these mounting challenges, formulators may need to deviate from their traditional approach to identify alternative solutions. From ICE to hybrids to battery electric vehicles, Evonik has the products and expertise to meet your current and future needs.

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

5 - 5:30 pm - **LANXESS**

2J Virtual Meeting Room 9

Synthetic Lubricants and Hydraulics II

Session Chair: Ryan Fenton, BASF Corp., Tarrytown, NY
Session Vice Chair: Rob Davidson, Afton Chemical, Richmond, VA

2:00 pm - 2:30 pm
3485572: Tribological Performance of Used and Artificially Altered Hydraulic Oils
Nicole Doerr, Serhiy Budnyk, AC2T research GmbH, Wiener Neustadt, Austria; Daria Kolbas, Oksana Elagina, Gubkin Russian State University of Oil and Gas, Moscow, Russian Federation; Ameneh Schneider, Optimol Instruments Prueftechnik GmbH, Munich, Germany; Franz Novotny-Farkas, Ingenieurbuero fuer Erdoelwesen, Schwechat, Austria

Short-time tribometrical tests were applied to characterize fresh and the respective used or artificially altered hydraulic oils according to friction behavior and wear formation. Hydraulic oils with different degrees of degradation were obtained from thermal-oxidative stability tests, Bosch Rexroth pump test and from the field after up to 40,000 operating hours. For tribometrial evaluation, a steel-steel contact with ball-on-disk configuration in the Schwing-Reib-Verschleiss-Tribometer SRV® 5 was applied. While conventional oil characterization did not show tremendous oil degradation compared to the fresh oil, tribometrical test results differentiated between fresh and used oil condition. For the understanding of the observed behavior, surface characterization was performed.

2:30 - 3 pm
3490868: Critical Shear Rate of Polymer-Enhanced Hydraulic Fluids
Pawan Panwar, Ashlie Martini, University of California Merced, Merced, CA; Paul Michael, Milwaukee School of Engineering, Milwaukee, WI; Mark Devlin, Afton Chemical Corp, Richmond, VA

Many hydraulic fluids exhibit shear thinning, where the viscosity decreases with shear rate above a critical shear rate (CSR). For fluids formulated with polymeric additives, CSR is a function of polymers' molecular weight and concentration. Here, we present a model for predicting CSR, to identify a fluid that shear thins in a specific range relevant to hydraulic pumps. The model is applied to predict the properties of fluids comprising polyisobutene polymer and polyalphaolefin base oil. Theoretical predictions are validated by comparing viscosities from experimental measurements and molecular dynamics simulations across many decades of shear rates. Results demonstrate that polymer's molecular weight plays a key role in determining CSR, whereas polymer concentration primarily affects Newtonian viscosity. The simulations are further used to show the molecular origins of shear thinning and CSR. Overall, the developed model can help formulate hydraulic fluids with a desired CSR.

3 - 4 pm - **Break**

4 - 4:30 pm
3498720: Dynamometer Testing of Energy Efficient Hydraulic Fluids and Fuel Savings Analysis for US Army Construction and Material Handling Equipment
Paul Michael, Milwaukee School of Engineering, Milwaukee, WI; Jill Bramer, Eric Sattler, US Army CCDC Ground Vehicle Systems Center, Warren, MI

The US Army uses MIL-PRF-2104 SAE 10 in the hydraulic systems of construction engineering and material handling equipment. This oil meets US military performance and logistics requirements but has not been optimized for efficiency. Efficiency is important because fuel transportation has unique costs and dangers in military applications. To evaluate the potential fuel savings of Energy Efficiency Hydraulic Fluids (EEHF), SAE 10 and two commercially available EEHF were evaluated in a combined hydraulic pump and motor dynamometer. Axial, variable-axial, and radial piston hydraulic motors were tested under a wide range of temperatures, pressures, and speeds. System flow losses due to internal leakage and motor torque losses due to friction were measured. The input and output power of the system was quantified and the potential fleet-wide fuel savings for EEHF was estimated for 11 vehicle platforms. A direct and fully-burdened fuel cost analysis is presented.

4:30 - 5 pm
3483443: Fluid Effects on Stick-Slip Friction in Hydraulic Cylinder Rod Seals
Paul Michael, Milwaukee School of Engineering, Milwaukee, WI; Oluwaseyi Ogunsola, Shell Technology Center, Houston, TX

Hydraulic cylinders are the primary linear actuators in fluid power equipment. They incorporate piston and rod seals. Piston seals isolate rod and cap-end pressures within a cylinder. Rod seals retain the fluid within a cylinder as it extends and retracts. In addition, rod seals must resist extrusion, operate in harsh environments, and minimize stick-slip friction. Rod seal stick-slip is characterized by a stop-start motion of the rod. This movement can produce vibration, noise, and machine oscillations. Machine oscillations are a particular concern in cranes, telescopic lifts, and utility trucks because boom instability affects machine control and operator safety. In this investigation, we examined the effects of fluid properties on seal stick-slip friction. Variations in cylinder forces were measured for several fluids with slipper, U-cup, and V-pack seals. Improvements in the lubricating properties of the fluid were found to reduce or eliminate stick-slip friction and noise.

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

3A Virtual Meeting Room 1

Condition Monitoring I

Session Chair: TBD

10:30 - 11 am
3533615: Monitoring of EGR Diesel Engines Lubricant: Should the Nitration be Considered?
Joseph Fotue, TOTAL Cameroon, Douala, Cameroon

Nitration is one of essential parameters for the monitoring of natural gas engines oil because of the common presence of organic nitrates in natural gas. For Diesel engines, nitration has not been an essential parameter but oxidation. However, to reduce NOx pollutant, diesel engines are more and more equipped with EGR (exhaust gas recirculation) system. EGR works by recirculating a portion of an engine's exhaust gas back to the combustion chamber. That recirculation charges the air admission with NOx and because of engine blow-by, engine oil nitration is much more likely to happen. This situation can be aggravated by the extreme operating conditions following the engine downsizing option chosen by manufacturers to reduce CO2 gas. This article explains the cause of oil nitration in the EGR diesel engine and why it is crucial to consider it as a key parameter during monitoring.

11 - 11:30 am
3499071: Laboratory Aging of Ester Oils and Its Effect on Friction and Wear
Debdutt Patro, Fabio Alemanno, Deepak Halenahally Veeregowda, Ducom Instruments, Groningen, Netherlands

Aging of oils can increase operation and maintenance cost of transmission systems. In this study, we aged the oils (additive free ester base oil -VG 100- and ester base oil additized with 5% glycerol monooleate, GMO) through shearing at 60 °C for 100 h using KRL Shear Stability Tester and at 120 °C for 100 h in oven. GMO decreased the KRL friction of ester base oil. Ester base oil showed 5% loss in viscosity; the additized ester base oil increased the viscosity by 3%. Oven aging increased the viscosity of all oils. Viscosity of additized ester oil was higher compared to ester base oil, because of GMO. Molecular weight increased for oils that gained viscosity and decreased for oils that lost viscosity. Aged oils were subjected to friction and wear tests with Four Ball Tester and HFRR, showing increase in friction and wear for aged oils. In conclusion this laboratory test method was useful to age the oils and measure its effect on friction and wear.

11:30 am - 12 pm
3500168: Diagnosing the Root Cause of an Overheated Gearbox
Evan Zabawski, TestOil, Strongsville, OH

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

12 - 12:30 pm
3472067: Product Quality Maintenance & Reliability in the Lubricant Supply Chain
Michael Roe, MJR Lubricant Distribution Consulting & Auditing, Cypress, TX

This paper discusses Lubricant Product Quality & Reliability Maintenance issues in the Lubricant Supply Chain. Topics include Lubricant Products, Lubricant Supply Chain & Focus Areas, Supply Chain Issues & Resolutions, Supply Chain Tools, and Key Takeaways. There are large variety of lubricants due to

application-specific requirements. The lubricants themselves range from very simple to highly complex. Because of their physical and chemical nature, lubricants are easily commingled if not handled properly. The supply chain is also varied and complex, including not only lubricants but non-lubricant products, with multiple entities handling lubricants with different equipment types, processes, activities, quality approaches, and personnel training. Product quality and reliability maintenance is essential because it is directly related to lubricant performance in the application, and directly affects customer perception, reputation and brand image, and the bottom line.

3B Virtual Meeting Room 2

Lab to Field: Bridging the Gap Between Bench and Engine: Engine and Drive Train and Lubrication Fundamentals Joint Session I

Session Chair: Babak Lotfi, ExxonMobil, Houston, TX

10:30 - 11 am
3485580: Correlation of Engine Oil Degradation in Large Scale Alteration Device and Engine Test Rig
Nicole Doerr, Adam Agocs, Serhiy Budnyk, Andjelka Ristic, Marcella Frauscher, AC2T research GmbH, Wiener Neustadt, Austria

Engine tests are typically performed with fresh oils whereby long-term effects such as oil degradation are neglected. A time-consuming, therefore expensive engine test would be necessary to gain insight into component performance dependent on the degree of oil degradation, fuel dilution, soot contamination, just to tell a few. A laboratory-based device for large scale alteration is proposed for the provision of sufficient quantities of a defined used engine oil. The example of a soot-contaminated oil from a diesel engine test rig shows how oils from the field are reproduced in the laboratory. The correlation between field and laboratory is determined by conventional oil parameters, molecular structure information provided by mass spectrometry, soot analysis and tribometrical experiments.

11 - 11:30 am
3498159: Piston Ring Coating Development - From Bench To Vehicle
Peter Lee, Southwest Research Institute, San Antonio, TX

Novel piston ring coatings were developed in the coatings lab and tested in the tribology labs using a reciprocating rig. The lowest friction coating that also survived the testing were then applied to a gasoline engine and diesel engine ring set. These were tested for friction response in a fired single cylinder gasoline engine and for durability in a fired single cylinder diesel engine. Having responded favorably for both friction response and durability in these tests, an engine from a vehicle was operated and the fuel economy measured before the rings were removed, coated and then the engine reassembled and vehicle tested for fuel economy again, yielding favorable fuel economy gains.

11:30 am - 12 pm
3471731: Cavitation Initiation and Patterns in Engine Lubricants as a Result of Different Operating Conditions and Lubricant Properties
Polychronis Dellis, ASPETE, Athens, Attiki, Greece

Experimental study for lubricant formulation is a challenge derived from demanding circumstances of efficient operation. The lubricant’s task is to perform these qualities, maintain a film between the ring and liner, reduce emissions, increase load capacity reducing cavitation and contribute to total efficiency. In a simplified test rig the piston-liner movement is reversed. Thus, tribological conditions from the unsteady operation in production engines are separated and simplified. Experimental data and further parametric analysis is given regarding cavitation in lubricants evident in laser induced fluorescence (LIF)

measurements. Different lubricants and setups are used for the experiments and signals are analyzed and interpreted compared to the lubricants' properties. With the aid of a high speed camera, a clearer picture is given regarding cavitation shapes combined with the respective LIF measurements. Thus, results are presented regarding cavitation initiation, size, and number.

12 - 12:30 pm
3495414: Low Friction Powertrains: Current Advances in Lubricants and Coatings
Boris Zhmud, BIZOL Germany GmbH, Berlin, Germany; Peter Lee, Southwest Research Institute, San Antonio, TX

Improving fuel economy and reducing emissions is nowadays more important than ever. Apart from powertrain electrification, automotive OEMs have constantly been seeking to improve the efficiency of the internal combustion engine. Downsizing and boosting have become common practice in the ICE design. Ever increasing power density and torque output of modern boosted engines, in combination with the introduction of automatic start-stop systems and ultralow viscosity lubricants tends to stress the engine beyond the limits foreseen in the classical design. This leads to wear problems as well as control issues such as LSPI. Each engine component comes with a unique landscape of competing manufacturing technologies. This presentation provides an overview of different trends related thereto. The role of lubricant on the engine tribology is studied for different engine designs. The importance of in-design "pairing" of low-viscosity motor oils with the engine characteristics is highlighted.

12:30 - 1 pm
3499242: Cooperativity between Zirconium Dioxide Nanoparticles and Extreme Pressure Additives in Forming Protective Tribofilms: Toward Enabling Low Viscosity Lubricants
Robert Carpick, Meagan Elinski, Parker LaMascus, Andrew Jackson, University of Pennsylvania, Philadelphia, PA; Lei Zhang, Robert Wiacek, Pixelligent, Baltimore, MD

Realizing the efficiency benefits of low viscosity lubricants requires strategies to avoid failures from increased boundary contact. ZrO_2 nanoparticles (NPs) form protective tribofilms through tribosintering at lubricated contacts in pure hydrocarbon base oils, suggesting they hold promise for reducing such contact-induced failures. However, their behavior alongside co-additives found in fully formulated oils is less examined. The tribology of dispersed ZrO_2 NPs with and without co-additives found in commercial gear oils was studied using a mini-traction machine (MTM). The NPs reproducibly develop surface-bound ~100 nm thick tribofilms under a range of rolling-sliding conditions. Traction coefficient values are similar to those found in polyalphaolefin base oils (0.10–0.13). A twofold reduction of wear of the steel is attributed to cooperating mechanisms, where extreme pressure additives protect the steel against early adhesive wear, allowing the protective tribofilm to form.

3C — Virtual Meeting Room 3

Nonferrous Metals I

Session Chair: Ariane Viat, Constellium Technology Center, Saint Egreve, France

10:30 - 11 am
3484255: A Non-Ferrous Study Investigating the Lubricity and Film Thickness Behavior of Rolling Oils Containing Mixed Ester Packages on Varying Grades of Aluminum
Emma Pates, Stephen Chestnutt, Total UK Ltd, Manchester, United Kingdom; Annie King, Total Specialties USA, Inc, Houston, TX

The global demand for pristine surface finishing within the non-ferrous rolling industry is the driving force behind this investigation surrounding high-performance lubricating oils. Studies relating to the lubrication properties of a modelled base oil formulation, based on current industrial knowledge, will be explored with

the addition of different functionality/mixed ester packages on numerous different grades of aluminum alloys using tribological methods developed specifically for non-ferrous rolling applications. The scientific goal is to compare how the effect of these diverse ester packages affect all regimes within the lubrication profile on these different grades of aluminum and relate them directly to their observed film thickness formation/strength and surface polarity. The range of these results will additionally aim to strengthen the accuracy and knowledge of mapping the friction and wear behaviour of lubricants within industrial rolling mills.

11 - 11:30 am
3480774: Metal Corrosion: Looking Farther Than the Eye Can See
Clayton Cooper, ANGUS Chemical Co, Buffalo Grove, IL

While the adage “Don’t judge a book by its cover” is relevant for various aspects of everyday life, like humans and books, it’s a completely different matter when discussing metal machining. Physical appearance of metal is often indicative of future complications. For example, metal corrosion of all types not only impedes adhesion of various coatings, it can also impact the integrity of the metal. A recent study investigating metal leaching in the absence of aluminum staining, uncovered another aspect of metal corrosion. In the presence of certain amines, increased leaching was observed without a visual increase in staining. Not only can metal leaching impact the next step in the machining process and overall metal quality, it can also impact the stability of a metalworking emulsion. This study further investigates staining in correlation to metal leaching on a wide variety of metals and outlines potential impact to the overall formulation.

11:30 am - 12 pm
3489606: Nuclear Magnetic Resonance Spectroscopy as a Useful Tool for Routinely Analyzing the Composition of Aluminum Hot Rolling Emulsions
Josef Leimhofer, AMAG Rolling GmbH, Ranshofen, Austria

The field of application of nuclear magnetic resonance spectroscopy (NMR) for the analysis of emulsions used in the hot rolling process of aluminum has been further investigated. NMR spectroscopy using a permanent magnet has been established at AMAG as a tool for analysis of hot rolling emulsions (oil phase). Measurements with NMR spectrometers using known substances, different solvents and different magnetic field strengths have been performed, as well as 2D-NMR-experiments, for the purpose of identification of individual ^{1}H- and ^{13}C-NMR signals. For the input analysis of emulsions as well as for the identification and quantification of selected additives, specific procedures have been established. This work will show the results of these measurements and how they are used to gain additional information for emulsion maintenance.

12 - 12:30 pm
3499533: Lubricant Additive Response Comparisons, in a Commercial Post Lubricant, on 3104 Aluminum D&I Can Stock, Using Twist Compression Tests (TCT)
Ted McClure, Sea-Land Chemical Co / SLC Testing Services, Westlake, OH

The Twist Compression Test (TCT) is a bench test that creates lubricant starvation under high pressures and sliding contact. It is used to compare coefficients of friction and adhesion prevention performance of lubricants. A common problem in the D&I can drawing process is bleedthrough or blush. Factors affecting bleedthrough include tool setup, sheet metal surface characteristics, post lubricant (PL) amount and compatibility with cupper lubricants (CL), lubricant cleanliness, and boundary and hydrodynamic lubrication. Control of friction is critical in metal forming operations. In this work, TCT is used to compare additive responses, in a commercial PL formulation, on 3104 aluminum can stock. Lubricants evaluated include polymers, acids, esters, alcohols, and phosphorus bearing additives. The aim is to provide useful empirical data for formulation of lubricants to address issues like bleedthrough on aluminum.

12:30 - 1 pm
3497932: Tramp Oils - What Are They and How Do They Effect a Hot Rolling Emulsion
Andrea Knopp, Constellium, Ravenswood, WV

In aluminum hot rolling a rolling mill utilizes a rolling solution to lubricate the rolls and generate a clean surface. During the rolling process, several things can occur, and one of the most common ones that we fight are leaked tramp oils. We need to understand what these tramp oils are, what they consist of, and what effect they have on the rolling solution. This presentation will define several different types of tramps, and their potential effects. It will also look at these effects from a production aspect, cost aspect, and product quality perspective.

3D — Virtual Meeting Room 4

Materials Tribology II

Session Chair: TBD

10:30 - 11 am
3499636: Data Science Techniques Applied to In-Situ XRD Measurements of Copper under Tribological Load
Nikolay Garabedian, Patric Gruber, Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Germany

Friction is inherently a multi-scale phenomenon: the mechanics that govern macroscale sliding originate at the nanoscale, and often leave permanent microstructural alterations even if no apparent wear occurs. Combining tribological experiments with in-situ X-ray diffraction (XRD) analysis is a promising avenue for unraveling the hidden connection between surface stresses and resulting microstructural alterations. We used KIT's ANKA synchrotron source to collect XRD patterns of copper, which was slid against a sapphire sphere. However, analyzing these patterns in a traditional manner can often be a daunting task due to their sheer number: >13,000. Furthermore, finding meaningful correlations with the tribological data which was acquired in parallel, makes this effort extremely time consuming, if at all possible. To tackle this, data science techniques were adapted and applied to identify previously concealed correlations between friction and changes in the material's structure.

11 - 11:30 am
3484803: Extreme Environment Tribological Study of Advanced Bearing Polymers for Space Applications
Kian Bashandeh, Vasilis Tsigkis, Texas A&M University, College Station, TX; Pixiang Lan, ATSP Innovations, Champaign, IL; Andreas Polycarpou, Texas A&M University, College Station, TX

Polymers with self-lubricating properties have been employed in various applications as bearing components and tribological surfaces, particularly where the use of liquid lubricant is infeasible, such as space-related applications. This study reports on tribological solutions for extreme temperature ranging from −196 to 300 °C, which simulates extreme operating conditions that bearing materials in space will encounter. Tribological performance of three polymeric-based coatings, namely ATSP-, PEEK-, and Fluoropolymer-based coatings was evaluated. Inspired by the benefit of transfer layer, we deposited the coatings on both pins and disks to simulate polymer sliding on pre-deposited "transfer layer." The ATSP-based coatings showed excellent tribological performance with low coefficient of friction and unmeasurable wear within a wide temperature range.

11:30 am - 12 pm
3483431: Reduced Cost NiTi-Alloy Bearings Made via Near Net Shape Powder Metallurgy Processes
Christopher DellaCorte, NASA, Cleveland, OH

NiTi alloys are emerging as an attractive bearing race material for bearings exposed to high static loads and highly corrosive environments. One obstacle yet to be overcome is the intrinsically high relative cost of these materials compared to traditional bearing steels. Traditional net-shape powder metallurgy methods, such as cold-press and sinter, are not applicable to NiTi alloys because they require hot isostatic pressing (HIP) to achieve full density, flaw free microstructures. Recently, innovative powder metallurgy processing has been successful in forming bearing ring blank shapes through the use of geometrically tailored HIP containers. Microstructural evaluations show that ring blanks made from this process are comparable to material made using conventional HIP containers while substantially reducing material usage.

12 - 12:30 pm
3503429: Ultralow Wear Plasma Enhanced Atomic Layer Deposited Nitrides: Exploring Processing, Structure, Properties and Mechanisms at Multiple Scales
Tomas Grejtak, Tomas Babuska, Jewel Haik, Istiaque Chowdhury, Nicholas Strandwitz, Lehigh University, Bethlehem, PA; Kylie Van Meter, Brandon Krick, Florida State University, Tallahassee, FL; Mark Sowa, Veeco, Waltham, MA; Alexander Kozen, University of Maryland, College Park, MD

Highly wear resistant and low friction metal nitride films are commonly used in many tribological applications such as wear resistant coatings for cutting tools, gas turbines and aerospace components. Tertiary nitrides deposited on silicon by plasma-enhanced atomic layer deposition (PEALD) have been shown to achieve ultra-low wear rates. PEALD technique allows atomic level thickness and compositional control at low energy and deposition temperatures. Additionally, single atomic layers can be uniformly grown on non-planar and porous architectures. Since ultra-low wear of PEALD nitride films has been discovered only recently, there's a lack of fundamental understanding of how PEALD deposition parameters impact tribological and mechanical properties of these coatings. In this work, the influence of substrate material and PEALD deposition parameters on tribological properties of metal nitrides are investigated at microscale using microtribometry and at nanoscale using AFM.

12:30 - 1 pm
3485898: Origin of Self-Healing in Dynamic Crosslinked Polymers: Experiments and Simulations
Zhijiang Ye, Nethmi De Alwis Watuthanthrige, Ballal Ahammed, Madison Dolan, Mehdi Zanjani, Dominik Konkolewicz, Miami University, Oxford, OH; Jian Wu, Harbin Institute of Technology, Weihai, Shandong, China

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

Metalworking Fluids III

Session Chair: TBD

10:30 am - 11:00 am
3485651: Model MWFs Based on Naphthenic Base Oils- Straight Cut or Blend?
Thomas Norrby, Linda Visuri, Jinxia Li, Nynas AB, Nynashamn, Sweden

In this study, several MWF Soluble oil and Semi-Synthetic emulsions based on two different naphthenic base oils were created. The purpose was to elucidate any and all influence on the properties of these emulsions arising from difference in the fundamental properties of the base oils employed. The naphthenic base oils utilized were two 22 cSt oils, one straight cut (narrow cut) and one blended oil (a wider cut). Two Soluble oil non-ionic emulsifier systems, and four different semi-synthetic (anionic and non-ionic blends) formulations were investigates in soft and hard water, with respect to emulsion droplet size and stability over time. The emulsion particle size, and the emulsion stability as a function of time, was determined by static light scattering utilizing a Malvern MasterSizer equipment, and a TurbiScan unit. The results show that the two base oils yield emulsions with very similar properties under a wide variety of chemistries and conditions

11 - 11:30 am
3492540: Novel Self Emulsifiable Esters for High Lubricity and Low Foam MWF's.
Ronald Hoogendoorn, Patech, Moordrecht, Nederland, Netherlands

In water-soluble Metalworking Fluids (MWF), emulsifiers are used to ensure a stable concentrate in emulsion. However, emulsifiers can have devastating effect in terms of foam, and emulsion stability. Unfortunately, the larger and more polar molecules for traditional mineral base oil, which are better lubricants, require more emulsifiers. Therefore, Self-Emulsifying Esters (SEE) got more attention on keeping lubricity and reducing emulsifiers usage at the same time. Using the study of interfacial properties between MWFs and metal, novel SEEs were developed to improve the lubricity and foam properties of MWFs. The molecular size and functional group effect on lubricity and emulsifiablity were also studied. This paper will compare novel SEE with these emulsifiable base oils in terms of foam, emulsion stability and lubricity in soluble oils. Moreover, comparison with PAG, EO/PO block-copolymers and commercial SEE were also conducted.

11:30 am - 12 pm
3484684: A New Method to Simulate Strip Drawing Tests on the Lab-Scale
Dirk Drees, Emmanuel Georgiou, Falex Tribology NV, Rotselaar, Belgium; Mark Veldhuis, Philips, Drachten, Netherlands; Javad Hazrati, Universiteit Twente, Enschede, Overijssel, Netherlands

Simulations and numerical modelling of forming processes depend on a good knowledge of the friction at the tool-sheet metal contact. To calculate the lubricating properties of forming oils, Boundary Lubrication Shearing (BLS) and Mini-Traction machine (MTM) lab-scale tests can be used. However, macroscopic strip drawing tests show a contradictory relationship of friction with increasing temperature. For this reason, in the framework of a large EU project named ASPECT, a new method was developed with a Multispecimen tester to simulate matching contact conditions and measure the friction during deformation of a sheet. The aim is to use this method as a simplified way of evaluating the temperature and speed dependence of friction, and to provide an efficient pre-screening and ranking of forming oils in deep drawing processes.

12 - 12:30 pm
3485050: Surface Behavior and Lubricative Properties of Hydroxyproline Rich, Natural Proteins in Metal Working Fluids
Eric Yezdimer, Gelita USA, Sergeant Bluff, IA; Matthias Reihmann, Gelita AG, Eberbach, Germany

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

12:30 - 1 pm
3499841: Tribological Study of Materials for Effective Cutting Tool Life
Carlos Sanchez, Peter Lee, Michael Moneer, Southwest Research Institute, San Antonio, TX

When machining large volumes of material, such is the case for various aerospace components, having to replace the tool can cost a lot of time and money. In this study, a pin on disc test was designed to model a real cutting process so as to rank the tribological behavior of different material pairs and cutting methods. A tungsten carbide pin was set to cut into titanium and Inconel discs under controlled conditions. Coolants such as liquid nitrogen, and emulsions were directed into the working interface to reduce heat and provide lubrication. Based on the pin on disc test results, certain combinations were chosen to run finishing operations on full scale machining of components. Results indicated a correlation to the bench test, as the material pairs out performed previously used methods. The implementation of these combinations lead to an increase in cutting tool life and up to an 83% reduction in cutter usage when machining large components.

3F — Virtual Meeting Room 6

Nanotribology III

Session Chair: Suvrat Bhargava, TE Connectivity, Middletown, PA
Session Vice Chair: Arnab Bhattacharjee, University of Delaware, Newark, DE

10:30 am - 11:30 am
3565571: INVITED TALK: Mechanical Dissipation of Energy: From Breaking of Bonds to the Release of Adhesive Contacts
Lars Pastewka, Antoine Sanner, Albert-Ludwigs-Universitat Freiburg, Freiburg im Breisgau, Germany; Richard Jana, Aalto-yliopisto, Aalto, Finland

Rate-independent energy dissipation is typically associated with mechanical instabilities, as prototypically described by the Prantl-Tomlinson model. This talk discusses two scenarios in which mechanical instabilities give rise to dissipation in real system. At the molecular scale, bond-breaking events are fast processes that can be regarded as mechanical instabilities. Molecular calculations using a machine-learning interatomic potential show that bond-breaking events in amorphous carbon can be described as a stress-assisted bond-breaking process. The energy dissipated in the process can be directly correlated with the yield stress of bulk material or the friction force during contact and sliding. At larger scales, adhesive interactions between rough surfaces can give rise to sudden detachment of asperities. This constitutes an instability that dissipates the energy difference between the attached and the detached state.

11:30 am - 12 pm
3499664: Tribological Experiments in the Age of Big Data
Nikolay Garabedian, Paul Schreiber, Christian Greiner, Karlsruhe Institute of Technology, Karlsruhe, Germany

Among the many reasons for implementing robust data management of scientific results, there are two that stand out: first, the now almost ubiquitous requirements put forward by public funding agencies, and, second, the potential for accelerated scientific discovery by integrating machine learning into tribology research. To formalize tribological knowledge and establish metadata standards in our group, we created a crowd-based wiki, which contains the precise meaning and frame of use for the terms that describe a tribological experiment. This knowledge-base is then paired with an electronic lab notebook that automatically annotates the data at source. Thus, the regulatory requirements for making our scientific data reusable are satisfied. To enable machine learning-based analysis, we drew the logical connections between the wiki entries, which had the additional benefit of making the results interoperable, allowing other scientists to use the same data to support their own research.

12 - 12:30 pm
3483709: Isopropanol Vapor Phase Lubrication of Multi-Asperity Interfaces: The Role of Capillarity and Boundary Lubrication
Bart Weber, Feng-Chun Hsia, Advanced Research Center for Nanolithography, Amsterdam, Netherlands

We observed that the static and dynamic friction generated by multi-asperity PMMA-on-glass interfaces is reduced by up to 50% when the ambient environment is replaced by isopropanol (IPA) saturated N_2. Three mechanisms that potentially contribute to the difference in friction were proposed: (i) capillary adhesion, (ii) shear forces generated by the stick-slip motion of capillary condensates at the sliding surfaces and (iii) boundary lubrication. The proposed mechanisms were studied in single nanoasperity contacts and related to macroscopic friction through BEM contact calculations. We conclude that boundary lubrication and capillary adhesion contribute to the changes in PMMA-on-glass friction upon IPA vapor phase lubrication.

12:30 - 1 pm
3476540: Tribological Performance of Piston Compression Ring in Artificial Intelligence Based Design Green Lubricant During Cold Start-Up
Shahid Imran, HITEC University, Taxila, Pakistan

This work presents the amount of loss of energy to overcome friction of piston rings and design of hybrid nano-fluids based on Artificial Neural Network during cold-start-up. The input feature parameters are load, concentration, speed, and concentration, and output parameter is Coefficient of Friction. Customized ANN was developed and pin on disc experimental data generated is used for training the model. New hybrid nanofluid was developed having better tribological properties by computational technique. Multi-physics numerical simulations were conducted on compression ring during cold start-up by combining the piston ring dynamic model with lubrication model for hybrid nano fluid and mineral oils. The development of film thickness, frictional force and power loss are studied during each cycle. Comparative analysis of the numerical simulation results was conducted and results showed that Artificial Intelligence based lubricant has 45-51% less COF than mineral oil.

3G — Virtual Meeting Room 7

Rolling Element Bearings I

Session Chair: Trevor Slacke, American Roller Bearing, Morganton, NC
Session Vice Chair: Hannes Grillenberger, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany

10:30 - 11 am
3485603: Contact Protection by Grease in Aeronautical Heavily Charged Oscillating Bearings
Lucas Frache, David Philippon, LaMCoS Laboratory, Villeurbanne, Rhône Alpes, France; Francesco Massi, DIMA - University of Rome "La Sapienza", Rome, Italy

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

11 - 11:30 am
3483102: Film Thickness and Starvation in Grease Lubricated Bearings
Piet Lugt, SKF Research and Technology Development, Houten, Utrecht, Netherlands; Hui Cen, Xuchang University, Xuchang, Henan, China

The film thickness for grease lubricated bearings is normally calculated using the base oil viscosity, where it is assumed that the bearing is running under fully flooded conditions. This paper shows that, for sealed-for-life bearings, starvation already occurs at relatively low speeds and that the film thickness can be described by the product of speed, viscosity and Hertzian semi-contact width. It is shown that replenishment is not significant on the tracks in-between the balls but that it is a local phenomenon. The relation between film thickness and speed times viscosity times contact size is different from what is found in single contacts. The film thickness decreases as a function of speed and viscosity, but the effect is only small leading to an almost constant film thickness with increasing product of viscosity and speed.

11:30 am - 12 pm
3499278: Friction-Based Calibration of Raceway and Flange Lubrication Models for Railway Bearing Performance Prediction
Arnaud Ruellan, Pietro Tesini, Lieuwe de Vries, Armin Schlereth, Giuseppe Guala, SKF Group, Vilar Perosa, Italy

In order to increase the maintenance interval of high-speed train wheelset bearings, the designs are optimized to reduce power losses, hence operating temperatures, and thereby increasing the life of the lubricant. To do so, quasi-static and dynamic simulations of full railway wheelset bearing units are performed using SKF proprietary software. To predict friction in bearing units the amount of lubricant available for the contacts between the rolling elements and the rings is key. In this study, a model has been developed for this amount to be function of the operating conditions, both on the raceways and on the flanges. To calibrate the model, a dedicated torque measurement device has been set-up on railway bearing test rigs. This strategy enables a prediction of the lubrication conditions and therefore a reliable prediction of power loss reduction in the optimized bearing units for various operating conditions.

12 - 12:30 pm
3484440: Wear Development Due to Oscillating Movement Operating Conditions as Employed in Rotor Blade Bearings in Wind Turbines
Sebastian Wandel, Gerhard Poll, Leibniz Universitat Hannover, Hannover, Niedersachsen, Germany; Arne Bartschat, Fraunhofer-Institut fur Windenergiesysteme IWES, Bremerhaven, Bremen, Germany

Rotor blade bearings enable the rotor blades to pivot about their longitudinal axis and thus control the power output and reduce the loads acting on the wind turbine. Over a design period of 20 years, rolling bearings are exposed to frequent oscillating movements, especially due to new control concepts such as Individual Pitch Control, which can lead to functionally relevant wear that reduces the service life. The

wear phenomenon False Brinelling plays a particularly important role. Qualitative and quantitative studies on the wear behavior of rolling element bearings using small scale tests provide insights about the extent to which wear develops under selected oscillating operating parameters . It is shown that a small number of oscillation cycles with small amplitudes can lead to significant damage, resulting in a tenfold increase in torque. It is also shown that the damage can be significantly reduced by choosing a grease with suitable properties such as low base oil viscosity.

12:30 - 1 pm
3482687: Transient Finite Element Simulation of Bearing Surface Damage Due to Oscillating Motion with Consideration of Mixed Lubrication Conditions
Jae-Il Hwang, Josephine Kelley, Qiongdan Hu, Gerhard Poll, Institute of Machine Design and Tribology, Garbsen, Germany

Surface damage in rolling bearings can be caused by small oscillating motion in the form of false brinelling or fretting corrosion. This surface damage depends on operating and lubrication conditions. An FE model of an angular contact ball bearing was created to transiently simulate the contact behaviour due to oscillating motions, depending on oscillation frequency and amplitude. To take into account the change in lubrication conditions over an oscillation cycle, the coefficient of friction was calculated using the Maxwell model, considering the kinematic conditions, the oil rheology, and the mixed lubrication conditions. The frictional work density resulting from the simulation shows a good correlation with the surface damage that occurs on the raceway of test bearings.

3H — Virtual Meeting Room 8

Lubrication Fundamentals I: Non-tribological Oil Properties

Session Chair: Jodie Nelson, American Refining Group, Bradford, PA
Session Vice Chair: Q. Jane Wang, ME, Northwestern University, Evanston, IL

10:30 - 11 am
3496577: Analytical Approaches to Chemical Structure and Physical Property Measurements of Lubricant Oils
Eleanor Riches, Caitlyn Da Costa, Jeff Goshawk, Michael Jones, Gordon Jones, Waters Corporation, Wilmslow, Cheshire, United Kingdom; James Browne, TA Instruments, New Castle, DE

Lubricant oils are typically a formulated product comprising a base oil and additive package that impart fundamental performance characteristics to the base oils such as viscosity control, resistance to oxidation, and overall stability. It is important to understand how both the physical properties and the chemical components of the formulated product may vary. Here we present analytical techniques that offer insight into both the chemical structure and the physical properties of different formulated lubricant oils. Thermal analysis was used to compare relative stability of the various oils, while high resolution mass spectrometry was used to investigate potential differences at the molecular level; both approaches were found to show fundamental differences between commercially available automotive lubricant oils.

11 - 11:30 am
3481748: Practical Considerations for the Development of Amine and Phenol Synergies
Jun Dong, SONGWON Industrial Group, Glen Allen, VA

To meet the ever-escalating performance requirements for oxidative stability, it has become a common practice to employ synergistic antioxidant systems in lubricants. One recognized system is the use of an alkylated diphenylamine (ADPA) with a hindered phenolic ester (HPE). The mechanism between the two antioxidants is well documented. However, in practice, successful reproduction of the synergy can still be a challenge from formulary perspective. In this presentation, some of the key factors such as base oil

chemistry, presence of natural sulfur and sulfur containing additives, antioxidant treat level and ratio were examined. It was found that all of the factors can play a profound role to influence the antioxidant synergy. Further consideration also goes to the type of the bench tests employed and the test conditions. Mechanistic hypotheses are provided to assist understanding of the lab observations.

11:30 am - 12 pm
3480826: Oxidative Stability of Estolides
Travis Thompson, Biosynthetic Technologies, Indianapolis, IN

A set of base oil samples, including estolides, esters, PAGs, PAOs, and mineral oils were tested for their resistance to oxidation, according to the industry standard RPVOT test (ASTM D2272). The raw data from these experiments suggest that the RPVOT method underestimates the oxidative stability of estolides and esters relative to the other base oils tested. Different oxidative stability methods were also explored and a comparative analysis was performed.

12 - 12:30 pm
3485249: Modeling Thermal Conductivity of Lubricants
Jannat Ahmed, Q. Jane Wang, Northwestern University, Evanston, IL; Ning Ren, Frances Lockwood, Valvoline Inc., Lexington, KY

Thermal conductivity (TC) of a lubricant has a profound influence on the life and efficiency of a system. Computational modeling and analysis of TC are imperative to consider structural attributes in thermal fluid design. This research aims to develop a computational model for TC of hydrocarbon lubricants through nanoscale simulation and to analyze the influence of molecular structures on TC. Results from non-equilibrium molecular dynamics simulations suggest that the model can capture the temperature sensitivity of TC. The computed TC values are in a good trend-wise agreement with experimental values. The simulation results also suggest the existence of size effect which requires examining the phonon mean free paths of the molecules and the selection of the simulation domain size accordingly. The authors intend to explore possible ways to deal with the size effect and validate the computational model, then study the nature of the relationship between TC and fluid molecular structure.

12:30 - 1 pm
3497278: Mechanistic Insights into Lubricant Foaming and Foam Control Utilizing Single Bubble Techniques
Vineeth Chandran Suja, Gerald Fuller, Stanford University, Stanford, CA

Lubricant foams are detrimental to lubricated machinery, causing well documented operational and maintenance challenges including increased wear of machine parts and reduced lubricant life. In this talk, we highlight advances in understanding lubricant foams using single bubble techniques (Adv. Colloids Interface Sci. 2020:102295), a class of foam characterization experiments where repeated coalescence experiments utilizing single bubbles are performed to evaluate foam stability and foam stabilization mechanisms. The utility of single bubble experiments for lubricant formulators will be highlighted through two separate examples. First, we use single bubble experiments to reveal a new mechanism of foam stabilization in blended lubricant base oils – evaporation induced Marangoni flows (PNAS 115(31) 7919-7924). Second, we show how this new foam stabilization mechanism can be utilized to develop lubricants and metal working fluids that are intrinsically foam resistant.

3I Virtual Meeting Room 9

Commercial Marketing Forum III

Session Chair: TBD

10:30 - 11 am - **BASF Corporation**

11 - 11:30 am - **Evonik Oil Additives USA. Inc.**

11:30 am - 12 pm
3568227: Effects of Filtration on Münzing Defoamer Performance in Aqueous Metal Removal Fluids
James Sullivan, Stefanie Velez, Munzing Chemie GmbH, Bloomfield, NJ

The defoamer is a critical component of an aqueous metal removal fluid formulation. During use of the fluid, the defoamer functions to minimize foam buildup, which is undesirable for reasons such as reduction of lubrication and heat removal. Although the defoamer is expected to perform well initially, its defoaming properties should also persist over an extended period of time. Filtration is one factor that is purported to affect the long term persistence of a defoamer, yet little has been reported on this topic. This paper will describe the effects of the filter media (material of construction) type and the defoamer chemistry on the defoaming performance. The results show that defoamers based on 3-dimentional (3D) siloxane technology generally outperform other technologies and that the filter media can have a significant impact.

12 - 12:30 pm - **Colonial Chemical Inc.**

12:30 - 1 pm
3573199: High VI 0W-16 and 0W-20 Engine Oils using Evonik's VISCOPLEX® Viscosity Index Improvers - The Optimal Choice for Hybrid Electric Vehicles
Peter Moore, Evonik Oil Additives, Horsham, PA

The global passenger car fleet is shifting to increased electrification to reduce greenhouse gas emissions, and hybrid electric vehicles continue to play a large part in this trend. Although the fuel economy of hybrid electric vehicles is achieved by taking advantages of aspects like regenerative braking and reduced engine sizes, the performance of the engine remains central to the consumption of fuel. With frequent stopping and starting, lubricant temperatures typically operate at lower temperatures than conventional ICE vehicles. Low viscosity engine oils with high-VI, such as 0W-16 and 0W-20 grades, provide the optimal balance of fuel economy performance and equipment protection by delivering a more consistent viscosity-temperature relationship. VISCOPLEX® Viscosity Index Improvers provide a straightforward solution to maximize the fuel economy and efficiency of hybrid vehicles.

4A Virtual Meeting Room 1

Condition Monitoring II

Session Chair: TBD

2 - 2:30 pm
3498173: Fluid Analysis in Condition Based Monitoring and Reliability
Julio Acosta, POLARIS Laboratories, Richmond, TX

In today's world, ensuring the uptime and reliability of equipment is vitally important to the success of a company's operations. There are many tools that can assist in monitoring your equipment. Fluid Analysis is a vital tool since it can detect problems before damage occurs and extend equipment life. But more importantly, how does fluid analysis impact your maintenance process? How can you use the data to create trends and set alarms to deviations from normal? How can these data assist in averting catastrophic failures and institute solutions prior to failures? How can you get the maximum benefit of your lubricants and your fluid analysis? This presentation will focus on Fluid Analysis' ability to pinpoint and monitor conditions that affect reliability and impact maintenance programs. The presentation will include real life scenarios so you can see how the principles can be applied to the challenges you face.

2:30 - 3 pm
3531472: Fast and Reliable Quality Control of Fresh and In-Service Lubricants by FT-MidIR Spectrometry.
Aaron Mendez, Ayalytical Instruments Inc., Houston, TX

Production, transportation, and processing in the oil industry are negatively impacted by loss of efficiency of lubricating systems. Lubricants degrade overtime with loss of viscosity, oxidation, nitration, sulfation, polar contamination and water and soot formation.
Additive depletion, properties and quality parameters of condition monitoring programs can reliably be measured in real time. These tests can be determined with an unattended software-controlled procedure by FT-IR analysis and chemometric models based on customer-expandable libraries. This highly utilized technology provides trending and quantitative high-speed analysis, robust calibration, ease of use and low maintenance, offering potential for analytical developments such as Gasoline, Diesel and FAME contamination among others.
Experimental results of formulations properties such as TAN, TBN and viscosity are discussed and their comparison to classical ASTM methods are presented showing excellent correlation.

3 - 3:30 pm - Break

3:30 - 4 pm
3559470: Analysis of Metal Additives and Wear Metals in Lubricants by High-Resolution ICP-OES
Oliver Buettel, Analytik Jena US LLC, Beverly, MA

The analysis of metals in lubricants serves different purposes: Product specification monitoring as part of quality control, to ensure the contents of metal-based additives, and wear metals analysis for monitoring equipment conditions and detecting potential failures before they occur. Metals can be present in lubricants over a wide concentration range, from traces to percent-levels.
ICP-OES, due to its wide working range and high sample throughput, is particularly suited for this type of analysis. Certain challenges exist to this technique, most of which are associated with analyzing organic solutions. These include plasma instabilities and carbon deposition, which affect precision and long-term stability, and complex background spectra from the organic solvent.
This presentation discusses the challenges of lubricant analysis by ICP-OES, and points out how modern instrumentation helps overcome these challenges and produce accurate, reproducible results at high sample throughput.

4 - 4:30 pm
3500173: Diagnosing Improper Bearing Lubrication Using Oil Analysis
Evan Zabawski, TestOil, Strongsville, OH

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

4:30 - 5 pm - **Condition Monitoring Business Meeting**

4B Virtual Meeting Room 2

Additive Manufacturing I: Special Symposium

Session Chair: TBD

2 - 2:30 pm
3551361: Wear and Friction of Additively Manufactured Stainless Steel Materials
Robert Jackson, Sanjeev KC, Pooriya Nezhadfar, Collin Phillips, Nima Shamsaei, Auburn University, Auburn, AL; Marian Kennedy, Clemson University College of Engineering Computing and Applied Sciences, Clemson, SC

This study investigated the tribological behavior of additively manufactured 17–4 PH SS specimens via the laser sintering process compared to that of wrought counterparts. The results obtained from a ball on disk tribometer experiment were used to evaluate the friction and wear properties in dry and lubricated conditions under various applied loads. Although the results showed that additively manufactured parts have good potential to be an alternative to wrought counterparts in terms of friction and wear behavior, they do appear to be more susceptible to surface fatigue wear mechanisms.

2:30 - 3 pm
3482009: Tribological and Mechanical Properties of High Entropy Alloys
Morgan Jones, Andrew Kustas, Ping Lu, Michael Chandross, Nicolas Argibay, Sandia National Laboratory, Albuquerque, NM

High Entropy Alloys (HEAs) show great promise for applications including coating technologies, anticorrosive high-strength parts, and integrated circuit foundries. Since the publication of Cantor's work on equi-atomic multicomponent alloys in 2004, there has been over 1000 publications on the chemical, mechanical, and electrical properties of this new material class. We present results of the tribological and mechanical properties of these materials in an ultra-high vacuum environment. Test specimens include the Cantor (CoCrFeMnNi) and 3- and 4-component refractory HEAs that were prepared with additive manufacturing methods. We present evidence of a low friction regime ($\mu<0.4$), and the link to extreme grain refinement achievable even in non-oxidizing environments. Scratch tests were also used to probe strain rate sensitivity and strengthening mechanisms, supported by transmission electron microscopy and chemical analysis.

4C Virtual Meeting Room 3

Nonferrous Metals II: Tribology and Biobased Session in Memorial of Girma Birresaw, PhD

Session Chair: Annie King, Houston, TX

2 - 2:30 pm
3476874: Correlation Between Microscopic Surface Damage and Frictional Behavior of Lubricants for Stamping Automotive Aluminum Sheet Products
Mehdi Shafiei, Shania Polson, Novelis, Novi, MI

Three different types of lubricants, namely a mineral oil-base lubricant, a wax-base dry film lubricant and a polymer-base dry film lubricant were applied to aluminum sheet samples. The frictional behavior of the samples were evaluated using a single draw bead simulation tool. The contact and non-contact surfaces

of the samples were characterized using optical microscopy, electron microscopy and topography measurements. The results showed a significant difference between the ability of the lubricants to reduce mechanical contact and surface damage during forming simulations. A direct correlation between forming friction and microscopic surface damage was observed.

2:30 - 3 pm
3479424: Filtration of Rolling Fluids
Craig Thomas, JR Schneider Co., Inc., Benicia, CA

The manufacturing of Aluminum foil and sheet requires the metal to be rolled to a precise gauge (thickness) for the particular application. This process requires the use of specific rolling oils to help form, cool, lubricate and remove debris from the process. The used and dirtied oil is then filtered to remove the particulate which is a waste formed from the rolling process. This used oil requires precise filtration to remove the particulate and clean the oil for reuse in the rolling process.
JR Schneider with its end users have been using a specific filter aid for use in this process. This filter aid (Acticel) provides for significant filtration and long cycle times for the end user's filter. This discussion will provide background on this type of oil/coolant filtration, the chemistry and mechanics of the filtration and the results from using this type of filtration method.

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

3:30 - 4 pm
3482772: Biobased Disulfide Additive Based on Soybean Oil
Grigor Bantchev, Girma Biresaw, James Lansing, Rogers Harry-O'Kuru, Yunzhi Chen, USDA-ARS National Center for Agricultural Utilization Research, Peoria, IL

This talk is in memory of Dr. Biresaw, who unexpectedly passed away September 8, 2020. The development of fully biobased lubricants requires the application of biobased base oils and biobased additives in the formulation to provide the full environmental, health, safety, and economic benefits expected from replacing petroleum-based products. In the past few years, there has been steady progress in the development and commercialization of biobased base oils. However, the development and commercialization of biobased additives has not been as robust as that for biobased base oils. As a result, most current biobased formulations are developed using commercial petroleum-based additives. Such formulations are partially biobased and not capable of providing the full benefit of a fully biobased formulation. In this presentation, recent work on the synthesis and characterization of a new biobased disulfide additive from soybean oil will be discussed.

4 - 4:30 pm
3484628: Vegetable Oils for Metalworking Lubricants: Physico-Chemical and Stability Aspects of Different Options
Joseph Pattathilchira Varghese, Formerly Indian Oil R&D Center, Faridabad, Haryana, India

Lubricants used for metalworking manufacturing processes should possess good boundary lubrication, load carrying and EP properties along with suitable physico-chemical and stability aspects. Natural esters (vegetable oils) and synthetic esters, because of their excellent boundary lubrication, have been conventionally used in metalworking lubricant formulations. Formulators are always on the lookout for natural and synthetic esters with improved characteristics for blending metalworking lubricants. In the presentation, requirements of vegetable oils used in metal working lubrication and their comparative properties will be discussed with specific focus on their performance in this particular application: mainly physico-chemical and stability related features. In the same line, in continuation to the author's earlier studies, stability aspects along with physico-chemical suitability of the non-edible vegetable oils will also be discussed for application in metalworking lubricants.

4:30 - 5 pm - **Nonferrous Metals Business Meeting**

Materials Tribology III

Session Chair: TBD

2 - 2:30 pm
3485503: Method for Tribological Experiment to Study Scuffing Instigation on AISI 52100 Steel and Hard Ceramic Coatings
Kelly Jacques, Diana Berman, University of North Texas, Burleson, TX; Stephen Berkebile, Nikhil Murthy, Army Research Laboratory, Aberdeen Proving Ground, MD

Scuffing is a wear mechanism experienced by materials during sliding that leads to catastrophic failure of fuel-lubricated mechanical components. In this study, a high-frequency reciprocating tribometer is used to determine a set of tribological experimental parameters that instigate scuffing on AISI 52100 steel. The high-frequency reciprocating rig fuel lubricity standard was used as a basis for the development of a new experimental method. The experimental parameters of interest include grinding lay orientation, temperature, counter body material, substrate hardness, contact load, and stroke length. Several protective coatings, such as Co-Cr-Mo alloy, WC-17Co, and WC-10Co-4Cr, were investigated with tribological experiments to determine their resistance to scuffing in low-viscosity fuel and compared to 52100 steel. The performance of these materials was characterized by determining the friction coefficients, chemical composition changes, and wear mechanisms experienced during wear.

2:30 - 3 pm
3484132: Tribological Behavior of Textured Polymer Surfaces
Mohammad Hossain, Emeka Chukwuonu, Texas A&M University-Kingsville, Kingsville, TX; Hung-Jue Sue, Texas A&M University, College Station, TX

Introduction of textures on polymer surfaces has been widely used to improve hydrophobic properties of polymers in various applications such as automotive, aerospace, biomedical, electronics, and household appliances. However, surface damage resistance of textured polymer surfaces is a major concern as the textured surfaces are highly susceptible to mechanical wear and abrasion. Understanding the development of scratch-induced surface damages in polymers, which arise due to sliding indentation of a rigid asperity, is rather challenging if the surface is textured. In this study, hydrophobic property of model polymer systems has been improved through introduction of various surface textures. Influence of surface texture on scratch resistance of model polymers is studied. A three-dimensional finite element method (FEM) modeling has been used to understand the stress and strain field development in textured polymer surfaces during scratching.

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

3:30 - 4 pm
3482506: Determination of Scuffing and Wear of Materials in Low-Lubricity Fuels
Stephen Berkebile, Nikhil Murthy, CCDC Army Research Laboratory, Aberdeen Proving Ground, MD; Kelly Jacques, Diana Berman, University of North Texas, Denton, TX; Caleb Matzke, Maharshi Dey, Surojit Gupta, University of North Dakota, Grand Forks, ND; Auezhan Amanov, Ruslan Karimbaev, Sun Moon University, Asan, Republic of Korea

High-pressure common-rail fuel delivery systems for internal combustion engines are typically designed to operate with diesel fuel. The pumps in these systems can fail prematurely by scuffing when used with fuels of low viscosity and lubricity. Materials resistant to scuffing in fuel-lubricated mechanical interfaces have the potential to expand the envelope of allowable fuel properties for such systems. We developed a measurement method to evaluate scuffing and wear of materials in fuels, adapted from the high-frequency reciprocating rig fuel lubricity standard measurement. Using this method in F-24 jet fuel,

ethanol, and dodecane, several hard coatings (iron boride, tungsten carbides, chrome carbide and oxide, some treated with ultrasonic nanocrystalline surface modification) experienced varied wear but increased resistance to scuffing overall vs. AISI 52100 steel, while composite materials (MAX/metal and MAX/polymer) demonstrated highly fuel-dependent behavior.

4 - 4:30 pm
3500772: Paleo-Tribology: Inspiration from Fossil Grinding Dentitions; From Wear Models to Damage Tolerant Composites
Tomas Grejtak, Tomas Babuska, Lehigh University, Bethlehem, PA; Soumya Varma, Siddhartha Pathak, Iowa State University, Ames, IA; Tyler Hunt, Stephen Kuhn-Hendricks, Gregory Erickson, Brandon Krick, Florida State University, Tallahassee, FL; Mark Norell, American Museum of Natural History, New York, NY

Biological systems have been used for inspiration in numerous applications in engineering. In our collaboration combining engineers, paleontologists, and comparative biologists, we present a new source of bioinspiration – the fossil record. Here, we specifically focus on the dentition of grinding animals and show how natural selection can inspire new design paradigms for applications in engineering. Grinding dentitions of grazing animals are designed to withstand millions of chewing cycles at high contact stresses and are typically composed of hard and brittle enamel, and soft, bone-like dentine and cementum. We use this biological system to inspire two engineering tools: 1) damage-tolerant materials for high pressure contacts with abrasive particles and 2) optimization tools for wear of multimaterial composites.

4:30 - 5 pm
3565111: A Novel Method to Assess Conventional Tribological Properties of Hard Coatings by Pin-On-Disc Testing
Edoardo Goti, Luigi Mazza, Andrea Mura, Politecnico di Torino, Torino, Italy; Jiri Nohava, Pavel Sedmak, Anton Paar TriTec SA, Corcelles, Neuchâtel, Switzerland

Pin-on-disc is commonly used to study the performance of wear resistant coatings but experiments usually stop before the coating failure, as ISO 18535 also prescribes. However, if suitable friction measurements are obtained, two representative values of the coefficient of friction (CoF), one before and the other after coating failure, can characterize the coating. A novel method is proposed to obtain these values by simply analyzing friction curves and a conventional lifetime of the coating can also be obtained. The method is applied to an extensive test campaign on a PVD TiN coatings and the two characteristic CoF display very low variability, below 5%. As to the coating lifetime, it correlates well with the thickness of the hard layer. Preliminary results with CrN and DLC are also presented to verify the method in different conditions. Nanoindentation test, scratch tests, ball-crater tests and SEM analysis supported the information obtained by pin-on-disc friction curves.

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

4E — Virtual Meeting Room 5

Metalworking Fluids IV

Session Chair: TBD

2:00 pm - 2:30 pm
3484869: The Future of Metalworking Fluid: It's Biobased!
Jeffrey Mackey, Biosynthetic Technologies, Indianapolis, IN

The environmental and safety aspects of metalworking fluids are becoming increasingly more important. Forced by new regulations lubricants manufacturers worldwide are replacing the mineral base oils in metalworking fluids by natural sourced derivatives. As several additives have been eliminated from use in MWFs, including nitrites and short-chain chlorinated paraffins, there is a growing pressure to further eliminate additives that may be harmful to the worker or the environment. In this session, we will cover the new requirements for performance and reduced environmental and human exposure that lead to the development of bio-based metalworking fluids. In addition, this session will cover how government regulation of MWFs (particularly their additives) is almost certain to tighten, creating a conundrum for formulators who need to produce fluids that perform well for extended periods and also protect the machinery, workpiece, environment and most of all the workers.

2:30 - 3 pm
3478594: New Solution for Aluminum Machining with Synthetic Fluids
Mickael Ponsardin, TOTAL LUBRICANTS, Pindamonhangaba, SP, Brazil

Metalworking synthetic fluids have been used since the 1950s for removal operations. Despite their many advantages such as sump life and tool life, their use remain limited at around 15% of the removal fluids. Typically based on PAG, standard synthetics fluids have one major weakness: they bring low lubricity. Substitutes of PAG hardly improve this feature. When raw materials are totally soluble into true solution they carry poor lubricity. This low lubricity impede the most stringent operations or the machining of ductile metals such as aluminum alloys which tends to form built-up edge. The growing demand for aluminum means that most of the machining workshops today require a product able to machine both ferrous and non ferrous metals. A new innovative solution allow to reach a new step in aluminum machining with true synthetic solution.

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

3:30 - 4 pm
3475839: Measuring Tapping Performance Parameters - Using Tapping Torque to Evaluate Coolants and Coolant Additives
Michael Miller, Univar Solutions, Houston, TX

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

4 - 4:30 pm
3479656: Polyglykol as Performance Wear Lubricant and Synergism with Extreme Pressure Additives on Net Oil Metalworking Fluid
Eduardo Lima, Dow Chemical Brazil, Jundiai, Sao Paulo, Brazil

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

4:30 - 5 pm
3500883: Multiple Light Scattering for Physical Stability Analysis of Concentrated Dispersions
Gordon Irvine, Charles Nider, Pascal Bru, Formulaction, Inc, Worthington, OH; Christelle Tisserand, Yoann Lefeuvre, Gerard Meunier, Formulaction, Dallas, TX

Emulsions, dispersions, and foams will eventually undergo destabilization processes related to sedimentation, creaming, clarification, flocculation, or coalescence which may reduce product performance. For formulators to optimize products such as metalworking fluids and other lubricants, in-depth examination of the product in its native state is critical to produce a quality product within a reasonable development time-frame. Herein, we present a technique based on Multiple Light Scattering (MLS) to fulfill this purpose. MLS is a proven technique that can rapidly characterize the dispersion state of concentrated samples and the mean diameter of dispersed particles. By detecting and predicting the product stability, overall product quality and shelf-life predictions can be made in a fraction of the time compared to simple visual stability tests. Moreover, the direct measurements of particle migration and size changes ensures accurate shelf-life predictions over qualitative measures.

5 - 5:30 pm - **Introduction to the Metalworking Course**

4F Virtual Meeting Room 6

Nanotribology IV

Session Chair: Filippo Mangolini, The University of Texas at Austin, Austin, TX

2 - 2:30 pm
3529206: MD Study of Adhesion between a Si tip and Si substrate During Indentation and Sliding
Judith Harrison, US Naval Academy, Annapolis, MD; Zachary Milne, Sandia National Laboratory, Albuquerque, NM; Robert Carpick, University of Pennsylvania, Philadelphia, PA; J. Schall, North Carolina AT&T University, Greensboro, NC

Adhesion between single crystal Si tips and Si(111) substrates was examined using molecular dynamics (MD) to model experiments of nanoscale silicon tip-tip contacts using nanoindentation coupled with TEM. Experimentally, adhesion was observed to increase by an average of nearly 20x when sliding occurred, while low adhesion was recovered when contact was made without intentional sliding. MD simulations of contact with and without sliding were performed using Si tip-substrates couples with matching degrees of hydrogen termination. Hydrogen terminations between 20-100% and two different tip-substrate alignments were examined. In general, friction and pull-off force increased when sliding occurred and is linked to covalent-bond formation. The increase in adhesion was larger for lower amounts of hydrogen termination. Simulation results will be discussed and they confirm the experimental hypothesis that repassivation of the surfaces reduces adhesion.

2:30 - 30 pm
3484691: Interfacial Interactions and Tribological Behavior of Metal-Oxide/2D-Material Contacts
Tobin Filleter, Shwetank Yadav, Taib Arif, Guorui Wang, Rana Sodhi, Yu Hui Cheng, Chandra Veer Singh, University of Toronto, Toronto, Ontario, Canada; Guillaume Colas, 4Univ. Bourgogne Franche-Comté FEMTO-ST Institute, Besançon, France

This work studies the interfacial tribological behaviour of ultrathin graphene and MoS_2 against oxidized pure metals (i.e. Cu and Ti) and oxidized metal alloys (i.e. 440C-Steel). Pure metals such as Cu and Ti oxidize to form CuO and TiO_2 while oxidized 440C-Steel surfaces have the presence of primarily Fe-oxides with traces of Mn- and Cr-oxides. These oxides change the nature and strength of interactions (i.e. chemical vs. physical bonding) with the basal planes of 2D-materials. The chemical interaction results in overall higher friction, interfacial-shear-strength (ISS) and adhesion as compared to a weaker physical

interaction. For strong chemically interacting interfaces, the difference in interfacial electronic charge distribution can further differentiate the tribological behavior between oxidized-metal/2D-material contacts. Lower interfacial energy variation and a more homogenized interfacial charge distribution along the interface were identified to lower friction and adhesion.

3 - 3:30 pm - Break

3:30 - 4 pm
3499774: Structure, Solvation and Friction of Cyclic-Hydrocarbons Confined at Graphitic Interface
Behnoosh Sattari Baboukani, Prathima Nalam, SUNY University at Buffalo, Buffalo, NY; Zhijiang Ye, Miami University, Oxford, OH

Recent advances in two-dimensional (2D) materials such as graphene have opened a new path in utilizing the atomically thin layers as lubrication additives due to their ultra-low shear strength, weak interlayer interactions and the surface chemical stability. The presence of single-layer graphene can enhance the load-bearing capacity of the contact through molecular ordering of solvent molecules at the interface. In this study, atomic force microscopy is employed to measure nanoscale friction of graphene layers immersed in cyclic hydrocarbon medium (i.e. cyclohexane, benzene). The commensurate effects (lattice-misfit) between the crystalline graphene and the adsorbed hydrocarbon molecules are shown to play an important role in the measured friction forces. An enhancement of layering has been observed for cyclohexane on graphitic surfaces in comparison to silica substrate, resulting in a 95% reduction in friction forces on graphitic surfaces.

4 - 4:30 pm
3500077: Nanoparticle Sintered Tribofilm Removal Study: An Experimental Approach
Steven Thrush, US Army CCDC GVSC, Warren, MI

An effort was conducted to investigate tribofilm removal mechanisms of a novel nanoparticle antiwear additive. Spherical five nanometer zirconium oxide (ZrO_2) nanoparticles were dispersed in polyalphaolefin (PAO) synthetic base oil and tested between AISI 52100 steel counterfaces in a ball-on-disk tribometer with a slide to roll ratio of 50%. The apparatus allowed tribofilm thickness data to be tracked in-situ at set intervals and tribofilms reaching a maximum thickness of 150 nanometers were measured. Tribofilm removal was quantified over time by removing the free particles from the sample cup after the generation of a tribofilm, followed by a subsequent tribological test in unadditized PAO base oil. The removal study revealed a thinner tribofilm, which was resilient to further wear and provided complete protection of the substrate steel. Comparatively, lack of an existing tribofilm would result in scuffing within the first 10 minutes when testing the unadditized PAO base oil.

4:30 - 5 pm
3516653: In-Situ SEM Nanomechanical Characterization of Tribofilms Derived from Inorganic Nanoparticles
Kora Farokhzadeh, Praveena Manimunda, Bruker Nano Surfaces, San Jose, CA; Steve Shaffer, Shaffer Tribology Consulting, San Jose, CA

Inorganic nanoparticles are introduced as lubricant additives to maintain low friction in extreme pressure and boundary lubrication regimes due to their ability to enhance load bearing capacity and thermal stability. To implement model lubricants on large scale and optimize performance it is essential to understand the mechanisms of lubrication and tribofilm formation in mixed or boundary lubrication regimes. In this study, MoS_2, ZrO_2, and CeO_2 nanoparticles were suspended in base (PAO, 75-P) and formulated (10W-30) oils and tested under pin-on-flat reciprocating conditions in steel-steel contact. The tribofilms generated during experiments were characterized using nanomechanical tests to characterize adhesion and shear characteristics of tribofilms. The findings were used to understand how the intrinsic properties of the nanoparticles affect tribofilm formation, friction behavior and interfacial phenomena at different length scales.

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

4G Virtual Meeting Room 7

Rolling Element Bearings II

Session Chair: Daulton Isaac, Air Force Research Laboratory, Wright Patterson AFB, OH

2 - 2:30 pm
3482402: The Next Generation Aircraft Engine High Speed Bearing
Peter Glöckner, Schaeffler Aerospace Germany GmbH & Co.KG, Schweinfurt, Bavaria, Germany

To cope with the requirements of next generation aircraft engines, new rolling bearing designs and oil-systems are required. In this presentation, the experimental and theoretical investigation results for an all-new aircraft engine ball bearing are shown. The ball bearing utilizes the Direct-Outer-Ring-Cooling (DORC) concept, ceramic balls, Squeeze-Film-Damping (SFD) and Duplex-Hardened (DH) raceways. Savings for oil flow quantity of more than 45 % and for power loss of more than 15 % were identified. Outer ring temperature reductions of more than 20 K were achieved, which enables a partial separation of bearing lubrication and cooling. The ultra-high-speed capability of the bearing was demonstrated. Rotational speeds of 24000 rpm – corresponding to DN-values of over 4 million mm/min – were achieved for the first time ever for aircraft engine high speed ball bearings. The environmental and economic benefits for the oil system and the gas turbine are presented.

2:30 - 3 pm
3477365: Innovative Bearing Solutions for E-Mobility Applications
Jitesh Modi, Schaeffler Group USA, Troy, MI

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

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

3:30 - 4 pm
3499371: An Investigation of the Effects of Surface Roughness on Rolling Contact Fatigue
Steven Lorenz, Farshid Sadeghi, Purdue University, West Lafayette, IN

This paper presents a continuum damage mechanics finite element model to study the effects of surface roughness on rolling contact fatigue (RCF) of non-conformal contacts. Surface measurements were performed on rolling element bearings to support the use of sinusoidal waveform to represent tribo-surfaces. EHL pressure distributions were developed, but were later replaced with equivalent symmetric pressure distributions to remove the asymmetry of EHL. The symmetric pressures were incorporated into the FE model to simulate the effect of roughness on RCF. The results indicate that long wavelength surfaces are the most susceptible to surface failure. The results also indicate that fatigue life is reduced as lambda ratio decreases. This is quantified by life reduction factors. These factors were later used to develop a fatigue life equation. The developed fatigue life equation as well as common RCF models, modified with the current life factors, were compared to simulation results.

4 - 4:30 pm
3493327: Tribological and Tribochemical Evaluation of Various Lubricants on Steel as well as WC-DLC Coating under Extreme-Pressure Boundary Lubrication Conditions: Rig Test
Kuldeep Mistry, The Timken Company, North Canton, OH

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

4H Virtual Meeting Room 8

2D Materials + Superlubricity - Materials Tribology and Nanotribology Joint Session I

Session Chair: Arzu Çolak, Clarkson University, Potsdam, NY

2 - 2:30 pm
3504641: Mechanical and Tribological Properties of MXene Nano-Sheets
Andreas Rosenkranz, Universidad de Chile, Santiago , Chile

With the tremendous growth of two-dimensional (2D) materials, these nanomaterials have experienced great relevance in energy storage, catalysis, flexible electronics, among others. MXenes, which have been discovered in 2011 and are 2D transition metal carbides, nitrides, and carbonitrides, are chemically represented by $M_{n+1}X_nT_x$ (n = 1 to 4). This describes alternating layers of early transition metals (M) interleaved with layers of carbon/nitrogen (X) surrounded by surface terminations (T_x: $-O_2$, $-F_2$, $-(OH)_2$, $-Cl_2$ or their combinations). Their structural and chemical diversity makes Mxene nano-sheets very promising candidates to rationally design the resulting mechanical and tribological properties, which is intended to be highlighted in this contribution.

2:30 - 3 pm
3492372: Wear Life of Ni-doped MoS_2 Dry Film Lubricants for Space Applications
Azhar Vellore, Sergio Romero Garcia, UCMerced, Merced, CA; Duval Johnson, NASA Jet Propulsion Laboratory, Pasadena, CA; Ashlie Martini, UCMerced, Merced, CA

Wear life of undoped and Ni-doped MoS_2 coatings was evaluated at application-relevant stress and speed conditions. Evolution of the coatings during run-in was characterized in terms of wear track depth, material composition and microstructure to study wear behavior and explain the longer life of Ni-doped coating. Microstructural analysis revealed that cracking and delamination of Ni-doped MoS_2 during the run-in stage led to more lubricious material available to facilitate sliding. Since mechanical components with these coatings are tested in ambient air condition before being sent to space, Ni-doped and undoped MoS2 coated samples were subject to air testing for varying durations followed by nitrogen environment testing (as a proxy for vacuum) at different contact stresses. These tests provide the first step towards development of a model that enables prediction of remaining coating life in vacuum after a given duration of testing in air.

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

3:30 - 4 pm
3504161: Probing the Influence of Water and Oxygen on the Friction and Wear of MoS2
Tomas Babuska, Tomas Grejtak, Lehigh University, Bethlehem, PA; John Curry, Sandia National Laboratory, Albuquerque, NM; Brandon Krick, Florida State University, Tallahassee, FL

MoS2 solid lubricants used in space applications experience a variety of environments before and during use. When stored, water, oxygen and long periods of aging can affect the lifetime performance of MoS2 lubricants through excessive wear and high initial first cycle friction. In orbit, MoS2 is exposed to atomic oxygen which can oxidize the surface inhibiting the tribological performance. The influence of water and oxygen on the degradation of MoS2 is still not well understood. Using pin-on-disk tribometry, friction and wear of MoS_2 coatings in various environments is explored. Ex-situ and in-situ spectroscopic techniques such as Raman, HS-LEIS, PEEM and KPFM are used to probe changes due to sliding and oxidation.

4 - 4:30 pm
3503112: Robust Solid Lubricant Operable in Multifarious Environments
Aditya Ayyagari, Kalyan Mutyala, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Conventional solid lubricants such as MoS_2 and graphene demonstrate excellent tribological performance in specific environments This limitation prohibits using these solid lubricants in environments that change dynamically We present the results of a novel solid lubricant that was developed using a combination of solution-processed MoS2 and GO that can be deposited using a simple spray-coating technique, showing exceptional performance in ambient atmosphere, dry nitrogen, and vacuum The tribological performance of the coatings evaluated using a ball-on-disc sliding test demonstrated excellent wear/friction performance. TEM and Raman spectroscopy of the tribolayers suggested in-operando friction-induced re-orientation of MoS_2 layers that were protected by GO layers. The simplicity and robustness of the hybrid MoS_2–GO solid lubricant in mitigating wear-friction behavior of steel-on-steel tribopair in a multifarious environment is a game-changing and is promising for various applications.

4:30 - 5 pm
3484970: Achieving Direct Macroscale Liquid Superlubricity under Boundary and Mixed Lubrication
Qiang Ma, Arman Mohammad Khan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL

Literature studies indicate that in order to achieve liquid superlubricity (i.e., coefficient of friction < 0.01) without the benefit of a full hydrodynamic fluid film, one has to satisfy at least two conditions: passivation of the contact surfaces and formation of low-shear-strength films that can withstand high contact stresses. Our research builds on this knowledge by exploring the concept of using two surface-active, fully mixable chemicals in combination to provide liquid superlubricity, one being robust enough for load bearing while the other to provide low shear strength. The surface-active nature of these chemicals allows them to readily adsorb on and passivate surfaces. Under boundary and mixed lubrication conditions, we observed these mixtures giving rise to friction coefficients of less than 0.01, some right from the start and all within less than 1 minute. These observations suggest a new strategy to achieve liquid superlubricity in engineering applications.

5 - 5:30 pm
3482121: Super Lubricity of Solids from Quantum Mechanics
Bo Zhang, Saga Daigaku Riko Gakubu Daigakuin Kogakukei Kenkyuka, Saga, Japan

It is proposed that incommensurate contact surfaces is associated with the super lubricity [1]. However engineering surfaces in contact are almost incommensurate because there are always exist misalignment in crystal orientation between two contact surfaces and crystal defects within the surfaces, while the super lubricity belongs to very limited special cases. Friction-induced low energy basal plane [2] and hydrogenation of carbon-contained materials [3] are also considered as possible mechanisms of super lubricity. Both give a good explanation of low friction but they are definitely not sufficient to substantiate

the super lubricity. Quantum mechanics shows that tangential force in contact surfaces is not directly associated with frictional force, and super lubricity is possible when some quantum criterion is satisfied. This analysis gives the derivation of the quantum criterion.

4I Virtual Meeting Room 9

Commercial Marketing Forum IV

Session Chair: TBD

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

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

3:30 - 4 pm - **Sea-Land Chemical**

4 - 5 pm - **The Lubrizol Corporation**

5 - 5:30 pm - **TestOil**

Biotribology I

Session Chair: Angela Pitenis, University of California, Santa Barbara, CA

10:30 - 11 am
3499561: Impact of Metal Release on Chondrocytes Due to Biotribocorrosion in CoCrMo Sliding against Articular Cartilage
Manel Rodriguez Ripoll, Bojana Simlinger, Friedrich Franek, AC2T research GmbH, Wiener Neustadt, Austria; Christoph Bauer, Christoph Stotter, Thomas Klestil, Stefan Nehrer, Danube University Krems, Krems, Niederösterreich, Austria

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

11 - 11:30 am
3490856: Experimental Biotribological Testing of Hydrogels and Articular Cartilage for Medical Engineering Applications
Paul Staudinger, Anton-Paar GmbH, Graz, Austria; Florian Rummel, Anton Paar Germany GmbH, Ostfildern, Germany; Kartik Pondicherry, Anton Paar India, Hyderabad, India; Dominique Felk, Tuebingen University, Tuebingen, Germany

The complex nature of biological tribosystems requires test scenarios as close as possible to the real life conditions. The current work presents a tribological method for the characterization of frictional behavior of porcine articular cartilage and polyvinyl alcohol (PVA) hydrogels, with the latter as a possible replacement material for cartilage. Extended Stribeck curve measurements and reciprocating sliding tests over a broad range of sliding speeds are carried out to measure the friction in static and dynamic friction regimes. PVA hydrogels are obtained by freeze-thaw (FT) technique (5 cycles from -20 °C to 8 °C). Viscoelastic properties of the PVA hydrogel are also characterized. Special adapters are used to accommodate the soft cartilage and PVA specimen. Results show, that the setup is suited to evaluate the tribological performance of an artificial cartilage system compared to real cartilage.

11:30 am - 12 pm
3499124: The Mechanics of Single Cross-Links which Mediate Cell Attachment at a Hydrogel Surface
Arzu Çolak, Clarkson University, Potsdam, NY; Bin Li, Technical University of Munich, Munchen, Germany; Johanna Blass, Aránzazu del Campo, Roland Bennewitz, Leibniz Institute for New Materials, Saarbrucken, Germany

The response of cells to the mechanical properties of hydrogels depends ultimately on the response of single crosslinks to external forces exerted at cell attachment points. In this study, we prepared hydrogels and confirmed fibroblast spreading after a hydrogel linker was functionalized with the RGD cell adhesive motif. We performed AFM force spectroscopy experiments on the same linkers to probe the mechanics of

single cross-links which mediate the cell attachment and spreading. We compared hydrogels of varying elastic modulus (E) between 4 and 41 kPa. An effective spring constant (k) for the displacement of single cross-links at the hydrogel surface was derived from the distributions of rupture force and molecular stiffness. A factor of ten in the elastic modulus of the hydrogel corresponded to a factor of five in the effective spring constant of single crosslinks, indicating a transition in scaling with the mesh size (ξ) from the macroscopic $E \propto \xi^{-3}$ to the molecular $k \propto \xi^{-2}$.

12 - 12:30 pm
3484432: A New Method to Evaluate Compression, Adhesion and Thread Formation (Tackiness) in Biomedical and Healthcare Products
Emmanuel Georgiou, Falex Tribology NV, Rotselaar, Belgium; Olaf Mollenhauer, Kompass Sensor GmbH, Ilmenau, Germany; Dirk Drees, Falex Tribology NV, Rotselaar, Belgium

Products in the biomedical and healthcare fields are often viscoelastic fluids. Typical examples are hydrogels for knee joints or everyday consumer products such as toothpastes and creams. Their behaviour can be linked to their cohesion, thread formation and adhesion.
For this reason, a new method was developed based on indentation/retraction curves to measure the adhesive strength, thread formation, compression, and separation energy of viscoelastic fluids. This method allows to investigate the influence of different test conditions on these properties. Thanks to the mN precision and high degree of automatization, a relative ranking of these characteristics can be easily obtained with high statistical confidence levels. The applicability of this method is demonstrated through a series of case examples and the relationship with the frictional behaviour of these fluids was investigated via Mini-Traction (MTM) tests.

5B Virtual Meeting Room 2

2D Materials + Superlubricity - Materials Tribology and Nanotribology Joint Session II

Session Chair: Kora Farokhzadeh, Bruker Nano Surfaces, San Jose, CA
Session Vice Chair: Mohammad Vaziriserehk, University of California Merced, Merced, CA

10:30 - 11:30 am
3565696: INVITED TALK: The Fascinating Frictional Properties of Layered Materials
Michael Urbakh, Tel Aviv University School of Chemistry, Tel Aviv, Israel

Structural superlubricity may provide a viable route to the reduction of friction and wear. In this talk I will present results of fully atomistic numerical simulations of static and dynamical properties of graphite/hexagonal boron nitride (h-BN) heterojunctions, performed adopting a recently developed inter-layer potential. We found that structural superlubricity at interfaces between graphite and h-BN persists even for the aligned contacts sustaining external loads. A negative friction coefficient, where friction is reduced upon increasing normal load, is predicted. It is demonstrated that further control over the physical properties of 2D layered materials can be gained via tuning the aspect-ratio of nanoribbons. The sliding dynamics of the edge-pulled nanoribbons is found to be determined by the interplay between in-plane ribbon elasticity and interfacial lattice mismatch.

11:30 am – 12 pm
3501572: Robust Vibration Induced Lubricity
Arnab Bhattacharjee, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

Vibration induced lubricity has gained significant interest over the years for its potential to make devices more efficient and durable. While the phenomenon has been well-documented by experimental studies, there remains no consensus on the underlying mechanics. Existing theories, such as vibration-induced contact separation, sensor resonance, and thermolubricity, have been difficult to test to date. We take a

unique approach in this study to test the robustness of vibration-induced lubricity and test specific predictions from existing theories. Specifically, we have decoupled the friction-measurement spring from a gold coated QCM oscillator, which oscillates laterally at 5 MHz. We observe that QCM oscillation reliably reduces friction coefficients from 0.3 to non-vanishing values on the order of 0.01-0.05. We discuss the results in the context of potential energy landscape and explain what it implies for robust vibration-induced lubricity.

12 - 1 pm
INVITED TALK:
3570304: 2D Materials as Solid Lubricants: ab initio Comparative Study of Tribochemical, and (Super)Lubric Properties.
M. Clelia Righi, Universita di Bologna, Bologna, Emilia-Romagna, Italy

Thanks to the in-plane strength, chemical stability, and weak interlayer interactions 2D materials have attracted considerable attention as lubricant material not only for nanoscale, but also for macroscale applications. We have applied ab initio calculations, eventually linked to classical molecular dynamics in a QM/MM approach, to unravel the atomistic mechanisms that rule the lubricant behavior of different 2D materials, including the tribologically-induced formation of their layered structure. I will focus in particular on: i) The effects of humidity in graphene [1] and MoS2 [2], ii) the superlubricity of phosphorene [3] iii) the in-operando formation of graphene [4] and MoS2 [5] layers from molecular compounds.

5C — Virtual Meeting Room 3

Engine and Drive Train I

Session Chair: William Anderson, Afton Chemical Corp, Richmond, VA

10:30 - 11 am
3483460: Component Wear in Diesel Engine High Pressure Fuel Pumps Operating with Heavy Fuel
Nikhil Murthy, Blake Johnson, CCDC Army Research Laboratory, Aberdeen Proving Ground, MD; Caleb Matzke, University of North Dakota, Grand Forks, ND; Stephen Berkebile, Army Research Laboratory, Aberdeen Proving Ground, MD

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

11 - 11:30 am
3498163: The Measurement of Wear in a GDI Engine Using Radioactive Wear Measurements – Phase II
Peter Lee, Gregory Hansen, Carlos Sanchez, Southwest Research Institute, San Antonio, TX

This is the second phase of work where a 2.0L turbocharged direct injection gasoline engine was disassembled, measured and parts irradiated to create measurable radio nuclides. In the first phase, the top rings, liner and connecting rod bearings were irradiated. In this phase the top rings, main crankshaft bearings, balance shaft bearings and turbo thrust plate, shaft and washer were irradiated. The engine

was then reassembled and operated through the same range of test conditions as in phase I of this work. As the engine was operated, the lubricant was pumped through a radio nuclide detector to measure , in real time, the wear taking place in the engine. This presentation will discuss the results obtained from this work.

11:30 am - 12 pm
3502029: Development and Testing of a Low Viscosity, Fuel Efficient, Heavy-Duty Diesel Engine Oil for Severe Service
Allen Comfort, Steven Thrush, US Army CCDC GVSC, Warren, MI

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

12 - 12:30 pm
3493035: Development and Demonstration of a Prototype 0W-20 Heavy Duty Diesel Engine Oil
John Pettingill, Petro-Canada Lubricants Inc, Mississauga, Ontario, Canada

Petro-Canada Lubricants has conducted on-road field trials with two novel SAE 0W-20 viscosity grade Heavy Duty Diesel Engine Oil (HDEO) formulations to demonstrate that reducing engine oil viscosity to lower viscosity grades is possible. Most engine oils designed for use in heavy duty diesel powered engines have traditionally been classified as high viscosity oils such as 15W-40. A key benefit with lower viscosity engine oil is the potential for improved fuel economy since lower viscosity oils can be circulated through an engine with less energy expenditure (hence less fuel usage) relative to higher viscosity engine oil. The most recent API category of HDEOs includes a very low viscosity grade identified as API FA-4 (5W-30, 10W-30), specifically having low high temperature high shear (HTHS) viscosity values, designed to improve fuel economy. A major challenge with formulating even lower viscosity HDEOs (0W-20) is to maintain the ability for the oil to provide full engine protection.

12:30 - 1 pm
3497070: Engine Efficiency Testing on Aggregated Textured Components
Stephen Hsu, Govindaiah Patakamuri, GWU, Germantown, MD; Timothy Cushing, General Motors Corp, Detroit, MI

Surface topography and discrete dimples, when properly designed; reduce friction of lubricated sliding contacts as shown in various laboratory simple bench tests and simulated rig tests. For the past two decades, many engine tests were carried out but either failed to show benefits or the textures actually increased friction and wear. A Gen 5 L-83 V8 engine was used to conduct the test using textured engine parts. Untextured part was tested as a baseline. Motored torque and fired engine tests were used to measure torque increase. The motored test showed 5% efficiency increase across the speed range. The fired engine test showed about 8% torque increase from 1200rpm to 2000rpm and about 2.5% from 4200-5800rpm torque increase. The overall net torque increase over the entire speed range is about 3%. The textured engine was then used for fuel economy tests on OW-16 oils. At the end of the testing program, the parts were inspected; no wear or little wear was observed on the textures.

Lubrication Fundamentals II: Oil Additives I

Session Chair: Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria

10:30 - 11 am
3497203: Tribochemistry – Past, Present, and Future
Stephen Hsu, GWU, Germantown, MD

In the 1960s, NASA assessed the field of lubrication science and identified the gap was the lack of basic understanding of the chemistry between lubricant and materials under sliding conditions. This was the beginning of Tribochemistry. Subsequent studies provided insights and mechanistic understanding on how boundary lubrication worked. This led to extensive research into lubricating films and tribo-layers. When nanotechnology arrived, a lot of studies begin to examine molecular and nanoscale tribochemistry, adding to the knowledge base.
Current emphasis on energy efficiency and eventually electrification creates revolutionary changes in engine design and new materials being introduced. New multilayer coatings was introduced into the engine. New materials create the need for new lubrication technologies and new additive chemistries. Looking forward, electrification of transportation will need electrochemistry and catalytic tribochemistry.

11 - 11:30 am
3479334: Torque Tightening of Threaded Fasteners: The Influence of Lubrication on Friction
Christopher Dyson, William Hopkins, ITW ROCOL, Leeds, West Yorkshire, United Kingdom; Martin Priest, Malcolm Fox, University of Bradford, Bradford, West Yorkshire, United Kingdom

The precision and variance of fastener tension when torque tightening depends greatly on the friction at the fastener interfaces. The influences of fastener material and thread lubricants have been studied experimentally. Changes at the fastener surfaces during assembly correlate closely with the frictional behaviour of the fastener system. In turn, these changes at the surface have a large influence on re-use of the fastener. A broad range of thread lubricant technologies was analyzed: Their different frictional mechanisms generated a wide range of different tension-torsion relationships. Some tribological trends have been identified that can address precision and variance in fastener tension during torque tightening.

11:30 am - 12 pm
3498214: Three-Dimensional Characterization of ZDDP Tribofilms
Nicole Doerr, Serhiy Budnyk, Marcella Frauscher, AC2T research GmbH, Wiener Neustadt, Austria

The chemical composition of tribofilms from zinc dialkyl dithiophosphate (ZDDP) has been verified by numerous studies. It is well known that ZDDP forms patch-like patterns on sliding surfaces, which grow onto the substrate while the underlying surface can be hardly affected by wear. In this work, an analytical methodology is shown that enables the three-dimensional depiction of the ZDDP tribofilm to provide insight into the lateral distribution of film thickness. Therefore, selected engine oils were evaluated in an oscillating ball-on-disk contact to produce wear scars typically in the square millimeter range. The three-dimensional distribution of tribofilms from fresh and used engine oils are compared and complemented by chemical composition determined by X-ray photoelectron spectroscopy.

12 - 12:30 pm
3494251: Using Oil-Soluble Ionic Liquids Together with Other Additives in a Lubricant
Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Physicochemical interactions among lubricant additives are critical for the lubricating performance. Here we present boundary lubrication behavior of selected ionic liquids (ILs) when used together with

conventional additives including a ZDDP, a MoDTC, and a dispersant (PIBSI) in a PAO base oil. Some phosphonium-based ILs were found to have ion-exchange with the ZDDP to provide superior wear protection. On the other hand, phosphonium-based ILs had strong interactions with PIBSI to reduce its availability for suspending MoDTC, leading to detrimental impact on the friction and wear behavior. In contrast, an ammonium-phosphate IL worked synergistically with MoDTC and PIBSI to deliver a sustainable, ultra-low friction coefficient (0.02-0.04). A three-stage tribochemical process is proposed to explain how this IL and MoDTC work together to form a chemically-reacted, wear-protective tribofilm supporting a physically-adsorbed, friction-reducing film on top.

12:30 - 1 pm
3490135: Research on Durable Organic Friction Modifiers for PCMO and HDDEO Applications
Brian Casey, Vincent Gatto, Vanderbilt Chemicals, LLC, Norwalk, CT

Organic friction modifiers are a cost-effective approach towards formulating engine oils with improved fuel economy. Traditional organic friction modifiers such as glycerol mono-oleate (GMO) tend to perform best in fresh oils, but are susceptible to oxidative and hydrolytic degradation upon aging. Depending on the additive chemistry, this degradation can result in lower frictional performance, increased wear, and corrosion concerns. The research discussed in this presentation focuses on: 1) identifying the problematic chemical structures in existing additives, 2) eliminating sites of instability through chemical synthesis, and 3) evaluating the performance and properties of novel organic friction modifiers in comparison to traditional additives in fully formulated engine oils under both fresh and aged oil conditions. The results indicate that small chemical modifications can lead to friction modifiers with simultaneously improved tribological performance and reduced corrosion concerns.

5E — Virtual Meeting Room 5

Wear I

Session Chair: Yan Zhou, Houghton International, Oak Ridge, TN
Session Vice Chair: John Bomidi, Baker Hughes Company, The Woodlands, TX

10:30 - 11 am
3471693: The Effect of Friction on Micropitting
Mao Ueda, Benjamin Wainwright, Hugh Spikes, Amir Kadiric, Imperial College London, London, United Kingdom

Micropitting is a type of surface fatigue damage caused by stress fluctuations. Owing to the ongoing trends for the use of lower viscosity oils and higher power densities in mechanical systems, leading to reduced oil film thickness, micropitting is fast becoming a major failure mode in gears and rolling bearings. Despite this, many of the relevant mechanisms are poorly understood hindering the production of design criteria. This is particularly true of the influence of friction on micropitting. The primary reason for this is the difficulty of isolating the effects of friction from other relevant factors in micropitting experiments. This study aims to address this by utilizing an experimental methodology designed to investigate the effects of friction in isolation from other influencing factors, particularly the changes of counterface roughness which can occur through mild wear which is known to have a significant influence on micropitting itself.

11 - 11:30 am
3498612: Wear Characterization and Mitigation for Knife Mills Used in Biomass Size Reduction
Kyungjun Lee, Oak Ridge National Laboratory, Knoxville, TN

The cutting tool material and working conditions are among the critical factors for the biomass size reduction process. Among the cutting machines, knife mills have been commonly used for biomass

preprocessing step thanks to the advantage of even cutting high-moisture biomass having high-toughness. They can shear the fed biomass to the desired size between rotating sharp-edged blades and fixed blades with a certain clearance. However, a large amount of biomass and accompanying extrinsic inorganic compounds like sand particles cause wear of the knife blades. In this study, we investigated the wear modes and mechanism of a selected knife mill and determined the wear modes and mechanism. Based on the characterization results, candidate alloys, coatings, and surface treatments were selected and evaluated using two-body abrasion tests. This study provides fundamental insights for the wear mechanism analysis and the tool material selection for biomass comminution equipment.

11:30 am - 12 pm
3490952: Effect of Nitriding and Carbonitriding on the Scuffing Resistance of Aerospace Bearing Steels
Daulton Isaac, Mathew Kirsch, Air Force Research Laboratory, Wright-Patterson AFB, OH; Hitesh Trivedi, UES Inc., Dayton, OH

Surface treatments such as carburizing, nitriding and carbonitriding are used to improve the fatigue and corrosion resistance of aerospace bearing steels. However, it remains largely unreported what effect these surface treatments have on the steel's scuffing resistance. An adhesive wear test protocol can be used to investigate this resistance since this wear mechanism is seen as a mild form of scuffing or a precursor to it. In this work, the scuffing propensity of select nitrided and carbonitrided aerospace bearing steels was investigated using a ball-on-disk tribometer in all-metal and hybrid configuration with a fully formulated MIL-PRF-23699 EE lubricant. Material pairs were assigned an adhesive wear score based on the traction behavior and the post-test surface condition of the specimens. Thus, quantitative comparisons are made and conclusions drawn as to the effect of nitriding and carbonitriding on scuffing in aerospace bearing steels.

12 - 12:30 pm
3476697: Developing an Innovative Next Generation Anti-Wear
Christelle Chretien, SOLVAY, Bristol, PA

New regulatory standards, growing environmental concerns, and the impending shift toward alternative transportation solutions are factors rapidly transforming the lubricant industry. As a consequence, formulation options around using traditional lubricant additives and compositions are shrinking. In this context, Solvay has chosen a new technology path to develop sustainable anti-wears with enhanced performances and milder classifications. The objective of this talk is to present an update on the development of a next generation of anti-wear technology based on a polymeric platform demonstrating high potential performances.

12:30 - 1 pm
3565800: Suppressed Triboluminescence Attributed to Electron Structure Changes in the Doped Surface
Changhui Song, Liran Ma, Jianbin Luo, Tsinghua University, Beijing, China

Triboluminescence(TL) is a fascinating phenomenon that occurs in the sliding contact surface, which directly transforms the mechanical energy into the light. In our work, the TL experiment between ZnS polycrystalline and SiO2 crystal was carried out, and we found suppressed TL emission when little amount CuS nanoparticles doped into the ZnS. The TL emission attributed to the nitrogen discharge between the contact surface. The microstructure of CuS doped ZnS was characterized by X-ray diffraction (XRD) and transmission electron microscopy(TEM). Conduction-band and Valence-band structures of the doped surface were studied by x-ray photoemission spectra (XPS) and further described by the first principle electronic structure calculation using CASTEP to show how the electron structure change due to the presence of CuS, which further lead to the suppressed TL emission. Our work may provide a possible approach to manipulate the TL emission and further insight into the TL mechanism.

Tribotesting I

Session Chair: Christopher DellaCorte, NASA, Cleveland, OH
Session Vice Chair: Ashish Kasar, University of Nevada Reno, Reno, NV

10:30 - 11 am
3479342: Fretting Wear in Contacts Representative of Wire Rope Internal Interfaces: The Influence of Key Lubrication Parameters
Christopher Dyson, William Hopkins, Michael Cassidy, ITW ROCOL, Leeds, West Yorkshire, United Kingdom; Richard Chittenden, University of Leeds, Leeds, West Yorkshire, United Kingdom; Martin Priest, Malcolm Fox, University of Bradford, Bradford, West Yorkshire, United Kingdom

The fretting fatigue life of wire ropes can be greatly influenced by the fretting wear at internal strand-on-strand contacts. Using a reciprocating tribometer, the influence of lubrication-related parameters on fretting wear of drawn wire and steel specimens has been measured. Key parameters have been identified and systematically investigated: The run-in phase and the base oil viscosity have been shown to be particularly important. Multivariate statistical analysis and surface analysis were used to illuminate these mechanisms.

11 - 11:30 am
3483644: Comparing Aftons Bespoke Stick Slip Rig with the Former Cincinnati Milacron Rig
Ralph Lumby, Afton Chemical Ltd, Bracknell, United Kingdom

In order to facilitate the development of our new generation of slideway additive packages, Afton Chemical utilizes a series of bespoke friction tests including the Darmstadt rig. As part of our efforts to stay at the forefront of slideway research, Afton has also purchased the former Cincinnati Milacron (CM) stick slip rig. This rig has historically been used to determine the ratio of static to dynamic friction for slideway fluids. Through thorough investigation of the key variables that impact performance and repeatability we have developed a new fully automated rig which can be used by customers that require a stick slip ratio. This talk will focus on a comparison between the former CM stick slip rig and Aftons own modern stick slip rig to demonstrate the more repeatable and reliable results produced by the Afton rig.

11:30 am - 12 pm
3519445: Depletion of MoDTC and Synergism with OFM in Boundary Lubricated Tribological Contacts
Simon Barnes, University of Leeds, Leeds, United Kingdom

Molybdenum dithiocarbamate (MoDTC) has proven to be an effective friction modifier (FM), reducing frictional losses through engine contacts. However, recent environmental concerns have sparked efforts to reduce levels used. One such is the use of organic friction modifiers (OFMs) in tandem with MoDTC. Various concentrations of MoDTC in fully formulated oil were tested using a reciprocating pin on plate TE77 tribometer, under harsh boundary conditions to accelerate depletion of the additive. An OFM was then blended in and the effects on friction and wear performance observed. Upon addition of OFM, low friction was maintained for longer than when only MoDTC was present. The MoDTC-OFM blend maintained low friction for a similar length of time as a blend containing just MoDTC at an equivalent treat rate to the sum of OFM and MoDTC and so giving a synergistic effect. Surface films have been characterized using Raman and AFM.

12 - 12:30 pm
3499299: Reconditioning Lubricating Oils: The Tribological Performance Perspective
Arnaud Ruellan, Aldara Naveira-Suarez, SKF Group, Goteborg, Sweden

Imagine the benefits of lubricating oils being continuously or regularly reconditioned to restore the tribological performance levels required for a specific application: reduced oil waste, less downtime, lower maintenance cost, circular use of oil, etc. A new reconditioning technology has been developed enabling the removal of contaminants down to the nano-size particles in most lubricating oils by combining chemical and advanced filtering techniques. By keeping the level of contaminants as low as possible, oxidation reactions will be limited, thereby extending the oil life. In this study, the tribological performance of the reconditioned oils of different applications have been compared to that of the new and used oil from application to make sure the key lubricating properties are not altered during the reconditioning process. To do so, specific tribological screening methods have been used in combination with standard chemical analysis and tribological tests.

12:30 - 1 pm
3484933: Electric Current Effects on Wind Turbine Bearing Steel: Test Rig and Results
Robert Erck, Benjamin Gould, Nicholaos Demas, Aaron Greco, Argonne National Laboratory, Lemont, IL

A PCS model MPR three-ring-on-roller benchtop test rig was modified to apply electric current on type 52100 steel samples undergoing rolling/sliding contact in commercial wind turbine lubricants. The rig used slip-rings and a current source/source measuring unit with 4-wire geometry. Failure manifested itself in pitting with white etching crack and white etching area formation. The ring and roller counterfaces, with 1-mm-wide contact area, were slid at typically -30% slide-to-roll ratio and 500 N load, at 100 °C. Failure was defined when machine vibration reached a predetermined limit or ran out at 300 million contact cycles. At high currents, the roller failed soon due to gross macropitting, with longer duration at intermediate currents, and no failure at 300 million cycles with no current. At low current, the failure mechanism was found to be either surface damage or micropitting. Optical post-test examination showed that tribochemical film density was enhanced by current density.

5G — Virtual Meeting Room 7

Rolling Element Bearings III

Session Chair: Hannes Grillenberger, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany

10:30 - 11 am
3483103: Formation of White Etching Areas/Cracks on a Four Disk Rig - Premature Failure Due to Microstructural Changes
Adrian Mikitisin, Rheinisch-Westfalische Technische Hochschule Aachen Fakultat 5 Georessourcen und Materialtechnik, Aachen, Nordrhein-Westfalen, Germany; Florian Steinweg, Rheinisch Westfalische Technische Hochschule Aachen Fakultat 4 Maschinenwesen, Aachen, Nordrhein-Westfalen, Germany

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

11 - 11:30 am
3483981: A Mechanistic Approach to Understand Rolling Contact Fatigue (RCF) Induced Microstructural Alterations
Muhammad Abdullah, Zulfiqar Khan, Bournemouth University, Bournemouth, Dorset, United Kingdom; Wolfram Kruhoeffer, Schaeffler Technologies AG und Co KG, Herzogenaurach, Bayern, Germany

Rolling bearing elements under rolling contact fatigue (RCF) exhibit subsurface microstructural alterations e.g. dark etching regions (DERs) and white etching bands (WEBs). The formation mechanism for such microstructural alterations is debatable and requires further understanding. Current research work presents a systematic approach where bearing balls of standard AISI-52100 steel are tempered at 400°C for 240 mins and then subjected to RCF test in a rotary tribometer at 5 GPa contact stress, 160°C till 37M cycles. Another virgin sample was RCF tested and subjected to similar heat treatment. Subsurface microscopic analysis for pre and post tempered RCF tested samples have revealed that the formation of these microstructural alterations is a combined effect of dislocation assisted carbon flux along with thermally activated carbon diffusion. Additional tests have been carried out to conduct the parametric study with variation in operating temperature, cyclic frequency, and applied load.

11:30 am - 12 pm
3489226: Rolling Contact Fatigue: Mechanistic Study of Dark Etching Regions and White Etching Bands in Bearing Steels
Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom; Bernd Vierneusel, Schaeffler Technologies AG and Co KG, Schweinfurt, Germany

Microstructural alterations such as dark etching regions (DER) and white etching bands (WEBs) manifest in steel bearings due to rolling contact fatigue. Multiple theories are presented in literature on the formation mechanism of DER/WEBs but show inconsistencies compared to experimental observations. This study aims to achieve a better understanding of the formation mechanisms of DER/WEBs by analyzing their development in angular contact ball bearings (ACBB). RCF tested ACBBs made from martensitic 100Cr6 and 50CRMo4 have been examined at 151-7668 million stress cycles to investigate the influence of material microstructures on DER/WEB. Micro and nano-scopic techniques, including SEM, nano-indentation, electron-microprobe (EMP) and FIB/TEM have been used to examine mechanical/chemical properties of the features and their alteration processes. Evidence show a continuous process of formation/breakdown of elongated/equiaxed ferrite grains and lenticular carbides during DER/WEB formation.

12 - 12:30 pm
3495122: Fracture-Mechanical Evaluation of Inclusions – Comparison with Test Results
Joerg Binderszewsky, Wolfram Kruhoeffer, Toni Blass, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany

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

12:30 - 1 pm - **REB Business Meeting**

Nonferrous Metals III

Session Chair: Tom Oleksiak, Quaker Houghton, Acworth, GA

10:30 - 11 am
3485144: Structure-Performance Evaluation of Synthetic Metalworking Fluid Additives
Tiffany Meyers, Stephanie Cole, Clariant, Mount Holly, NC

As the need for continuous productivity is required, machines are getting faster and operational severity is increasing. During manufacturing and processing of these nonferrous materials (e.g. rolling, cutting, forming, grinding), a metalworking fluid could be exposed to a variety of conditions that a metalworking fluid must withstand. Corrosion inhibitors can be a valuable tool used for formulating synthetic fluids. These additives are effective in protecting aluminum and, at the same time, deliver additional functionalities which help metalworking fluid formulators address today's formulation challenges. Lubricity additives can vary with shape, size, and solubility, contributing to the overall fluid performance. As improved health and safety attributes are becoming a necessity, it's important to understand how molecular structure can impact product labeling. This paper highlights the relationship of molecular structure to performance for a variety of additive types.

11 - 11:30 am
3476767: Chemistry Behind Settling Metal Fines in Aqueous Metalworking Fluids
Stefanie Velez, Munzing Chemie GmbH, Bloomfield, NJ

Metal fines will only settle out of the fluid after the liquid effectively wets the surface of the fine. Wetting agents are a specific class of surfactants that expediate this process by reducing a fluid's surface tension, or the interfacial tension, between the fluid and a solid substrate. The chemistry of the surfactants can be specifically identified and formulated to provide a strong reduction in dynamic surface tension, little to no foam generation, and optimal fluid compatibility. A low dynamic surface tension results in rapid spreading on the metal surface during high speed processes. This paper will discuss the theoretical aspects of surface tension reduction using wetting agents and demonstrate how this translates into an improvement in metal fines settling and cleanliness through application testing in metal working fluid systems as well as the reduction in the fluids surface energy as measured by contact angle.

11:30 am - 12 pm
3495372: Gas-to-Liquids (GTL) Technology Offers Advances in Metalworking and Aluminum Rolling Fluids while Enhancing Safety, Performance, and Environmental Sustainability
Gregory Wehr, ChemGroup, Inc, Louisville, LA

Use of patented Gas-to-Liquids (GTL) technology today to produce a full range of synthetic hydrocarbon fluids, solvents, & mineral/process oils brings significant advantages to MWFs and aluminum rolling oils. When compared to traditional crude oil-derived distillate fluids of similar carbon/boiling ranges, high purity GTL solvents & fluids enhance fire safety; reduce operational downtime; reduce worker exposures; improve aluminum processing performance at lower speeds with better lubrication in the boundary regime; improve flowability & wetting properties; reduce product loss from evaporation; maintain ultra-low staining and residue potential; reduce VOC emissions; reduce environmental concerns; and ultimately deliver lower total cost of ownership. Therefore, GTL technology in use today is already a "gamechanger" addressing many of the immediate and future industry demands for improvements in Safety, Performance, and Environmental Sustainability, while delivering real tangible value.

5I Virtual Meeting Room 9

Commercial Marketing Forum V

Session Chair: TBD

10:30 - 11 am - **Functional Products**

11 - 11:30 am - **ANGUS Chemical Co.**

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

12 - 12:30 pm - **TestOil**

12:30 - 1 pm - **Chevron Phillips**

6A Virtual Meeting Room 1

Biotribology II

Session Chair: Alison Dunn, University of Illinois, Urbana, IL

2 - 2:30 pm
3483667: Acoustic Emission Signals as a Diagnostic Tool for Joint Wear
Khadijat Olorunlambe, Zhe Hua, Duncan Shepherd, Karl Dearn, University of Birmingham, Birmingham, United Kingdom

Acoustic Emission (AE) testing detects the onset and progression of mechanical flaws. AE as a diagnostic tool is gaining traction for providing a tribological assessment of human joints and orthopaedic implants. Recent developments show that there is potential for using AE as a tool for diagnosing joint pathologies such as osteoarthritis and implant failure but to realize AE full potential, the analysis of the signal must differentiate between wear mechanisms. A challenging problem! This study uses supervised learning to classify AE signals from adhesive and abrasive wear processes under controlled joint conditions. Using Principal Component Analysis, uncorrelated AE features were derived and classified using three methods, logistic regression, k-nearest neighbors, and Back Propagation (BP) neural network. The BP network performed best with a classification accuracy of 97%. An exciting development for the supervised classification of AE signals as a bio-tribological diagnostic tool.

2:30 - 3 pm
3499235: Wear of Antibacterial Coatings on CoCrMo under Butterfly Motion and Dynamic Loads in a Biotribometer
Deepak Halenahally Veeregowda, Angela Maria Tortora, Ducom Instruments, Groningen, Netherlands

Conventional tribometers with an unidirection motion and fixed load are not suitable to investigate wear behavior of implant materials. We have designed a biotribometer that is compatible with physiological dynamic loads (250 to 400 N) and multi-direction motion (butterfly stroke), to investigate the wear behavior of antibacterial coatings on CoCrMo. In this study, the counter body was an UHMWPE pin and the lubricant used was calf serum at 37 °C. Friction and wear behavior of these coatings were monitored for 106 cycles. In general, the deformation and wear rate of UHWMPE was in the same order as that of clinical reports on UHMWPE cup penetration and wear rate. Results from the biotribometer showed the differences between coatings. The post-test wear images showed severe scratches on one coating. The coatings showed no significant differences in the Co or Cr ion release. This study shows that

biotribometer can mimic the wear behavior of implant materials.

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

3:30 - 4 pm
3515762: Oral Tribology, Lubrication and Adsorption of Alternative Food Proteins
Ben Kew, Anwesha Sarkar, Melvin Holmes, University of Leeds, Leeds, Yorkshire, United Kingdom

Oral tribology and adsorption techniques such as quartz crystal microbalance-dissipation (QCM-D) has been recognized to provide advanced insights into key lubrication properties of proteins. The aim of this study was to compare the lubrication properties of alternative proteins with whey protein isolte (WPI) as a control using apparent viscosity, soft tribology QCM-D with hydrophobically-modified sensors, particle size and ζ-potential. Pea, potato, lupine and insect protein isolate (PPI, PoPI, LPI, IPI respectively) were chosen as alternative proteins. The boundary friction coefficient (μ) of proteins at 5 wt% concentration followed the trend as $\mu_{PPI} > \mu_{LPI} > \mu_{IPI} > \mu_{PoPI} > \mu_{WPI}$, However, at higher protein concentrations (10%), the μ values of LPI, PoPI and IPI increase (+15-50%) visa-versa in WPI behaviour (-15%). These novel insights show early promises for formulation design with alternative proteins in future with possibility of predicting lubrication-related mouthfeel perception.

4 - 4:30 pm
3512880: Soft Matter Tribology in Biology
Angela Pitenis, Allison Chau, Jonah Rosas, George Degen, University of California Santa Barbara, Santa Barbara, CA

Biology largely manages friction in two ways: (1) eliminating sliding, or (2) protecting the sliding interface with aqueous gels capable of supporting loads whilst reducing shear stresses. Aqueous biopolymer gels are typically composed of at least 90% water, and serve multiple lubrication, hydration, barrier, and protective functions. The precise energy-dissipative mechanisms in biological aqueous gels are still not well understood, in part due to the difficulties in obtaining samples and high sample-to-sample variability. Synthetic aqueous gels, including hydrogels, have provided new opportunities to model the complex lubrication strategies of biological gels but with the tunability and repeatability of established chemistries. In this work, we discuss the mechanics and tribology of high water content synthetic aqueous gels and highlight new approaches for understanding soft matter tribology in biology.

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

6B Virtual Meeting Room 2

2D Materials + Superlubricity - Materials Tribology and Nanotribology Joint Session III

Session Chair: Azhar Vellore, Martini Research Group, University of California Merced, Merced, CA
Session Vice Chair: Mohammad Vaziriserehk, University of California Merced, Merced, CA

2 - 2:30 pm
3499763: Phase Transitions in Alkanes Confined at Graphitic Interface
Prathima Nalam, Behnoosh Sattari Baboukani, SUNY University at Buffalo, Buffalo, NY; Zhijiang Ye, Miami University, Oxford, OH

Two-dimensional materials such as graphene are emerging as novel friction-reducing additives for transmission fluids and lubricating oils to enhance sliding metallic components' service life. The tribological performance of single or few-layers of graphene suspended in a lubricating oil containing linear and branched alkanes is critical for developing oil-based additives. In this study, the influence of hydrocarbons' molecular structure on the solvation and friction forces generated on the mechanically-

exfoliated, single-layer graphene will be investigated using atomic force microscopy. Further, equilibrium studies will be conducted to measure diffusion and intercalation of hydrocarbons at the confinement generated by 2D material as a function of hydrocarbon branching (hexadecane, squalene, phytane).

2:30 - 3 pm
3492606: Nanotribology of 2D Transition Metal Dichalcogenides: The Effect of Chalcogen Variation on Frictional Behavior of MoS_2, $MoSe_2$ and $MoTe_2$
Mohammad Vaziriserehk, Ashlie Martini, University of California Merced, Merced, CA; Kathryn Hasz, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Two-dimensional (2D) transition metal dichalcogenides (TMDs) are promising candidates for applications ranging from nanoelectronics to next generation solid lubricants thanks to their unique mechanical and electronic properties. Despite extensive studies on the tribological properties of MoS_2, the frictional behavior of other members in this family has remained relatively unexplored. To understand the effect of the chalcogen variation on the tribological behavior of these materials, we characterized the nanoscale friction of MoS_2, $MoSe_2$, and $MoTe_2$ using AFM experiments and MD simulations. Experiments and simulations showed that MoS_2 has the highest friction, and $MoTe_2$ has the lowest. Simulations complemented by theoretical analysis revealed that the observed friction contrast between the TMDs was attributable to the interplay between the potential energy barrier along AFM tip trajectory and the lattice constant that varied depending on chalcogen.

3 - 3:30 pm - Break

3:30 - 4 pm
3516776: Friction Characteristics of HOPG and 2D Transition Metal Di- Chalcogenides under Cryogenic Conditions- Role of Interfaces
Praveena Manimunda, Douglas Stauffer, Bruker Nano Surfaces, Minneapolis, MN; Sandhya Susarala, Rice University, Houston, TX

Superior mechanical properties and chemical inertness of 2D TMDs made them ideal candidate for lubricating coatings in micro- and nano-electromechanical devices. However, the temperature effects on frictional characteristics of vertically stacked 2D materials are not well understood. In this study, cryo-environmental stage was integrated with nanoscratch, device to probe temperature effects on microscale friction characteristics of HOPG, vertically stacked atomically thin $MoSe_2$, WSe_2 and MoS_2/WS_2 hetero structures. On monolayered samples, under wearless sliding conditions, increase in friction was observed over 0 to -120 °C. On multilayered structures, interlayer shear dominated friction characteristics. Changes in inter layer interaction as a result of external deformation and temperature was investigated using in situ Raman spectroscopy. Further, sliding speed dependency and the effect of number of layers on friction characteristics were explored in detail.

4 - 4:30 pm
3484804: Contact Aging in Structural Superlubricity
Wai Oo, Mehmet Baykara, University of California Merced, Merced, CA

Structural superlubricity -a state of ultra-low friction between two incommensurate, atomically flat surfaces in relative motion- shows great promise for intrinsic lubrication schemes in small-scale mechanical systems. Despite recent demonstrations of structural superlubricity under ambient conditions, many questions remain regarding the physical limits and robustness of this elusive ultra-low friction state. Here, we perform “tip-on-top” manipulations on gold nano islands on graphite via atomic force microscopy to investigate the influence of contact aging on structural superlubricity. By manipulating individual islands multiple times, we show that (i) the friction force significantly decreases after the initial manipulation, and (ii) the friction force increases back to higher values after hold times of about thirty minutes. These results reveal the non-negligible effect of contact aging on superlubric sliding.

4:30 - 5 pm
3484587: Inverse Layer Dependence of Friction on Chemically Doped MoS_2
Mehmet Baykara, Ogulcan Acikgoz, UC Merced, Merced, CA; Alper Yanilmaz, Cem Celebi, Izmir Yuksek Teknoloji Enstitusu, Izmir, Turkey; Omur Dagdeviren, McGill University, Montreal, Quebec, Canada

We present the results of atomic-force-microscopy-based friction measurements on Re-doped molybdenum disulfide (MoS_2). In stark contrast to the seemingly universal observation of decreasing friction with increasing number of layers on two-dimensional (2D) materials, friction on Re-doped MoS_2 exhibits an anomalous, i.e. inverse dependency on the number of layers. Raman spectroscopy measurements reveal signatures of Re intercalation, leading to a decoupling between neighboring MoS_2 layers and enhanced electron-phonon interactions, thus resulting in increasing friction with increasing number of layers – a new paradigm in the mechanics of 2D materials.

5 - 5:30 pm
3498096: Why is Friction at the Graphene Step Edge so High while Friction on the Basal Plane is So Low?
Zhe Chen, Seong Kim, Pennsylvania State University, University Park, PA

Graphene is an ideal material for lubrication coatings. However, graphene step edges, which are nearly inevitable on the graphene coating, have a much higher friction than the graphene basal plane and thus deteriorate the overall lubricity of the coating. In this work, the friction properties of a single layer graphene edge on highly oriented pyrolytic graphite (HOPG) are investigated with atomic force microscopy (AFM). It was found that the friction of an exposed step edge is very different from a buried step edge. It was also found that the friction of an exposed step edge is largely dependent on the environment. Then, based on the above results, the friction origins of exposed and buried step edges are discussed. This work enriches the understanding of frictional properties at atomic step edges and is helpful for the application of 2D materials as lubrication coatings.

6C Virtual Meeting Room 3

Engine and Drive Train II

Session Chair: Hamed Ghaednia, Gehring Group, Farmington Hills, MI

2 - 2:30 pm
3482399: The Effect of Engine Oil and Lubrication System Design on Engine Friction as Demonstrated in a Motored Engine
William Anderson, Kongsheng Yang, Zhang Yun, Sha Yang, Afton Chemical Corp, Richmond, VA; Yuelei Ding, Pan Asia Technical Automotive Center Co Ltd, Pudong, Shanghai, China

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

2:30 - 3 pm
3484731: Friction and Wear of Thermal Spray Coatings for Cylinder Bores
Arup Gangopadhyay, Cliff Maki, Larry Elie, Robert Zdrodowski, Zhiqiang Liu, Urban Morawitz, Ford Motor

Company, Dearborn, MI; Hamed Ghaednia, Gehring Group, Farmington Hills, MI; Joachim Patschull, Ford Motor Company (Retired), Cologne, Germany

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

3 - 3:30 pm - Break

3:30 - 4 pm
3499847: Benchtop Test for Screening Wet Clutch Materials
Carlos Sanchez, Southwest Research Institute, San Antonio, TX

This work discusses the use of a benchtop screening test for evaluating the performance of wet clutch materials and automatic transmission fluids. Tests were conducted with a Bruker TriboLab using small scale friction discs and reaction plates to replicate the SAE #2 test. Specifically, the bench was modeled after the GM 3-Day wear test; contact pressures, sliding speeds, temperatures, engagements, and a condensed test profile that runs over a few hours. Friction coefficient is measured throughout, and 3D wear profiles are measured ex situ. Tests conducted using the condensed test profile show correlation to the full scale test in ranking different types of friction materials, and potential for ranking fluid formulations. Similar to the full scale test, one of the primary indicators is the gradient of friction coefficient versus sliding speed. Although the bench results vary in magnitude from the full scale, the slopes show an indication of performance for clutch materials and fluids.

4 - 4:30 pm
3499481: Wear Model Investigating the Effect of Abradable Powder Coated Pistons on Engine Cylinder-Kit Performance
Sadiyah Sabah Chowdhury, Michigan State University, East Lansing, MI

Surface coatings are one of the most widely used routes to enhance the tribological properties of cylinder kits due to effective sealing capability with low friction coefficient, high wear resistance, and low-cost. In the current study, we have conducted the characterization of the coatings on piston skirt and development of a wear model to explore the impact of abradable powder-coated (APC) piston skirts on piston rings. The underlying physical and mechanical properties, plus surface topology of the selected piston coating materials, are characterized at discrete depths moving from the top towards the substrate. The calibrated wear model is used to compare the APC coated piston and uncoated piston. The model depicts the benefits of APC in terms of the areas of hydrodynamic versus boundary lubrication of skirt and rings, wear, blow-by, reverse blow-by, and oil consumption. The goal is to explore the properties of the APC and link them to the performance of operating cylinder-kits.

4:30 - 5 pm
3484474: Road to Ultra-Low Viscosity 0W Oils: Quantifying Frictional Benefits on the Journal Bearing Machine
Priyanka Desai, Shell Global Solutions (US) Inc., Houston, TX; Konstantinos Kalogiannis, Omar Mian, MAHLE Engine Systems UK Ltd., Rugby, United Kingdom; Francesco Manieri, Tom Reddyhoff, Imperial College London, London, United Kingdom; Robert Mainwaring, Shell Global Solutions UK, London, United Kingdom

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

5 - 5:30 pm - **Engine and Drive Train Business Meeting**

6D Virtual Meeting Room 4

Lubrication Fundamentals III: Oil Additives II

Session Chair: Brendan Miller, Chevron Oronite Co., Richmond, CA
Session Vice Chair: Stephen Hsu, MAE, GWU, Germantown, MD

2 - 2:30 pm
3497165: Engine Test of Microencapsulated Friction Modifier Additives for Fuel Economy Enhancement
Stephen Hsu, Govindaiah Patakamuri, GWU, Germantown, MD; Timothy Cushing, General Motors Corp, Detroit, MI

Microcapsules provide timed-release of additives to maintain a sustained additive level to provide prolonged effectiveness during in service conditions. This potentially can be applied to autonomous vehicles to provide "long drain" oil change intervals, prolonging the maintenance intervals. To enhance fuel economy, we fabricated microencapsulated friction modifiers for automotive application. In this study, successfully used several microfabrication techniques to fabricate single component FM, and multi-component FMs. The microcapsules were tested in a Gen 5 V8 L-83 engine. The fuel economy tests use a chassis dynamometer running EPA high way and city driving cycles. The microcapsulated FM showed fuel economy improvement after mileage accumulation.

2:30 - 3 pm
3497186: Fuel Economy Improvement Using Ultralow Viscosity Lubricants
Stephen Hsu, Govindaiah Patakamuri, GWU, Germantown, MD; Timothy Cushing, General Motors Corp, Detroit, MI

Under DOE sponsorship, we have developed and tested 0W-16 lubricant formulations to achieve fuel economy improvement in ASTM Seq. VI engine tests and chassis engine dynamometer tests. The extent of fuel economy improvement depends of engine design, tolerance, duty cycles, fuel used, advanced materials and fuel economy technologies employed in the engine. The effectiveness of the formulations used for ultralow viscosity lubricants depends on ash level, base oils used, and the chemical structures of the key additives. We will describe the bench screening tests results used to select additives, and the engine test results.

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

3:30 - 4 pm
3478919: Tuned Polar Methacrylate Viscosity Index Improvers for Enhanced Shear Stability and Wear Prevention
Lelia Cosimbescu, Kristen Campbell, Miao Song, Dongsheng Li, Marie Swita, Pacific Northwest National Laboratory, Richland, WA; Robert Erck, Argonne National Laboratory, Lemont, IL

VIIs can be designed to perform secondary roles, most commonly friction- and wear-reducers. A major consideration for VIIs design in applications which encounter shear, such as hydraulic fluids, is permanent shear loss of the polymer, a common phenomenon among high molecular weight polymers. Our strategy is to employ a controlled-radical polymerization technique to design PAMAs of moderate polarity and molecular weight, with linear architecture, which are expected to have good viscosity index, good shear stability and have the added benefit of lowering friction or wear. Herein, we present the synthesis of copolymers containing varying amounts of polar methacrylate and a lipophilic methacrylate as multifunctional VIIs, with anti-wear and shear stability benefits. In addition, the elemental composition and surface morphology of solid tribochemical films formed on steel surfaces as a result of friction experiments conducted using polymer containing base oils, is demonstrated.

4 - 4:30 pm
3499618: Exploring New and Innovative Additives for Extreme Tribological (ET) Performance
Liwen Wei, Novitas Chem Solutions, Houston, TX

Extreme Tribology (abbreviated as ET) describes the tribological situations under extreme operating conditions such as high temperature, heavy loads, and harsh system and environmental challenges. In this presentation, through our newly established tribological testing laboratory, we wish to address these challenges for a range of industrial and grease applications based on the performance targets set at 800 plus Kg 4-ball weld load, 4,500 plus pounds Falex load, and zero wear on Ball on Disc (BOC) and Pin on Disc (POC). Achieving all of the above, maximum and robust tribological performance with no wear and low friction, is no small feast and an ultimate goal in the pursuit of ET performance that is not easily feasible via traditional additives such as sulfurs and heavy metals. We will present and discuss our findings and the chemistries through the use of new and novel additives and synthetic base oils that exceed and work extremely well under these ET targets.

4:30 - 5 pm
3483942: Investigation on the Superlubricity and Nanomechanics of Liposome Adsorption on Titanium Alloys
Yuhong Liu, Tsinghua University, Beijing, China

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

5 - 5:30 pm - **Lubrication Fundamentals Business Meeting**

6E Virtual Meeting Room 5

Wear II

Session Chair: Ali Beheshti, George Mason University, Fairfax, VA

2 - 2:30 pm
3541859: Effects of Lubricant Additives on Fretting Wear
Artemis Kontou, Hugh Spikes, Imperial College London, London, United Kingdom; Ian Taylor, Shell

Global Solutions UK, London, Cheshire West and Chester, United Kingdom

This study examines the effect of dispersant and anti-wear additives on fretting wear in bearing steel contacts. Reciprocating sliding ball-on-flat fretting tests with a stroke length of 50 μm have been carried out on steel-to-steel contacts in both dry and lubricated conditions. Wear and friction coefficient have been measured, and surface characterization has been carried out to investigate fretting wear. The presence of base oil reduces fretting wear compared to dry conditions, but fretting damage is still observed at low reciprocation frequencies. As frequency is increased, there is a transition from oxidative to adhesive/scuffing damage. The anti-wear additive is effective in forming a tribofilm on the surfaces and reducing visible oxidation and wear. A succinimide dispersant reduces the accumulation of solid debris but not the wear damage. The combination of both ZDDP anti-wear additive and dispersant in base oil shows to provide significant protection against fretting wear.

2:30 - 3 pm
3519346: Friction and Surface Interaction Analysis of PDC on Granite and Carbonate Rocks
John Bomidi, Chengjiao Yu, Marc Bird, Baker Hughes Company, The Woodlands, TX; Maria Cinta Lorenzo Martin, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL

PDC (polycrystalline diamond compact) - rock friction sliding contact is experienced by worn and shaped cutting elements in rock drilling designs. This is especially relevant in hard rock, geothermal drilling. Granite is therefore chosen as one of the rocks and is compared alongside carbonate. The effect of surface roughness, contact shape, and aqueous environment are investigated. The rock and PDC surfaces are investigated for surface interactions after both short and extended durations of sliding. The friction results show a higher friction in carbonate 0.4 compared to granite 0.2. Importantly, the friction in granite is highly dependent on the surface condition or shape but not so in carbonate. The surface analysis and observations of rock adhesion indicate significantly less adhesion onto PDC from granite than carbonate rocks. Finally, sliding friction regime is not affected by aqueous environment confirming the importance of surface mechanisms of PDC – rock sliding interaction.

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

3:30 - 4 pm
3486651: A Review of Tribological and Surface Behavior of MAX Phase Based Composites
Surojit Gupta, Maharshi Dey, Sabah Javaid, Caleb Matzke, University of North Dakota, Grand Forks, ND; Nikhil Murthy, CCDC Army Research Laboratory, Aberdeen Proving Ground, MD; Stephen Berkebile, Army Research Laboratory, Aberdeen Proving Ground, MD

MAX phases (a family of over 70 carbides and nitrides) have emerged as potential materials for structural applications. In this presentation, we will review the tribological behavior of different types of MAX phases-based composites. More particularly, the tribological behavior of different metal matrices and polymer matrices reinforced with MAX Phases will be presented. Some examples of composites are Ag-MAX, Ni-MAX, PEEK-MAX, and HDPE-MAX composites. The effect of processing parameters on tribological behavior will be also documented. Detailed mechanism of tribological behavior will be presented by evaluating the tribofilms by SEM analysis. In addition, the wettability behavior of these composites by different fluids will be also presented.

4 - 4:30 pm
3496983: The Surface Effects of Nanofluid Action on Heat-Exchanger Materials: Testing and Assessment
Gustavo Molina, Fnu Aktaruzzaman, Mosfequr Rahman, Valentin Soloiu, Georgia Southern University, Statesboro, GA

Nanofluids are suspensions of nano-size powders in ordinary fluids, as water and ethylene glycol, with enhanced-cooling properties. But the tribological effects on typical heat-exchangers material surfaces are still little studied. The author developed two instruments to test nano-alumina fluid action on typical materials (aluminum, copper, and stainless steel) and to study the suitability of several measurements

(roughness changes, weight-removal, and microscopy) to assess the material wear and corrosion. Results are presented for the three materials when subjected to nanofluids of alumina in distilled water and its solutions with ethylene glycol as base fluids. The proposed assessment methodology and its integration with other critical nanofluid tests (as heat-transfer measurements) are discussed.

4:30 - 5 pm
3498960: Elevated Temperature Fretting Wear Study of Additively Manufactured Inconel 625 with Varying Process Parameters
Manisha Tripathy, Ali Beheshti, George Mason University, Fairfax, VA; Keivan Davami, The University of Alabama, Tuscaloosa, AL

Additive Manufacturing is a novel manufacturing process only a few decades-old with great potential to carve out better and more efficient manufacturing techniques. While investigations on mechanical properties such as strength, fatigue, and to some extent corrosion are abundant in the literature, friction and wear studies of additively manufactured materials are scarce especially for metals at high temperatures. This presentation reports the fretting friction and wear properties of traditionally and additively manufactured Inconel 625 from room temperature up to 700°C for less than 1mm stroke length. The samples are manufactured using laser powder bed fusion process with different process parameters for the fretting tests. SEM/EDS analysis is also performed to further investigate the wear and friction behaviors. At higher temperatures, lower friction coefficient and higher wear volume are observed with the significant deviation between the additively manufactured and wrought samples.

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

6F Virtual Meeting Room 6

Tribotesting II

Session Chair: Daulton Isaac, Air Force Research Laboratory, Wright Patterson AFB, OH
Session Vice Chair: Alessandro Ralls, University of Nevada Reno, Reno, NV

2 - 2:30 pm
3499215: Repeatability of Friction and Wear of Different Material Pairs at 1000 °C under Unidirectional Sliding Motion
Debdutt Patro, Harish Prasanna, Sravan Kumar Josyula, Angela Maria Tortora, Fabio Alemanno, Deepak Halenahally Veeregowda, Ducom Instruments, Groningen, Netherlands

Temperatures up to 1000 °C pose a challenge to the test instruments and stability of the tests results. The repeatability and reproducibility of test results are difficult to achieve. In this study we analyzed the friction and wear behavior of six tribopairs at high temperature. The samples used were in the form of balls (silicon nitride, sapphire, alumina) and disks (Inconel 725, GPS silicon nitride). The tests were conducted in a unidirectional sliding motion (rotation), under a 5 N load, both at ambient temperature and 1000 °C. At ambient temperature, friction followed an increasing trend for all tribopairs, whereas at 1000 °C the increase in friction over the test time was minimal. In the case of alumina ball on IN 725 disk, the wear on the ball increased at high temperature; in all the other cases, the wear on the ball was lower at 1000 °C. The repeatability of friction and wear results varied with the test temperature: at 1000 °C the wear results were more scattered.

2:30 - 3 pm
3473453: Testing for Friction Differences Between Oils
Kenneth Budinski, Bud Labs, Rochester, NY

How does one determine if an oil will produce lower friction than other candidate oils in a given tribosystem? That is the objective of this study. Current oil friction tests (like the 4-ball, SRV, HFRR etc.) are reviewed and results are presented on a variety of non-standard tests that show that there can indeed be significant differences in the friction component of oils. The concept of attritious friction is introduced as a possible test for comparing parasitic friction loses from splashing of oil in crankcases.

3 - 3:30 pm - Break

3:30 - 4 pm
3481715: Wear and Viscosity Effects of Mineral Oil Dilution by Biodiesels and Their Methyl Esters
Gustavo Molina, John Morrison, Emeka Onyejizu, Valentin Soloiu, Georgia Southern University, Statesboro, GA

The dilution of IC engine-oils by unburned biodiesels may substantially alter oil lubricity and reduce its viscosity. Previous tribometer research showed enhanced degradation of engine materials, but also substantially different wear for different feed-stock biodiesels in the mixture. Some of these tribological effects were studied by individual wear-testing each of the main biodiesel components (typically methyl-esters) in mineral oil, and the viscosity reductions vs. temperature resulting from such dilution. Results of tribometer wear and of dynamic viscosity vs. dilution rates at different temperatures are presented for SAE 15W40 mineral-oil diluted by four biodiesels and by six pure fatty-acid methyl-esters, which suggest that viscosity of commercial biodiesels blended in oils could only partially be explained by assuming the former as mixtures of pure methyl-esters.

4 - 4:30 pm
3484531: Extracting More Value From Tribofilm Images
Oluwaseyi Ogunsola, Shell Global Solutions USA Inc, Houston, TX; Chaitanya Pradan, Aarthi Thyagarajan, Vishal Ahuja, Shell India Markets Private Limited, Bengaluru, Karnataka, India

One of the functions of a lubricant is to form tribofilms that reduce wear of contacting surfaces. Tribofilms are formed through the chemical bonding of additives in the oil with the metal engine surfaces. Stronger and thicker tribofilms offer wear protection by preventing metal-to-metal contact. Analysis of tribofilm thickness is crucial to development of lubricant formulations that exhibit enhanced wear protection as engine oil viscosities are becoming lower, to increase fuel economy. Tribology-based test methods generate many wear images that are post-processed and analyzed to determine the tribofilm thickness. This presentation features the development of a method to extract more value out of tribofilm images from MTM Spacer Layer Imaging experiments via automated extraction of the tribofilm region and generation of thickness distribution. Extracting more value from tribofilm images is crucial to develop lubricants with enhanced tribofilm attributes and protection capabilities.

4:30 - 5 pm
3490126: Friction Behavior of TiN Coatings under Sliding Friction Conditions
Daria Kolbas, Oksana Elagina, Andrey Buklakov, Gubkin Russian State University of Oil and Gas (National Research University), Moscow, Russian Federation; Franz Novotny-Farkas, Ingenieurbuero fuer Erdoelwesen, Schwechat, Austria

The paper presents experimental results of friction pair “TiN coating – 100Cr6 steel”. Tests were conducted on SRV® tribometer under conditions of cyclic loading, oscillation motion and varying load. This given friction pair provides stable friction characteristics over a contact load range from 1 N to 35 N. Load increasing causes smooth reduction and stabilization of the coefficient of friction (COF). Under fixed load average speed reduction versus movement results COF reduction, which prevents stick-slip and vibration in the friction unit. Comparison of COF dynamics under cyclic loading of friction pair “TiN coating – 100Cr6 steel” shows high COF stability at 30 Hz. The increase of oscillation frequencies to 70 Hz leads to COF destabilization and causes coating destruction. The influence of lubricant temperature on COF is nonlinear. The formation of a stable tribofilm on the TiN coating surface was fixed during tests in a range of high loads, while in low loads it was not observed.

5 - 5:30 pm
3522420: Advanced Capacitance Sensors for Tribological Characterization of Super-lubricity Conditions
Tushar Khosla, Jun Xiao, Nick Doe, Rtec-Instruments, San Jose, CA; Pradeep Menezes, University of Nevada Reno, Reno, NV

Most experimental work in super lubricity has been limited to small scale tests through AFMs. We present the use of advanced capacitance sensors for tribological characterization of superlubricity conditions at macro levels. Compared to the typical strain gauge sensors, these capacitance sensors are robust and offer inherently reduced noise and drifts without electronic filtering. Using high resolution capacitance sensors, friction and downforce is measured independently and accurately. Tests were conducted to characterize friction between a ceramic disc and ball lubricated with phosphoric acid in a pin on disc configuration. The test set up also includes leveling stage to level the tribo pair and eliminate effect of sample run out. A friction coefficient of 0.004 was observed demonstrating the efficiency of the sensor in characterizing superlubricity. The set up provides a simple easy to use platform to characterize super lubricity on macro scales.

5:30 - 6 pm
3479016: Synergistic Action of Friction Modifier (MoDTC) with PTFE NPs as an Additive
Vinay Saini, Jayashree Bijwe, IIT Delhi, Delhi, India

This research work investigates the combined effect of PTFE nanoparticles and MODTC, in order to minimize the friction losses and enhance extreme pressure properties. Thus, Influence of (PTFE NPs-230 nm and MoDTC NPs (30 nm) on tribo-performance as EPA, AFA and AWA is evaluated. A series of nano-oils was formulated by adding varying amount, PTFE NPs and MoDTC in group III base oil. The formulated oils were characterized for physical and tribological properties. Moreover, the stability of oils (sedimentation tendency) was monitored through visual photography. Results revealed the inclusion of these particles showed a synergistic effect by enhancing the overall weld load of oils than the individual NPs by 120 kg. The surface analysis was carried on pre-weld balls in order to understand the possible wear mechanism through scanning electron microscope coupled with energy dispersive and Raman spectroscopy. The chemical nature of tribo-film is evaluated using X-ray photo spectroscopy.

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

6G — Virtual Meeting Room 7

Rolling Element Bearings IV

Session Chair: Bryan Allison, SKF Aeroengine, Clymer, NY

2 - 2:30 pm
3543554: Influence of Vibration Induced Standstill Marks (Fretting) on Bearings of E-drives
Markus Grebe, Hochschule Mannheim, Mannheim, Germany

The lecture presents the current state of research in the field of false brinelling and standstill marks. Main topic will be the differences between brinell marks (plastic deformation), false brinelling marks (due to small swivel movements) and standstill marks (due to vibrations, micro movements). This research work is becoming increasing relevant in connection with wind turbines due to the fact that the newest control technologies like individual pitch control (IPC) lead to more critical loading of the pitch bearings. With IPC the pitch bearings oscillate at angles of a range of less than one up to several degrees. This requires a detailed analysis of both types of damage, false brinelling (larger pivoting angles) and standstill marks (small pivoting angles or vibration).

2:30 - 3 pm
3483088: Numerical Modeling of Three-Dimensional Crack Propagation under Rolling Contact Fatigue
Florian Meray, Daniel Nelias, Anthony Gravouil, Thibaut Chaise, Univ Lyon, INSA-Lyon, CNRS, LaMCoS, Villeurbanne, France; Bruno Descharrieres, Airbus Helicopters, Aéroport International Marseille Provence, Marignane, France

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

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

3:30 - 4 pm
3480860: Experimental Investigation of Influence of Different Heat Treatments on Fracture Behavior of High Strength Bearing Steels
Nikhil Londhe, Scott Hyde, Timken Company, Canton, OH

Rolling element bearings used in mechanical power transmission applications operate under high contact loads which are concentrated over small volume of the material. Due to the localized nature of loading, inclusions or material imperfections can act as stress concentration sites for fatigue crack initiation and propagation. For reliable prediction of fatigue performance, an acceptable size of inclusions must be established based on material’s resistance to fracture. This study presents comprehensive experimental investigation on fracture behavior of high strength bearing steels. Steels were induction hardened, carburized and through hardened with varying microstructures. Tests were conducted using static and dynamic loading conditions as per ASTM standards. The Influence of different stress ratios was also analyzed on fracture behavior of bearing steels. The data generated is useful to predict crack initiation & growth behavior in materials under various bearing operating conditions.

4 - 4:30 pm
3498853: Propagation of Rolling Contact Fatigue Cracks in Ball Bearing
Kenji Matsumoto, Honda Research and Development Japan Inc, Tochigi, Takanezawa, Tochigi, Japan; Naoaki Yoshida, Kyushu University, Kasuga, Fukuoka, Japan; Akira Sasaki, Maintek Consulting, Yokohama, Kanagawa, Japan

We believe that it is important to elucidate wear mechanisms of rolling contact surfaces in order to predict the life of a ball bearing. Therefore, we focus on the inner race wear of the bearing and conduct a detailed investigation. Results of cross-sectional TEM observation revealed that there are three typical patterns beneath the rolling surface. Based on that fact, we hypothesized that wear debris formed in the following process. he crystal grains underneath the rolling surface become smaller and a fine crystal layer is formed. Then, cracks occur in the layer and scaly wear debris is formed. Precipitates just under the rolling surface prevent wear, but when the limit is reached, cracks occur along the precipitates and large wear debris is formed. Precipitates and grains just below the rolling surface are crushed finely, causing plastic flow. Then cracks propagate along the interface between the precipitates and grains, and wear debris is formed.

4:30 - 5 pm
3485677: The Effect of Electrical Current on Premature Fatigue and Microstructural Alterations in Bearing Steel
Benjamin Gould, Robert Erck, Nicholaos Demas, Oyelayo Ajayi, Maria Cinta Lorenzo Martin, Aaron Greco, Argonne National Laboratory, Lemont, IL

Premature fatigue failures associated with local regions of microstructural degradation (i.e. White Etching Cracks (WECs)) are the predominate mode of failure within wind turbine drivetrain bearings, and numerous other applications. Although WECs have been reported in the field for over a decade, the conditions leading to this failure, and the process by which this failure culminates, are both highly debated. Recently NREL instrumented a wind turbine drivetrain and measured bearing characteristic such as excessive slip, and small electrical currents during turbine operation. The present work, intends to highlight the effect that these realistic conditions have on the formation of WEC failures at the benchtop scale. It was documented that the levels of electrical current documented uptower are able to significantly accelerate the formation of WECs within several commercially available wind lubricants. The effect of DC current level and lubricant composition is presented.

6H Virtual Meeting Room 8

Tribochemistry - Materials Tribology and Nanotribology Joint Session I

Session Chair: TBD

2 - 2:30 pm
3498014: Wear Penalty for Steel Rubbing Against Hard Coatings in Reactive Lubricants
Xin He, Harry Meyer, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Hard coatings and surface adsorptive/reactive lubricants are two common strategies for wear protection, but what if they are used together? In this study, an AISI 52100 steel ball was slid against an M2 tool steel flat and two commercial hard coatings, diamond-like carbon, and chromium nitride. Selected base oils included two polar base oils, polyalkylene glycol (PAG) and oil-soluble PAG, and a non-polar mineral oil blend. The anti-wear additives were a ZDDP and an ionic liquid. Based on lubricant chemical analysis, worn surface examination, and tribofilm characterization, the ball wear is proposed as a combined effect of chemical-mechanical polishing (CMP), tribofilm formation, and sometimes adhesive wear. Specifically, CMP-induced wear is proportional to the counterface hardness as well as the lubricant-surface reactivity; tribofilm wear protection increases along with the lubricant-surface reactivity; and adhesive wear depends on the material compatibility of the contact pair.

2:30 - 3 pm
3498032: Investigation of Friction and Wear Behavior in Chloride Molten Salt for Concentrating Solar Power Pump Bearings
Xin He, Rick Wang, Dino Sulejmanovic, James Keiser, Kevin Robb, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

One engineering challenge regarding the next-generation concentrating solar power systems is to increase the operating temperature of the heat transfer and thermal energy storage media. A chloride salt mixture was proposed as a potential media. Candidate bearing materials were first selected based on corrosion resistance and thermal expansion. The tribological performance of several ceramic-alloy contacts was evaluated in the lubrication of the molten chloride salt at 750 ^{0}C in an argon environment. Characterization of worn surfaces suggested the wear mechanism as a combination of adhesive wear, abrasive wear, and tribocorrosion. The top-performing pair, zirconia ball sliding against Haynes 244 alloy disc, was further studied for the influence of impurity, magnesium oxide (MgO) particles. Two main factors, particle size, and concentration were investigated. This study provides fundamental insights for

the development and selection of bearing materials for molten salt powered CSP pumps.

3 - 3:30 pm - Break

3:30 - 4 pm
3485147: Tribological Behavior of PS400-related Tribopairs for Space Exploration
Vasilis Tsigkis, Kian Bashandeh, Andreas Polycarpou, Texas A&M University System, College Station, TX; Pixiang Lan, ATSP Innovations, Champaign, IL

PS400 is a multi-component alloy developed by NASA and intended for high temperature bearing applications. This study reports on four mating surfaces, namely bulk 4130 steel, diamond-like carbon (DLC), polycrystalline diamond, and molybdenum boride cobalt chrome coatings sliding against PS400 coating, and the best performing tribopair at 25 and 500°C was identified. The temperature range and sliding speeds simulate extreme conditions for low-speed space-related applications, such as bearings on landing probes for future missions to Venus. PS400 vs. DLC showed low friction and excellent wear resistance up to 500°C. DLC provided good lubrication at 25 °C, whereas at 500°C oxide glazes transferred on DLC, maintaining low friction. The worn surfaces and the transfer films were analyzed using different analytical techniques.

4 - 4:30 pm
3485317: Development of Self-Adaptive Lubricating Silver Aluminum Borate Composite for Wide Temperature Range
Ashish Kasar, Pradeep Menezes, University of Nevada Reno, Reno, NV

An alumina self-lubricating composite is developed for wide temperature range by the formation of in situ phases (boron oxide, aluminum borate, and silver aluminum borate). Additionally, the composition used in the study also adds in achieving liquid phase sintering and densification. The composites were characterized using X-ray diffraction to confirm the phases present, and strength was measured in terms of microhardness The X-ray diffraction results revealed the formation of boron oxide and aluminum borate. Sliding tests on the composites were carried out using alumina balls from room temperature to 500 °C to investigate the friction and wear performance and responsible phases. The tribological performance strongly depends on concentration of different phases. The fabricated composites are self-adaptive lubrication at different temperatures due to formation of desired phases. The mechanisms for friction and wear behavior at different temperatures and loads are explained.

4:30 - 5 pm
3484977: Dependence of Tribological Performance and Tribopolymerization on the Surface Binding Strength of Selected Cycloalkane-Carboxylic Acid Additives
Qiang Ma, Arman Mohammad Khan, Q. Jane Wang, Yip-Wah Chung, Northwestern University, Evanston, IL

Cyclopropanecarboxylic acid (CPCa) has been explored as a model additive that can readily react under the combined effect of flash heating and stress to form tribopolymers. Here, we present results of how the chemical structural modification of CPCa may impact the formation of tribopolymers and hence friction and wear properties. Four lubricant additives, viz., CPCa, cyclobutanecarboxylic acid (CBCa), cyclopropane-1,1-dicarboxylic acid (CPDCa), and cyclobutane-1,1-dicarboxylic acid (CBDCa) consisting of a metastable ring structure and one or two carboxyl groups dissolved in an ester base oil were studied. Molecular dynamics simulation shows that CPCa with the less stable cyclopropane ring fragments more readily than CBCa. These simulations further demonstrate that having two carboxyl groups as in the case of CPDCa results in stronger binding of the additive molecules to the surface. The net result is that CPDCa gives the lowest friction and negligible wear under our testing conditions.

Grease I

Session Chair: TBD

2 - 2:30 pm
3532329: Fully Customizable Calcium Sulfonate Greases for Optimum Performances
Marie Legatte, Guillaume Notheaux, SEQENS, Porcheville, France

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

2:30 - 3 pm
3484679: Adhesion and Tackiness of Greases: From Concept to an ASTM Standard Method
Emmanuel Georgiou, Dirk Drees, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium; Michael Anderson, Falex Corporation, Sugar Grove, IL; Satish Achanta, ASML Netherlands BV, Veldhoven, North Brabant, Netherlands; Manfred Jungk, MJ Tribology, Geisenheim, Germany

The performance of lubricating greases which are extensively used in diverse industrial applications, is strongly dependent on their adherence to the substrate, cohesion, and thread formation (tackiness). This issue attracts more industrial interest, as complexity in grease formulation evolves, and it is harder to differentiate between available greases. Until now the most widely used tackiness measurement was the very subjective and non-quantifiable ‘finger test’.
For the last 8 years we have developed a quantitative tackiness measurement based on indentation retraction curves. In this work we review how the procedure and the test instrument have evolved from an experimental concept to an ASTM standard method. In particular, we explain how the method works, we define the terminology, give experimental examples, illustrate the sensitivity and repeatability, and its correlation with friction. The resulting quantitative measurements will improve further development of greases.

3 - 3:30 pm - Break

3:30 - 4 pm
3480662: New Method to Measure Grease Tackiness and Comparison with Water Resistance and Low-Temperature Mobility
Anoop Kumar, Chevron Lubricants, Richmond, CA

In this paper we focus on measuring tackiness, water resistance and low temp mobility for a wide range of grease and studying the synergy and dysergy between these properties. In order to do so we have designed and used new test instrumentation and test methods to measure tackiness and low temp mobility. Traditionally, the tackiness of a grease has been described using a qualitative approach known as the “finger test.” However, this crude way of measuring tackiness may differ from person to person and lacks any standardized procedure for assessing and comparing this adhesive property among different greases. One aim of this paper is to study the tackiness of different types of greases by a newly developed tackiness tester and construct the framework for a future ASTM method. The collection of this

interesting tackiness data, along with comparative and correlation studies with water resistance and low-temperature properties, will be covered in this paper.

4 - 4:30 pm
3473181: Back to the Basics – Part II: Fundamental Building Blocks of Grease Formulation – The Next Story
Joseph Kaperick, Afton Chemical Corporation, Richmond, VA

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

Grease II

Session Chair: TBD

10:30 - 11 am
3490804: The Effects of Addition of Zinc Carboxylate in Grease on the Tribological Properties of PA66-GF Composite in Contact with Carbon Steel
Takeshi Kunishima, Jules Galipaud, Gaylord Guillonneau, Gaëtan Bouvard, Jean-Christophe Abry, Clotilde Minfray, Vincent Fridrici, Philippe Kapsa, Laboratoire de Tribologie et Dynamique des Systemes, Ecully, Auvergne-Rhône-Alpes , France

In this research, influence of temperature on the tribological properties of glass fiber reinforced PA66 in contact with carbon steel under boundary lubrication of grease was studied, with consideration of the temperature dependence on the mechanical properties on the sliding surface of PA66 composite and tribochemical reaction related to zinc carboxylate and sulfur type anti-oxidation agent in grease. XPS and ToF-SIMS analyses revealed the formation of heterogeneous fatty acid tribofilm on the steel surface and zinc sulfide reactive film on PA66 surface related to the tribochemical reaction of the zinc carboxylate and sulfur type anti-oxidation agent present in the grease. The improvement effect of the addition of the zinc carboxylate was not observed at room temperature. However, the formation of the tribofilm contributed to the improvement of the tribological properties of the contact, particularly at 80°C.

11 - 11:30 am
3499579: Tribology Bench Tests for the Development of Next-Generation Greases with Optimized Lubrication Properties
Rory McAllister, Marc Masen, Philippa Cann, Imperial College London, London, United Kingdom

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

11:30 am - 12 pm
3484425: Yielding Behavior of a Fumed Silica Lubricating Grease
Behzad Zakani, Dana Grecov, University of British Columbia, Vancouver, British Columbia, Canada

Lubricating greases have been widely used for rail lubrication systems. There are two main components in the composition of these colloidal suspensions known as base oil and thickener. The latter is known to dictate grease rheology. It is crucial to study grease yielding behavior to evaluate its consistency on rail surface and other lubrication applications. The main objective of the present study is yield stress analysis of a lubricating grease thickened by fumed silica nanoparticles, as a newly developed nano-grease. Commercial rheometers and visualization techniques such as SEM and Cryo-SEM are used to characterize this material. Using several yield stress measurement approaches, it is shown that the obtained yield points have roughly similar values, since yield point is a transition from predominant elastic response to the viscous one. The slight differences between yield stresses measured by these

techniques has been addressed and discussed.

7B Virtual Meeting Room 2

Contact Mechanics I

Session Chair: Morgan Jones, Sandia National Laboratory, Albuquerque, NM
Session Vice Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

10:30 - 11 am
3483691: The Origin of the Friction Coefficient for Randomly Rough Surfaces in Elastic Contact
Feng-Chun Hsia, Cyrian Leriche, Steve E. Franklin, Bart Weber, Advanced Research Center for Nanolithography, Amsterdam, Netherlands; Daniel Bonn, Universiteit van Amsterdam Faculteit der Natuurwetenschappen Wiskunde en Informatica, Amsterdam, Noord-Holland, Netherlands

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

11 - 11:30 am
3499189: High Temperature Contact Creep and Friction of Inconel 617 Surface Oxides
Sepehr Salari, Ali Beheshti, George Mason University, Fairfax, VA; Saifur Rahman, Andreas Polycarpou, Texas A&M University College Station, College Station, TX

Inconel 617 is a principal candidate for VHTR with outlet temperatures of 700-950 °C. Surface friction, wear, and contact properties of the contacting pairs degrade at high temperatures, due to the presence of oxides, which in turn impacts the performance of parts. This study investigates the influence of high temperature creep on friction and evolution of contact area for Inconel 617 at high temperatures up to 600 °C using finite element analysis and machine learning. The mechanical properties of the oxide layer are obtained through nanoindentation and implemented into a finite element model to study friction and contact area of a spherical asperity. Using a machine learning approach, friction coefficient sensitivity on load, temperature, and holding time is measured and consequently, a nonlinear empirical model at asperity level is obtained. The findings show a high dependency of the oxide friction coefficient on creep of the material during dwell time, especially at higher loads.

11:30 am - 12 pm
3497896: Analysis of Asperity Creep of a Rough Random Surface in Contact with a Rigid Flat Surface
Fernando Alamos, David Go, University of Notre Dame College of Engineering, Notre Dame, IN; Martin Philo, GKN Aerospace, Santa Ana, CA; Steven Schmid, University of North Carolina at Charlotte, Charlotte, NC

High-temperature gas pressure forming (HTGF) is often used in the production of a wide range of aerospace structures. However, one of the pressing concerns is the ability to predictively and quantitatively model the HTGF process in order to effectively design tooling. Current finite element method (FEM) simulations for HTGF generally do not include the evolutionary nature of friction under

creeping conditions nor model proper constitutive behavior. The presence of creep strain leads to junction growth and saturated contact areas at longer time scales than conventional metal forming; therefore, friction models that ignore creep-induced strains will underpredict asperity contact and friction levels. In this work, a new micro-contact model of a rough surface in contact with a rigid flat surface is created to predict asperity flattening under creep behavior. An empirical equation of the real contact area and friction at different HTGF conditions is established.

12 - 12:30 pm
3498933: Investigating the Influence of Topography on the Magnitude and Variation of Surface Adhesion in Hard Contacts
Luke Thimons, Abhijeet Gujrati, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA; Antoine Sanner, Lars Pastewka, University of Freiburg, Freiburg, Germany

Adhesion in hard-material contacts is highly sensitive to roughness. Recent models suggest that large-scale adhesion depends strongly on the topography across many length scales, from the scale of the contact down to the nanoscale. In this experimental investigation, micro- to millimeter-scale spheres of ruby were brought into contact with nanodiamond substrates of varying roughness. The spheres and substrates were characterized across multiple length scales using stylus profilometry, atomic force microscopy, and transmission electron microscopy. Contact tests were performed on each substrate to measure adhesion and to evaluate statistical fluctuations. Pull-off force distributions were measured for each substrate. The shape of the distributions was explored and results were analyzed in the context of an exponential interaction potential. Results suggest that these surfaces interact at ranges up to a few nanometers. Roughness below this threshold plays a less critical role in adhesion.

7C — Virtual Meeting Room 3

Engine and Drive Train III

Session Chair: Feng Dong, Borg Warner, Auburn Hills, MI

10:30 - 11 am
3499264: A System Engineering Approach to Reduce Soot Wear
Deepak Halenahally Veeregowda, Angela Maria Tortora, Edona Hyla, Ducom Instruments, Groningen, Netherlands

In this study, Four Ball Tester was used to determine in situ friction and temperature of fully formulated semi-synthetic lubricant 10W40 and 10W40 with 1% carbon black (a model for engine soot), at 0.7 GPa and 75°C. Profilometry was used to measure surface topography and wear volume of the test balls. Results showed that carbon black increased the friction and lubricant temperature. Surface topography study on the steel balls tested in 10W40 showed a thick adsorbed film on the surface. An organic friction modifier added to the 10W40 with 1 % wt carbon black reduced the friction and also improved the thermal stability of the contaminated oil. Furthermore, the steel balls were coated with tungsten doped diamond like carbon (W-DLC) further reduced friction and wear. A lubricant system comprising of W-DLC coating and organic friction modifier can improve retention of protective surface film, and resist abrasive nature of carbon black due to increase in surface hardness of steel surface.

11 - 11:30 am
3485400: Tribofilm Chemistry for Engine Oils Formulated with Organic Polymeric Friction Modifiers
John Eastwood, Croda International PLC, Goole, East Yorkshire, United Kingdom

Tribofilm formation is a complex process dependent upon factors such as conditions (temperature, pressure, materials, etc.); viscosity, base oil, type; dispersant; detergent; viscosity modifier and friction

modifier chemistries, be they inorganic or zero Sulphated Ash and Phosphorus and Sulphur (SAPS) organic friction modifiers (OFMs). Inclusion of optimized OFMs can result in tribofilms that form at lower temperatures and are thicker and richer in organic oxygen, calcium, phosphorus, zinc, sulfur and when present, Molybdenum. While there can be fuel economy benefits of Molybdenum dithiocarbamate (MoDTC), the effects can be short-lived, even with high levels. High treat-rates of MoDTC and similar compounds can also result in some harmful effects, such as increased deposits. Tuning OFM chemistry to different styles of engine oil containing MoDTC can result in even lower friction and extended low-friction durability under different tribological conditions, as determined in bench top tests.

11:30 am - 12 pm
3483859: Enhanced Tribofilm Formation and Wear of Engine Oils under Stressed Boundary Conditions
Hong Gao, Shell Global Solutions, Houston, TX

One of the biggest challenges to formulate fuel efficient engine oils is to design unsacrificed and enhanced wear protection while optimizing the viscosity profile. The additive components in a fully formulated engine oil will affect the final tribofilm formation on the surface. The tribofilm and wear were studied using MTM and wear tribotester for different fully formulation engine oils under boundary lubrication conditions. The correlation between tribofilm and wear was discussed and analyzed to better understand the influence of additives on wear protection.

12 - 12:30 pm
3497315: An Integrated Approach to Measure Electrical Conductivity of Working Lubricants
Yan Chen, Hong Liang, Texas A&M University, College Station, TX

We designed a tribo-electrochemical configuration to measure electrical conductivity and thickness of a lubricant against friction. This test system consisted of an impedance measurement and a disc-on-disc tribotester. Using this system, we tested mineral oil and PAO. Experimental data showed that in hydrodynamic regime, a lubricant behaves non-ohmic, contradictory to that of an oil in stationary. In this presentation, we discuss about the new test system and principles behind the performance of lubricants.

7D Virtual Meeting Room 4

Lubrication Fundamentals IV: EHL

Session Chair: Daniele Dini, Imperial College of London, London, United Kingdom
Session Vice Chair: Q. Jane Wang, ME, Northwestern University, Evanston, IL

10:30 - 11 am
3519637: Friction Increase in Starved EHL Contact
Petr Sperka, Ivan Krupka, Martin Hartl, Vysoke Uceni Technicke v Brne Fakulta Strojniho Inzenyrstvi, Brno, Czechia

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

11 - 11:30 am
3516692: A New Thermo-Elastohydrodynamic Lubrication Model for Journal and Sliding Bearing Systems
Suhaib Ardah, Imperial College London, London, United Kingdom; Francisco Profito, Polytechnic School of the University of São Paulo, São Paulo, Brazil; Daniele Dini, Imperial College London, London, United Kingdom

The current contribution proposes an integrated finite-volume framework aimed at solving transient mixed thermo-elastohydrodynamic lubrication (TEHL) problems to predict the lubrication performance of conformal bearing systems. Fluid flow effects are considered using the generalized Reynolds equation with the p-θ Elrod-Adams mass-conserving cavitation model to ensure mass flowrate conservation throughout the lubricated domain. The thermal behavior of the lubricating oil is described through the solution of three-dimensional energy equation with proper boundary conditions for the fluid-solid interfaces. Advanced numerical techniques are employed to handle the strong nonlinearities exhibited by the system of equations. Experimental validation of the proposed work will be based on friction data and infra-red thermal maps. The TEHL framework is a unique numerical tool which correctly captures cavitation boundary conditions and transient behavior to study thermal effects in bearing systems.

11:30 am - 12 pm
3493168: Fluid-Structure Interaction Modeling of 2D Elastohydrodynamically Lubricated Contacts
Kushagra Singh, Farshid Sadeghi, Purdue University, West Lafayette, IN

A two-way coupled Fluid-structure interaction (FSI) solver to model elastohydrodynamic lubrication (EHL) in line contacts is presented. The lubricant behavior is described by Navier-Stokes equations and solved using Finite Volume Method (FVM) based CFD solver. The Finite Element Method (FEM) was utilized to model the elastic deformation of the solid. Multiphysics simulation software Ansys was employed to develop the FSI model with an iterative implicit coupling scheme. Pressure and film thickness results predicted by the model show excellent corroboration with open published results for a wide range of contact conditions. The FSI model is robust, easy to implement, and computationally efficient. The model is used to investigate the effects of plasticity, surface features, and microstructural inhomogeneities under heavily loaded lubricated line contacts as can be found in gears and rolling element bearings.

12 - 12:30 pm
3520760: Visco-Elastohydrodynamic Lubrication of Imperfectly Bonded Polymer Coating on Elastic Substrate
Q. Jane Wang, Tao He, Xin Zhang, Northwestern University, Evanston, IL; Yuchuan Liu, Zhe Li, Hun June Kim, Seongchan Park, General Motors Corp, Pontiac, MI

Polymer-based materials are now widely used in various engineering products. This presentation reports a novel visco-elastohydrodynamic lubrication (VEHL) model for the lubrication of a rigid sphere and a viscoelastic layer imperfectly coated on an elastic half-space. Two interfaces are modeled, which are the lubrication interface between the sphere and the coated half space, and the material interface between the viscoelastic coating and the elastic substrate. The surface viscoelastic deformation is calculated based on contact viscoelasticity. The contact solution is pursued through the discrete convolution and fast Fourier transform (DC-FFT) algorithm by using the influence coefficients (ICs) converted from frequency response functions (FRFs). This VEHL model is implemented to explore the effects of material properties, operating conditions, and coating-substrate imperfection of the lubrication characteristics of such material systems

12:30 - 1 pm
3520772: Thermal-Visco-Elastohydrodynamic Lubrication (TVEHL) of Polymer-Based Materials
Q. Jane Wang, Tao He, Xin Zhang, Northwestern University, Evanston, IL; Yuchuan Liu, Zhe Li, Hun June Kim, Seongchan Park, General Motors Corp, Pontiac, MI

Temperature affects the behavior of polymer-based materials at tribological interfaces. This presentation reports a novel thermal-visco-elasohydrodynamic lubrication (TVEHL) model for analyzing the lubrication

behavior at the interface formed by an elastic sphere and a polymer half-space. The temperature-dependent viscoelastic displacement of the polymer surface is calculated through contact viscoelasticity and frequency-temperature superposition. The discrete convolution and fast Fourier transform (DC-FFT) algorithm is used for efficient solution computation. The lubrication analysis results with and without considering the effects of viscoelasticity and temperature are compared. The influences of entraining speed and sliding-to-rolling ratio are explored. Thermal-viscoelasticity coupling in TVEHL is also addressed, and a non-dimensional parameter is defined to characterize the coupling effects.

7E Virtual Meeting Room 5

Tribochemistry - Materials Tribology and Nanotribology Joint Session II

Session Chair: TBD

10:30 - 11:30 am
INVITED TALK:
3573521: Effect of Environment on Friction Reduction Capabilities of Spin-coated MoDTC
Clotilde Minfray, Jules Galipaud, Mayssa Al Karboutly, Julien Fontaine, Thierry Le Mogne, Manuel Cobian, Ecole Centrale de Lyon, Ecully, Rhône-Alpes, France; Gleb Veryasov, Pooja Gaval, Alexandre Verchere, Clément Camp, Alessandra Quadrelli, Chimie Catalyse Polymeres et Procedes, Villeurbanne, Rhône-Alpes, France; Bruno Reynard, Laboratoire de Geologie de Lyon Terre Planetes Environnement, Villeurbanne, Auvergne-Rhône-Alpes , France

It is proposed to investigate the effect of the environment (UHV and O_2) on friction reduction capabilities of MoDTC molecules deposited by spin-coating on steel samples.
Friction tests are first carried out under UHV and coupled with in-situ XPS analyses as well as ex-situ Raman analyses. The ability to generate MoS_2 sheets from MoDTC molecules within the tribological contact is first investigated (kinetic of MoS_2 sheets generation, effect of normal load, effect of surface nature…). Then, the effect of the environment (UHV versus 5 mbar O_2) on the friction behavior of in-situ formed MoS_2 sheets will be as well studied.
All the results are discussed for a better understanding on how O_2 environment mitigates the friction behavior of MoS_2 sheets.

11:30 am - 12 pm
3499581: In-Situ Tribochemical Formation of MoS_2 and WS_2 Tribofilms Using Mo and W-Containing Surfaces
Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria; Bernhard Kohlhauser, Carsten Gachot, TU Wien, Vienna, Austria; Carmen Vladu, CEST GmbH, Wiener Neustadt, Austria

In the present work, we study the in-situ reactive formation of MoS_2 and WS_2 tribofilms in lubricated contacts. Instead of using Mo-containing friction modifiers or MoS_2/WS_2 nanoparticles, we aim to generate MoS_2/WS_2 in-situ via a tribochemical reaction between Mo/W-containing substrates and S-containing extreme pressure (EP) lubricant additives. MoS_2/WS_2 formation is verified using Raman spectroscopy and transmission electron microscopy (TEM). Under certain testing conditions, the in-situ tribochemical formation of MoS_2 is accompanied by the presence of oil-derived carbon tribofilms. In a second step, we address the synergies and antagonisms of the in-situ formed MoS_2 tribofilms with co-additives, such as ZDDP and succinimide dispersants. MoS_2 tribofilms can be tribochemically formed in conjunction with ZDDP tribofilms, as evidenced using TEM. On contrary, the use of dispersants prevents MoS_2 tribofilm formation, analogous to observations with MoS_2 nanoparticles as lubricant additives.

12 - 12:30 pm
3499082: Mechanisms for Decomposition of Antiwear Additives on Ferrous Surfaces: A REAXXFF Study of Phosphate Esters
Carlos Ayestaran Latorre, James Ewen, Daniele Dini, Imperial College London, London, United Kingdom; Arash Khajeh, Ashlie Martini, University of California Merced, Merced, CA; Joshua Moore, Joseph Remias, Afton Chemical Corp, Richmond, VA

We employ reactive Non-Equilibrium Molecular Dynamics simulations to study the dissociation of phosphate ester with different substituents on several ferrous surfaces . To this goal, we employ α-Fe(110), Fe_3O_4(001) and hydroxylated, amorphous Fe_3O_4 substrates which aim to represent the heterogeneous surfaces observed experimentally. Our models include both pure thermal decomposition on exposed surfaces, and sliding-wall simulations representative of a tribological contact where mechanochemistry is expected to drive film formation. By studying the surfactants-surface interactions and the bond cleavage within the phosphate molecules we shed light on the chemical pathways driving the lubrication process, the role of substituents and molecular structure, and underpin current experimental results.

12:30 - 1 pm
3491049: Shear-Driven Dissociation of Organosulfur Compounds on Iron
Karen Mohammadtabar, Ashlie Martini, University of California Merced - Merced, CA, Merced, CA; Stefan Eder, Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria

Tribofilms protect the surface of mechanical components by reducing friction and wear, resulting in increased lifetime. The rate of the reaction that induces film formation is increased by shear, the mechanism of which is poorly understood. In this study, we use reactive molecular dynamics simulations to study the reactions between di-tert-butyl disulfide, an extreme pressure additive, and an iron (100) surface in different temperature and pressure conditions. We analyzed the rate of reaction in the context of the classic Bell and extended Bell models. Results show that the second-order effects of force significantly affect this reaction by changing the shape of the reaction energy profile. Additionally, we calculated the energy barrier and activation length of the reaction directly using nudged elastic band calculations. We conclude that the mechanism by which shear increases the reaction rate both reduces the barrier height and changes the curvatures of reaction energy profile.

7F — Virtual Meeting Room 6

Tribotesting III

Session Chair: Robert Jackson, Auburn University, Auburn, AL
Session Vice Chair: Md Hafizur Rahman, University of Nevada Reno, Reno, NV
Session Vice Chair: Pawan Panwar, University of California Merced, Merced, CA

10:30 - 11 am
3496872: Effects of N-Butanol in Ultra-Low-Sulfur Diesel Mixtures on Wear, Friction and Viscosity
Gustavo Molina, John Morrison, Valentin Soloiu, Cesar Carapia, Georgia Southern University, Statesboro, GA

The poor lubricity of ULSD (ultra-low sulfur diesel) is a major concern that is often solved by mixing in biodiesel or alcohols, which typically also decrease mixture viscosity. N-Butanol in ULSD mixtures is studied as lubricity additive by viscosity measurements, pin-on-disk tribometry and a crankcase lubricant interaction with oils. Viscosity for the tested mixtures (of up to 35% of added N-Butanol) does not decrease below the recommended by standard ASTM D-975. Tribometer wear shows, however, a unique minimum for the 25% N-butanol in ULSD mixture, a wear reduction of 43% as compared to that of pure ULSD; tribometer friction force evolution data supports that there would be a lubricity improvement for

such a dilution ratio. Finally, crankcase lubricant interaction tests show good compatibility of the N-Butanol/ULSD blend when mixed in engine oil, with no visible hazing or build up after one-month shelving.

11 - 11:30 am
3498614: Improving Tool Life for Rotary Shear Biomass Comminution System
Kyungjun Lee, Oak Ridge National Laboratory, Knoxville, TN

A biomass comminution system is essential for efficient biomass conversion. Variability of size and shape in wood chips is a major source of inconsistent feed rate, plugging, and poor flow. The new Crumbler® rotary shear system has benefits of tolerance of high moisture variation within bale or production run, narrow particle size distribution, higher yield of feedstock due to lower fines, higher flowability due to lower aspect ratio. However, rotary shear experiences significant tool wear in processing dirty biomass. The wear mechanism of each component of the rotary shear was investigated and identified candidate alloys, coatings, and surface treatments for enhanced tool life. The tribological performance of the candidate materials was evaluated by 2-body and 3-body abrasion tests. In addition, the cutter tooth design was improved aided by finite element analysis.

11:30 am - 12 pm
3499241: An Updated Method for Fuel Lubricity: Line-on-Cylinder Lubricity Evaluator (LOCLE)
Gregory Hansen, Southwest Research Institute, San Antonio, TX

In diesel engines, the fuel pumps and injectors are subjected to tremendous pressures, upwards of 30,000 psi in modern systems. In order to generate and maintain this level of pressure, the internal pump and injector components are made to an exacting standard. The drawback is that the moving components are lubricated with only the fuel. If the fuel has insufficient lubricating properties, catastrophic wear and subsequent failures can occur. In an ongoing effort to modernize sliding wear tests, work was undertaken to improve lubricity testing for aviation turbine fuels that are utilized in diesel powered ground vehicles. This is the second part of this work in which unidirectional sliding wear is studied. The end goal is to have two appropriate lubricity tests (oscillating and unidirectional) that are able to screen fuels and their additives for acceptable use in modern fuel system hardware.

12 - 12:30 pm
3499325: Impact-Slide Wear Testing for Evaluation of Hard Coatings for Tooling Applications
Suvrat Bhargava, Ranjan Deshmukh, Bradley Schultz, Rodney Martens, TE Connectivity, Middletown, PA

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

12:30 - 1 pm
3499723: Use of Gas-Phase-Synthesized Grapened as an Anti-Wear Lubricant Additive
Gordon Krauss, Albert Dato, Harvey Mudd College, Claremont, CA; Matthew Siniawski, Loyola Marymount University, Los Angeles, CA

Gas-phase-synthesized graphene (GSG) has benefits over traditional graphene when used as a lubrication additive. GSG exhibits a high degree of persistent dispersion in synthetic, petroleum, and bio-derived base oils as well as commercially available fully formulated oils motor oils. GSG exhibits a crumpled morphology that remains during suspension or during tribological application. This morphology

is believed to limit the opportunity for stacking of layers and thus surface energy reduction through agglomeration. In this study, GSG is evaluated as an anti-wear lubricant additive in oils of interest during pin on disc testing. Lubricated tests of a 52100 steel ball sliding on a 52100 steel disc indicate significantly reduced wear of the ball surface for minute amounts of GSG (≤ 0.1 wt%) added to canola oil, polyalphaolefin (PAO), fully formulated petroleum oil, and synthetic motor oil. GSG is produced in a single-step through an environmentally friendly atmospheric plasma process.

7G Virtual Meeting Room 7

Rolling Element Bearings V

Session Chair: Daniel Merk, Schaeffler Technologies, Schweinfurt, Bavaria, Germany

10:30 - 11 am
3480732: Dynamics in Kinematics - Running Noise Calculation of Bearings in the Kinematic Regime
Hannes Grillenberger, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany

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

11 - 11:30 am
3481713: Dynamic Modeling of Cage Flexibility in Ball Bearings
Karine Petuya, Univ Lyon, INSA-Lyon, CNRS, LaMCoS, Safran Aircraft Engines, France, Villeurbanne, Rhône, France; Daniel Nelias, Nans Biboulet, Univ Lyon, INSA-Lyon, CNRS, LaMCoS, Villeurbanne, France

Aeronautical industry is currently developing ball bearings with cages made of lighter but softer materials. Such high-speed rolling element bearings experiences cage deformation and stress concentration due to ball-to-pocket impacts. These are produced during acceleration and deceleration phases, and also during cruise when operating with combined thrust and radial load. However, few dynamic ball bearing models consider global and local cage elasticity, especially in 3D. We propose a high-speed ball bearing model where the cage can deform. For that purpose, the cage is divided into finite elements. The model takes into account ball-to-pocket contacts, lubrication, friction and damping. A Newton-Raphson algorithm solves the quasi-static problem while the Runge-Kutta method is used in dynamics. Outputs of the model are the deformed geometry of the cage and the cage center motion depending on the ball bearing operating conditions.

11:30 am - 12 pm
3485034: Backward Whirl-Shaped Cage Instability in Rolling Bearings
Florian Unterderweide, Matthias Weigold, Eberhard Abele, Technical University Darmstadt, Darmstadt, Germany

Rattling or screeching noises can occur during operation of rolling bearings: the cage rattling or squealing. The consequence is: Increased wear and breakage. In order to investigate the cause of the

unstable cage movement, there is a test bench that enables the movement of the outer ring-guided cage of a spindle bearing to be recorded during operation using a high-speed camera. In the stable state, the center of the cage runs on a circular path at the rolling element set speed. In the unstable case, the orbit is reversed, the orbit speed increases sharply and a screeching noise is created. The movement is reminiscent of the backward whirl, which is an unstable state in the area of the general rotor-stator contact. In addition, the cage vibrates at a frequency that is close to the first natural frequency. It is assumed that a brief static friction contact of the cage on the guidance rip caused by increased friction, reinforced by the natural vibration, triggers the backward whirl.

12 - 12:30 pm
3483379: A First Approximation of the Global Energy Consumption of Ball Bearings
Vasileios Bakolas, Philipp Roedel, Oliver Koch, Michael Pausch, Schaeffler Technologies AG und Co KG, Herzogenaurach, Germany

The contribution that widely used components have on global energy emissions has not been investigated up until now. Rolling element bearings are found in every piece of machinery and are, therefore, a source of energy losses that can't be ignored. During the last years, a series of energy efficient bearings have been developed using specific designs or new materials aiming to reduce the losses of a bearing without sacrificing its load carrying capacity. The effect that these designs have on the global emissions hasn't been quantified until now. A methodology to estimate the energy losses of the usage of a specific bearing type on a global scale is presented in this paper. The method that is based on current norms, provides a first approximation for the determination of the CO_2 emissions of bearings and it is tested for its plausibility. The pros and cons of the proposed method are discussed, and a proposal is made on how to calculate the potential energy efficiency of newer designs.

12:30 - 1 pm
3483683: Voltage Induced Roller Bearing Fatigue
André Harder, Lukas Piske, Tobias Schirra, Eckhard Kirchner, Technical University Darmstadt, Darmstadt, Germany

The emergence of electric mobility increases the number of electric actuators in vehicles, particularly traction drives. A common failure mechanism for electric actuators is the damage of the roller tracks in roller bearings due to an electrical current between the inner ring, the rolling elements, and the outer ring, e.g. EDM-current. Literature shows that an increased electrical current reduces the remaining lifetime of roller bearings.
So far, research focused on the fatigue of the roller bearing as part of an electric actuator on a systemic level. This paper intends to investigate the influence of an electric load on the mechanical load capacity of a roller
bearing directly on a machine element level. A novel test rig is presented to apply combined mechanical and electrical loads on the machine element in order to determine the impact of varying parameters like voltage amplitude and frequency on the remaining lifetime and first experimental results are shown.

7H — Virtual Meeting Room 8

Surface Engineering I

Session Chair: Ali Beheshti, George Mason University, Fairfax, VA
Session Vice Chair: Suvrat Bhargava, TE Connectivity, Middletown, PA

Session starts at 11 am

11 - 11:30 am
3497576: Evaluation Tests of MAO-Coatings in Environmentally Safe Lubricants

Nikita Poches, Vladimir Malyshev, National University of Oil and Gas (Gubkin University), Moscow, Russian Federation; Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria

Micro-arc oxidation (MAO) method is a relatively new technology to enhance surface properties which allow the creation of coatings with a wide range of properties such as wear-, heat-, corrosion resistance and etc.
This study is a summary of five-year cooperative research of Gubkin University (Russia) and AC2T research GmbH (Austria) which is devoted to the investigation of MAO-coatings wear resistance formed on aluminum alloys in environmentally safe lubricants. Initially, investigations were carried out by two friction schemes: reciprocating sliding on the “ball-disk” and unidirectional sliding on the “pin-disk”. As lubricants were used some base oils like diisotridecyl adipate ether (DITA), polyalphaolefin (PAO), polyethylene glycol (PEG). In order to widen the range of contact loading, the tests with the scheme “ring-ring” were additionally carried out. The study represents a generalization and analysis of tests' results obtained. Further steps of the research were marked out.

11:30 am - 12 pm
3499607: In-Situ SEM Tribological Studies of 3D-Printed Superhydrophobic Hierarchical Textures
Mahyar Afshar Mohajer, Min Zou, University of Arkansas, Fayetteville, AR

Surfaces with functionalities such as superhydrophobicity are increasingly gaining attention due to the wide variety of applications that they offer, ranging from self-cleaning to open microfluidics. Surface textures are crucial to achieving superhyhdrophobicity as evidenced by the extreme water repellency of natural surfaces such as lotus leaf. Moreover, the hierarchy of textures, in the form of nanoscale structures on top of microstructures, is shown to be essential to improving superhydrophobicity. Utilizing two-photon lithography, hierarchical textures consisting of micro-/nano-scale structures were fabricated. Tribological testing of individual hierarchical structures was carried out inside a scanning electron microscope (SEM), enabling in-situ monitoring of the friction, normal and lateral displacement, and deformation of structures. This targeted testing of textures provided insights into the tribological performance of the building blocks of superhydrophobic surfaces.

12 - 12:30 pm
3497892: Fabrication and Friction Characteristics of Arbitrary Biosurfaces
Shelby Maddox, Xiaoxiao Han, Xiangbo Meng, Min Zou, University of Arkansas, Fayetteville, AR

Many naturally occurring surfaces have desirable tribological properties, such as the well-known frog toe or lotus leaf. Current methods for replicating these surfaces for engineering applications, such as molding, are limited in surface scale and are often destructive to the original surface. A new process is needed to take advantage of this natural tribological engineering for industrial applications. In this work, we present a novel method for replicating biosurfaces using confocal laser scanning microscopy and 3D two-photon lithography. Two natural surfaces (banana skin and daffodil flower petal) were replicated. A tiling process is applied to the surface so that an area of arbitrary size can be textured. The printed surfaces are coated with a hard atomic layer of zinc oxide to improve tribological performance. These replicated textures reduced friction up to 42% compared to a flat control and demonstrated increased hydrophobicity.

8A — Virtual Meeting Room 1

Grease III

Session Chair: TBD

2 - 2:30 pm
3481391: Grease Improvement Process for High Speed Passenger Trains

Lieuwe de Vries, Sathwik Chatra, SKF, Houten, Utrecht, Netherlands

Main drivers in passenger train operations is the extension of maintenance intervals in addition to an increase of operating speed. This combination leads to very demanding conditions for the wheelset bearings and in specific the lubricant used. A thorough improvement process is needed to improve the current grease solutions for these demanding conditions. This process consists of several screening steps combining grease parameter tests, tribological tests as well as full bearing tests ranging from small size bearings to actual wheelset bearings. The process leads to concrete improvement requirements on specific grease properties and these are used to improve the grease formulations and/or grease manufacturing processes.

2:30 - 3 pm
3499663: Effect of Temperature and Surface Roughness on the Tribological Behavior of Electric Motor Greases as a Baseline for Electric Vehicle Bearing Applications
Daniel Sanchez Garrido, Samuel Leventini, Ashlie Martini, University of California Merced, Merced, CA

Greased bearings in electric vehicle (EV) applications are subjected to a wide range of operational temperature requirements, micro-environments, and operating speeds. Consequently, chosen greases must function effectively in these conditions. Here, the tribological performance of four market-available, electric motor (EM) greases are characterized by measuring friction and wear of silicon nitride sliding on hardened 52100 steel to simulate conditions in EV applications and investigate their performance under various conditions as a baseline for future studies. Tested EM greases have similar viscosity grade, but different combinations of polyurea or lithium thickener with mineral or synthetic base oil. Tests are performed between 40-150°C with samples having a range of surface roughness to capture changes in the lubrication regime. Results show market available products can vary significantly in performance, giving us insight into operating condition effects and design limitations.

3 - 3:30 pm - Break

3:30 - 4 pm
3485475: Oscillating Wear – A Little Back and Forth
Rajeev Kumar, Larry Decker, ExxonMobil Research and Engineering Company Annandale, Annandale, NJ; Joseph Kaperick, Afton Chemical Corporation, Richmond, VA

Fretting wear is the oscillating motion of two mating pieces against each other and can result in significant damage to grease lubricated bearings and other components. Examples of such wear are seen in wheel bearings, heavy machinery, and wind turbines. The measurement and prevention of this type of wear is critical for grease formulators. This paper presents an examination of oscillating wear and its measurement with specific focus on the Fafnir fretting wear test including historical context, critical aspects of measurement and a discussion of its value to the grease industry today. Data will be presented from studies to highlight additive effects as well as the variability of the test.

4 - 4:30 pm
3499464: Using Polymers to Improve Water Resistance in H1 or Biobased Greases
Erik Willett, Functional Products Inc, Macedonia, OH

Water resistance is often an obstacle in developing specialty greases for the NSF H1 incidental food contact or biobased grease markets. A grease may perform well but fail ASTM D4049 water spray off or ASTM D1264 water washout. Fixing water resistance late in development can involve extensive changes to the formula. Highly refined H1 base stocks have low cohesion to resist the ingress of water and poor solubility for additives to fix the problem. This work shows how two H1 grease polymers in a variety of non-PAO/mPAO H1 oils can give high water resistance and significant cost reduction. Conversely, biobased oils have high cohesion but are limited by their low viscosities and affinity for water. This work includes examples of how biobased viscosity modifiers can be used to build base oil viscosity, reduce thickener treat rates, and greatly improve water resistance of the biobased grease.
Greases were made with GRAS and biobased pre-formed hydrous calcium and calcium complex

thickeners.

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

8B Virtual Meeting Room 2

Contact Mechanics II

Session Chair: Kylie Van Meter, Florida State University, Tallahassee, FL
Session Vice Chair: Tomas Babuska, Lehigh University, Bethlehem, PA

2 - 2:30 pm
3520752: Mechanics Models for Contacts in Lithium Metal Batteries
Q. Jane Wang, Xin Zhang, Northwestern University, Evanston, IL; Stephen Harris, E O Lawrence Berkeley National Laboratory, Berkeley, CA

The development of liquid electrolytes (LE) has faced problems of the Li-electrolyte reaction and dendrite formation, both of which can lead to loss of active lithium. On the other hand, using solid electrolyte (SE) is expected to suppress dendrite formation due to its high modulus. However, poor physical and electrical contact at the Li-SE interface can cause high interface resistance that constrains Li ion transport. Recent experiments suggest that applying stack pressure can suppress dendrite formation at the Li-LE interface while enhancing the contacts of the materials. This presentation reports a modeling approach to investigate the contact at the Li-LE and Li-SE interfaces. The proposed models consider surface roughness, Li elastoplasticity, Li creep, and Li metal plating/stripping processes. The analyses of the Li-SE interface reveal the preferred stack pressure to maintain a relatively small interface resistance while reducing the void volume.

2:30 - 3 pm
3490405: Exact Spectral Moments and Differentiability of the Weierstrass-Mandelbrot Fractal Function
Itzhak Green, Georgia Institute of Technology College of Engineering, Atlanta, GA

Fractal mathematics using the Weierstrass-Mandelbrot (WM) function has spread to many fields of science and engineering. One of these is the fractal characterization of rough surfaces, which has gained ample acceptance in the area of contact mechanics. The well-known model by Greenwood and Williamson (GW) depends on parameters that are direct outcomes of these moments. Despite the vast amount of publications on the Weierstrass-Mandelbrot (WM) function dedicated to surfaces, two papers stand out as originators, however, they contain some omissions and approximations that may lead to gross errors in the estimation of the spectral moments. The current work revisits these papers, adds information, but departs in the mathematical treatment to derive exact expressions for the said moments. First, the complete mathematical treatment of the WM function is made, then the spectral moments are derived to yield exact forms.

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

3:30 - 4 pm
3491370: An Investigation of the Elastic Cylindrical Line Contact Equations for Plane Strain and Stress Considering Friction
Robert Jackson, Kefei Xu, Nolan Chu, Auburn University, Auburn, AL

This work presents a finite element model (FEM) based study of elastic cylindrical contact. The aim is to evaluate the transition between the plane stress and plane strain based Hertz solutions and when each assumption is most applicable. To accomplish this, a range of curvatures, widths, Poisson’s ratios, and

friction coefficients are considered. The FEM results for the elastic cylindrical contact cases are compared to the Hertz contact model when assuming plane stress or plane strain. Perhaps surprisingly, the FEM predictions show little dependence on Poisson's ratio and friction coefficient. The FEM predictions of force as a function of deflection agree relatively well with the plane strain Hertz prediction for all cases considered. The FEM predictions of contact width as a function of force actually fall below all the analytical Hertz predictions. Therefore, an adapted version of the Hertz equations is provided which shows better agreement with the cases considered in this work.

4 - 4:30 pm
3499152: Contact Mechanics Simulations of Gradient Stiffness Soft Materials
Alison Dunn, Md Mahmudul Hasan, Christopher Johnson, University of Illinois at Urbana-Champaign, Urbana, IL

Soft surfaces made of elastomers and hydrogels are the biomedical materials of the future because they can mimic the mechanical response of tissues. Researchers are now making multi-layered surfaces that mimic the layers found in tissues. However, interpreting the force-depth curves of probe-based measurements to determine local elasic properties cannot be done with existing contact models which require homogeneous samples. Thus we have performed a series of case studies comparing the force and contact area response of surfaces with a gradient of stiffness with depth. We simulate hard-probe indentation of surfaces with gradient stiffness defined by linear functions, step functions, exponential functions, and parabolic functions. We find that when the outer layers are softer, the greatest errors with contact models are found at the shallow-depth regime. This work is expected to assist experiments and theories regarding probe-based testing of soft composite materials.

4:30 - 5 pm
3490556: Molecular Dynamics Studies of Interfacial Interaction between Ti(Ti6Al4V) and TiB2
Shaoping Xiao, Siamak Attarian, The University of Iowa, Iowa City, IA

Boron (B) compounds have many applications in the industry and have been incorporated in a variety of composite materials. For example, adding TiB2 whiskers to Ti(Ti6Al4V) enhances the mechanical and thermal properties, especially when the composite is manufactured as a spatially tailored material to obtain the desired properties. Current standard practice for numerical modeling of Ti6Al4V/TiB2 uses principles of micromechanics without considering the interfacial interactions taking place at the molecular level due to the lack of proper potential functions. In this research, we developed potential functions to describe interatomic interactions in boron and some of its compounds based on quantum mechanical calculations. Then, molecular dynamics with the developed potential functions was adopted to study the material interfacial interactions between Ti(Ti6Al4V) and TiB2 at various temperatures. The simulation results were compared to the published experimental measurements.

5 - 5:30 pm - **Contact Mechanics Business Meeting**

8C — Virtual Meeting Room 3

Engine and Drive Train IV

Session Chair: TBD

2 - 2:30 pm
3485320: Power Loss Measurement of Planetary Gear Stages with High Power Density
Felix Siglmüller, Joshua Götz, Martin Sedlmair, Thomas Lohner, Karsten Stahl, Gear Research Centre (FZG), Technical University of Munich, Garching bei München, Germany

Planetary gear stages can reach very high power densities in comparison to conventional spur or helical gear stages with the same gear ratio. During the development of those gear stages, the acquisition of empirical data is necessary in order to validate a good efficiency, load carrying capacity and NVH behavior. A test rig was designed and built to test planetary gear stages with a power throughput of up to 3.77 MW. It features a mechanical back-to-back principle and is equipped with sensors for torque, speed, temperature, acceleration, strain, flow, and force, as well as a telemetry system for measurements on rotating parts. The sensors and measurement system are explained and analyzed in the context of measurement uncertainty. It is shown, that measurements with focus on power loss determination can be conducted with high quality and accuracy. Furthermore, first measurement results for a double-helical planetary gear stage from the test rig are shown and discussed.

2:30 - 3 pm
3488659: Correlating Viscosity to Fuel Efficiency in the Heavy-Duty Diesel Engine Fuel Efficiency Tests and the Influence of Viscosity Index Improvers.
Lucas Camposo, Phil Hutchinson, Boris Eisenberg, Julien Couet, Evonik Oil Additives, Horsham, PA

Durability has been the primary objective when formulating heavy-duty diesel engine oils. However, fuel economy has recently received increased international attention. For example, the introduction of the API FA-4 performance standard allows lubricant formulators to specify an oil with lower high-temperature high-shear (HTHS) viscosity to help achieve fuel efficiency. Currently there are no internationally recognized fuel efficiency tests for heavy-duty diesel engines, but there have been OEM developments in this direction. For example, Volvo and Daimler have developed their own fired engine tests to determine the fuel efficiency effect of the oil. In this paper, we report our findings regarding the influence of viscosity and viscosity index improver on the Daimler OM501 fuel economy test. These findings include strong relationships between HTHS viscosities at 80 and 100C and fuel economy.

3 - 3:30 pm - Break

3:30 - 4 pm
3480558: Effects of Lubricant Additives on Copper in Soaking Test
Xinggao Fang, Afton chemical, Richmond, VA

Copper materials are widely used in automotive transmissions. Transmission fluids are required to protect these materials for extended time. This study will focus on the effects of common additives on copper in an extended soaking test. End of test (EOT) fluids are analyzed for leached copper and changes in chemistry. EOT coupons are analyzed with energy-dispersive X-ray spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS) to uncover underlying mechanisms. The learnings are then applied to formulate additive packages that provide superior copper protection.

4 - 4:30 pm
3483835: Frictional Performance of Novel Eco-friendly Organic Lubricity Additives in Passenger Car Motor Oil (PCMO) Formulations.
Ramesh Navaratnam, Patech Fine Chemical, Dublin, OH

As environmental regulations are getting more stringent globally, the lubricant Industry has to respond by developing lubricants that will reduce energy consumption and impact to the environment. Comparing to typical lubricity additives with Metals and SAPS, Friction Modifier based purely on Carbon, Hydrogen and Oxygen can perform in highly effectively by reducing wear and friction coefficient in PCMO formulations. By using novel molecular modeling, optimal molecules can be designed to increase adsorption rate on metal surface to enhance lubricity. Besides friction reduction, other PCMO formulation criteria can be also addressed by real tests or simulation, including additive solubility, oxidation performance or elastomer compatibility. This paper will also explore the effect in reconditioning used oils that have been in service for 7,500 KM. Other than PCMO, these additives are formulated in other automotive, marine, and industrial applications.

4:30 - 5 pm
3484509: Organic Polymeric Friction Modifiers Effects on Tribofilm Formation and Properties in HDDEO Formulations
Alexei Kurchan, Croda, New Castle, DE

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

5 - 5:30 pm
3484985: Study on Polymer Colloids as a Friction Modifier
Kenji Yamamoto, Kazuki Marumo, Tsuyoshi Hirmatsu, ADEKA Corporation, Arakawa-ku, Tokyo, Japan

It is well known that low viscosity lubricant with effective friction modifiers contributes to improve energy efficiency. Although MoDTC formulated low and ultra-low viscosity engine oils are put in place in the market, more effective FM system is demanded especially for improving low temperature friction property, which is considered to be more important under operation in hybrid system equipped vehicle. Polymer type friction modifier is one candidate which is attracting the attention for enhancing low temperature friction property under combination with other FMs. In this study, friction reducing ability of colloidal polymer is evaluated under several condition, and it is found that it can lower the friction under low temperature without competitive relation with MoDTC. Friction test and surface analysis were carried out to discuss the mechanism for friction reduction, and it is indicated that colloidal polymer reduces friction by supporting surfaces without chemical reaction.

8D — Virtual Meeting Room 4

Lubrication Fundamentals V: Viscosity

Session Chair: Ashlie Martini, University of California Merced, Merced, CA
Session Vice Chair: Nicole Doerr, AC2T Research GmbH, Wiener Neustadt, Austria

2 - 2:30 pm
3486295: Estimating the Viscosity-Pressure Response from Friction and Film Thickness Measurements under Elastohydrodynamic Conditions
Eliane Gendreau, Janet Wong, Imperial College London, London, United Kingdom; Sarah Matthews, Shell Global Solutions (UK) Ltd, London, United Kingdom

Developing high-performance lubricants is crucial to ensure durability and reliability of engines, and thus increase fuel economy. Therefore, it is key to access the rheology, and more particularly the viscosity response of lubricants. Various methods have been developed to measure the viscosity-pressure relationship of fluids, such as high-pressure rheometry or local viscosity measurement using in-situ fluorescence anisotropy. However, these techniques are complex and require advanced equipment. In this work, we propose an alternative method built on standard friction and film thickness tests, coupled with a least-square regression, to estimate the viscosity of lubricants at high pressure. The results obtained for two fluids, a polyalphaolefin and an ester, at mean pressures ranging from 0.1 to 1.5 GPa, will be presented. The thermal effect and the sensitivity of the method will also be discussed.

2:30 - 3 pm
3473059: Viscosity-Temperature Equations for Petroleum-Based Lubricating Oils
Jack Zakarian, JAZTech Consulting, LLC, Orinda, CA; Ashlie Martini, Shaun Flannigan, Julian Gonzalez, University of California Merced, Merced, CA

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

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

3:30 - 4 pm
3500906: A Novel Microfluidic Rheometer for Rapid Viscosity Measurements over Wide Shear Rate Ranges
Gordon Irvine, Charles Nider, Pascal Bru, Formulaction, Inc, Worthington, OH; Patrycja Adamska, Yoann Lefeuvre, Gerard Meunier, Formulaction, Dallas, TX

Understanding the behavior of liquids under varying shear rates will help deliver quality results when products are subjected to different conditions during various applications. This can help reduce the risk of developing an excessively viscous or thin sample. However, determining the viscosity of concentrated dispersions using a rotational rheometer can suffer from inconsistencies at high shear rates and temperatures. Herein, we describe the use of a novel instrument that utilizes a co-flow microfluidic principle to determine the viscosity of various products run against a reference inside of a microfluidic chip. Dual syringe pumps control the shear rate of the flows while a high-definition camera detects the laminar flow interface of the two substances and plots a rheological curve. We will show how select concentrated dispersions behave at varying shear rates and temperatures and make comparisons to mechanical rheometers and literature values.

8E — Virtual Meeting Room 5

Tribochemistry - Materials Tribology and Nanotribology Joint Session III

Session Chair: TBD

2 - 3 pm - **From Friction to Function**

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

3:30 - 4 pm
3496775: Tribocatalysis of Lubricating Carbon Films
Diana Berman, Asghar Shirani, Daniel Pleshek, University of North Texas, Denton, TX; Stephen Berkebile, Army Research Laboratory, Aberdeen Proving Ground, MD

High contact pressure and shear during relative movement of the sliding interfaces provide the unique capability of local heating and shear- and load-induced compression of the materials in contact. For a correct combination of materials, these conditions may induce tribomechanically or tribochemically-activated transformations of the surfaces into protective damage-suppressing tribofilms that are capable of significantly minimizing friction and wear of the sliding systems. Here, we demonstrate the tribo-

assisted transformation of hydrocarbon sources, such as fuels and alcohols, into adaptive and self-replenishing low friction and wear coatings. The characterization analysis revealed the onset of the hydrocarbon decomposition and reconstruction correlating with applied load and temperature conditions. We show that activation of the tribocatalysis process allows to significantly reduce the wear of the contacting surfaces and extend the lifetime of the mechanical systems.

4 - 4:30 pm
3499515: Stress-Induced Mechanochemical Decomposition of Methyl Thiolate on Cu(100)
Alejandro Boscoboinik, University of Pennsylvania, Philadelphia, PA; Wilfred Tysoe, University of Wisconsin Milwaukee, Milwaukee, WI

Improving the tribological properties of lubricants has become an important field of study for increasing engines efficiency at macroscopic and microscopic level (e.g. cars and micromachines).[1] By dosing dimethyl disulfide (DMDS) on Cu(100) a model lubricant film of methyl thiolates is produced.[2] The mechanically induced rate of a chemical reaction is described by the Bell model [3] where the rate constant for a reaction under an applied stress σ is given by $k(\sigma)=k_0\exp(\sigma\Delta V^{\ddagger}/k_BT)$, where k_B is the Boltzmann constant, k_0 is the reaction rate in the absence of stress, $\Delta V^{\ddagger}$ is known as the activation volume, and T is the absolute temperature. While exponential increases in reaction rates with stress have been reported, there are currently no quantitative experimental measurements of $\Delta V^{\ddagger}$. This is addressed in this work by using contact-mode atomic force microscopy (AFM) to measure the kinetics of the mechanochemically induced C-S bond cleavage of methyl thiolate on Cu(100) in ultrahigh vacuum.[4]

4:30 - 5 pm
3483055: In Situ Study of the Normal Pressure-Dependent Lubrication Mechanism of Phosphonium Phosphate Ionic Liquid in Nanoscale Single-Asperity Sliding Contacts
Filippo Mangolini, Zixuan Li, Andrei Dolocan, Oscar Morales Collazo, Hugo Celio, Joan Brennecke, The University of Texas at Austin, Austin, TX; Jerzy Sadowski, Brookhaven National Laboratory, Upton, NY

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

5 - 5:30 pm
3483058: Encapsulation of Lubricious Ionic Liquids within Polymer Microshells
Filippo Mangolini, Erynn Naccarelli, Jieming Yan, Ryan Misage, 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, the limited solubility of the majority of ILs has hindered their employment in engine oils. Here, we develop a methodology, based on mini-emulsion polymerization, for encapsulating ILs within methacrylate-based polymer shells with the aim of introducing ILs in hydrocarbon fluids in a concentration that exceeds their solubility limit. Macroscale steel-vs-steel tribological tests performed using synthetic oil containing polymer-encapsulated halogen-free ILs together with ex situ X-ray photoelectron spectroscopy (XPS) 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. The new methodology paves the way towards the implementation of a broad class of ILs in lubricant formulations.

5:30 - 6 pm
3483064: Effect of Halide Contaminants on the Lubricating Properties of Phosphonium Phosphate Ionic Liquid
Zixuan Li, Filippo Mangolini, Hugo Celio, Nicolás Vergara, Jude Kershaw, Oscar Morales Collazo, Andrei Dolocan, Joan Brennecke, The University of Texas at Austin, Austin, TX
Phosphonium phosphate ionic liquids (PP-ILs) have attracted considerable attention in tribology owing to their good miscibility in hydrocarbon fluids and excellent lubrication performance. The majority of the studies in the literature evaluating the lubricating properties of PP-ILs was carried out with high-purity ILs, whose high cost mainly derives from difficult and time-consuming purification required to remove contaminants (e.g., residual halide ions from the synthesis). Here, we perform macroscale tribological (52100 steel-vs.-52100 steel) experiments in the presence of PP-ILs with systematically-varied concentration of a common halide contaminant, i.e., bromide, to identify its influence on the tribological response of PP-ILs. Based on subsequent analyses of the surface chemistry of steel by X-ray photoelectron spectroscopy and time-of-flight secondary ion mass spectrometry, a simple phenomenological model will be proposed to account for the observed tribological behavior.

8F Virtual Meeting Room 6

Additive Manufacturing II: Special Symposium

Program Information Coming Soon.

8G Virtual Meeting Room 7

Rolling Element Bearings VI

Session Chair: Nikhil Londhe, Timken Company, Canton, OH

2 - 2:30 pm
3485344: Experimental and Numerical Assessment of Power Loss in an Aero-Engine Cylindrical Roller Bearing
Rami Kerrouche, Azzedine Dadouche, Mahmoud Mamou, National Research Council Canada, Ottawa, Ontario, Canada; Salah Boukraa, Universite Saad Dahlab Blida 1 Institut d'Aeronautique et des Etudes Spatiales, Ottawa, Ontario, Canada

Rolling-element bearings operate in the elastohydrodynamic regime where only a thin layer of lubricant is needed in the contact area. However, under severe operating conditions such as those encountered in aircraft engines (high speeds and heavy loads); a significant amount of heat is generated due to friction. Therefore, fresh oil must to be constantly pumped into the contact to address the cooling needs and maintain acceptable operating temperatures.
The main objective of this study is to assess heat generation and determine temperature distribution within typical aero-engine cylindrical roller bearings (CRB) lubricated using under-race technique and operating at various speeds and under different radial loads. The experiments were carried out on an M50 roller bearing. A comparison of friction torque, power loss and temperature is presented and discussed. The numerical results are based on thermal network approach.

2:30 - 3 pm
3495520: A Novel Test Rig for the Investigation of Ball Bearing Cage Friction
Thomas Russell, Farshid Sadeghi, Wyatt Peterson, Purdue University, West Lafayette, IN

This presentation presents a novel experimental test rig for the investigation of friction between a ball and cage of a deep groove ball bearing (DGBB). The experimental apparatus was designed and developed to measure the friction between a single ball and cage segment under steady state operating conditions. A six axis load cell is used to record force and torque values generated due to contact between a rotating ball and rigidly fastened cage segment. Values from the load cell are used to derive a steady state friction coefficient. Custom cage clamps were designed to secure four varieties of cage segments to the load cell. Each of the cage designs was tested with oil lubrication at speeds ranging from 300 to 3600 rpm and applied loads of 1.5 to 4 N. Friction coefficient values in the different cage pockets are stochastic in nature and range from a low of 0.02 to 0.10. Average values of the friction coefficient for all cages increase with speed and reduce with applied load.

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

3:30 - 4 pm
3499500: CFD Investigation of Deep Groove Ball Bearing Fluid Flow
Wyatt Peterson, Purdue University, West Lafayette, IN

ANSYS FLUENT computational fluid dynamics (CFD) software was used to develop a full-scale model of a single-phase oil flow in a deep groove ball bearing (DGBB). The CFD model was used to investigate fluid flow characteristics as a function of bearing geometry and operating conditions. The underlying theory, boundary conditions and development of the model are described in detail. Major features of the model, including meshing techniques, mesh density and geometric clearances, were determined by performing parametric studies. Streamlines, velocity vectors and pressure contours are used to investigate various DGBB aspects such as cage design and lubricant properties. The CFD model developed provides a novel approach to study DGBB fluid flow and the effect of cage geometry on bearing performance.

8H Virtual Meeting Room 8

Surface Engineering II

Session Chair: Harpal Singh, Sentient Science, West Lafayette, IN
Session Vice Chair: Kora Farokhzadeh, Bruker Nano Surfaces, San Jose, CA

2 - 2:30 pm
3472312: Friction Reduction Effect of Soft Coatings
Zhou Chen, Zhejiang University, Hangzhou, Zhejiang, China

Finite element analysis is conducted on an elastic-plastic full stick contact between a rigid flat and a deformable coated sphere with a soft coating. A combined normal and tangential load is applied to the rigid flat, and the sliding inception is assumed as a result of the decreasing tangential stiffness of the contact junction. As the coating becomes thicker, the static friction coefficient first decreases reaching a minimum and then increases. This demonstrates a friction reduction effect of soft coatings that is opposite to hard coatings. The static friction coefficient decreases with increasing normal load as the contact junction contains more plasticity and becomes more compliant.

2:30 - 3 pm
3500367: Post-Additive Manufacturing Surface Modification Technology for Controlling Microstructure and Tribological Properties of Materials
Auezhan Amanov, Ruslan Karimbaev, Seimi Choi, Young-Sik Pyun, Sun Moon University, Asan, Republic of Korea

This paper presents the microstructural evolution and tribological properties of materials manufactured by additive manufacturing (AM). The samples were subjected to ultrasonic nanocrystal surface modification (UNSM) technology at room and high temperatures. Experimental results revealed that the UNSM technology was able to reduce the surface roughness of the as-printed state, where the surface hardness and surface roughness were increased with increasing the temperature of UNSM technology. Moreover, the friction coefficient of the UNSM-treated samples was found to be lower, while the wear resistance was found to be higher in comparison with the as-printed samples throughout the temperature, which are mainly attributed to the reduction in surface roughness and elimination of pores from the surface, and also due to the increase in hardness and also yield strength.

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

3:30 - 4 pm - **Surface Engineering Business Meeting**