2017 STLE Annual Meeting and Exhibition

Hyatt Regency Atlanta
Atlanta, Georgia

2017 Preliminary Technical Program
as of 1/27/17

Preliminary

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Program At A Glance
As of 1/27/2016

Sunday, May 21, 2017

Registration
7 am– 6 pm – Grand Hall Foyer

Speakers Breakfast
7- 7:45 am – Centennial II

Education Courses - 8 am - 5 pm
Synthetic Lubricants 203 – Hanover A/B
Metalworking Fluids 115 – Hanover C/D
AMBA Bearings Course - Hanover E
Advanced Lubrication 301 – Hanover F/G
Hydraulics 201 – Courtland
Gears 101 – Dunwoody
Biofuels and Biolubricants – Baker
Nanotribology Special Session – *(1 – 5:00 pm)* – Greenbriar

Student Gathering- 6:30 – 8 pm – TBD

Monday, May 22, 2017

Registration
7 am – 6 pm – Grand Hall Foyer

Speakers Breakfast
7 - 7:45 am – Centennial II

Technical Sessions - 8 am - 10 am
1A STEM Camp – Hanover A/B
1B Commercial Marketing Forum I – Hanover C
1C Metalworking I – Hanover D
1D Materials Tribology I – Hanover E
1E Environmentally Friendly Fluids I- Hanover F
1F Fluid Film Bearings I – Hanover G
1G NanoAdditives Joint Session I – Regency V
1H Tribotesting I – Dunwoody
1I Wind Turbine Tribology I – Courtland

Opening General Session – 10:30 am - 12Noon
Keynote Address TBD– Centennial I/II

Lunch on your own - 12Noon – 1:30 pm

Commercial Exhibits and Student Posters – 12Noon - 5 pm – Grand Hall

Technical Sessions - 1:30 pm – 6 pm
2A Nanotribology I – Hanover AB
2B Commercial Marketing Forum II – Hanover C
2C Metalworking II – Hanover D
2D Materials Tribology II – Hanover E
2E Environmentally Friendly Fluids II – Hanover F
2F Fluid Film Bearings II– Hanover G
2G NanoAdditives Joint Session II – Regency V
2H Tribotesting II – Dunwoody
2I Wind Turbine Tribology II – Courtland

Beverage Break -10 - 10:30 am – Centennial Foyer
Exhibitor Appreciation Break - 3 – 4 pm – Grand Hall

Welcome Reception/Party – 6:30 – 8 pm – Centennial I/II

Tuesday, May 23, 2017

Registration
7– 6 pm – Grand Hall Foyer

Speakers Breakfast
7 – 7:45 am – Centennial II

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

Technical Sessions - 8 am - 12Noon
3A Nanotribology II – Hanover AB
3B Commercial Marketing Forum II – Hanover C
3C Metalworking III – Hanover D
3D Materials Tribology III – Hanover E
3E Surface Engineering I – Hanover F
3F Fluid Film Bearings III – Hanover G
3G Lubrication Fundamentals I – Additives & Additives Degradation – Regency V
3H Synthetics & Hydraulics I – Regency VII
3I Engine & Drivetrain I – The Learning Center (TLC)
3J Tribotesting III – Dunwoody
3K Ceramics and Composites I – Courtland

President's Awards Luncheon/Business Meeting -
12Noon - 2:00 pm – Centennial I/II

Technical Sessions - 2 pm – 6 pm
4A Nanotribology III – Hanover AB
4B Commercial Marketing Forum IV – Hanover C
4C Metalworking IV – Hanover D
4D Materials Tribology IV – Hanover E
4E Surface Engineering II – Hanover F
4F Fluid Film Bearings IV – Hanover G
4G Lubrication Fundamentals II – Additives & Additives Degradation – Regency V
4H Grease I – Regency VII
4I Engine & Drivetrain Special Session I – The Learning Center (TLC)
4J Tribotesting IV – Dunwoody
4K Condition Monitoring I – Courtland
4L Rolling Element Bearings Roundtable Discussion – Baker

Beverage Break – 10 - 10:30 am –Grand Hall
Exhibitor Appreciation Break - 3 – 4 pm – Grand Hall

Wednesday, May 24, 2017

Registration
7am – 6 pm – Grand Hall Foyer

Speakers Breakfast
7 – 7:45 am – Centennial II

Commercial Exhibits & Student Posters -
9:30 am – 12Noon – Grand Hall

Education Courses - 8 am - 5 pm

Automotive Lubrication 201 – Embassy A/B
Synthetic Lubricants 204 – Centennial III
Advanced Lubricants 302 – Centennial IV
Basic Lubrication 302 – Embassy C/D
Metalworking Fluids 250 – Embassy E/F

Technical Sessions - 8 am - 12Noon

5A Nanotribology IV – Hanover AB
5B Commercial Marketing Forum V – Hanover C
5C Rolling Element Bearings I – Rolling Contact Fatigue I – Hanover D
5D Materials Tribology V – Hanover E
5E Surface Engineering III – Hanover F
5F Fluid Film Bearings V – Hanover G
5G Lubrication Fundamentals III – EHL Modeling and Evaluation – Regency V
5Ga Lubrication Fundamentals III – Molecular Dynamics – Regency V
5H Wear I – Regency VI
5I Grease II – Regency VII
5J Tribochemistry I – **Joint Session-**The Learning Center
5K Non-Ferrous Metals I (Working) – Dunwoody
5L Gears I – Courtland
5M Condition Monitoring II – Baker

Technical Sessions - 1:30 pm - 6 pm

6A Nanotribology V – Hanover AB
6B Commercial Marketing Forum VI – Hanover C
6C Rolling Element Bearings II – Hanover D
6D Materials Tribology VI – Hanover E
6F Surface Engineering III – Hanover F
6G Fluid Film Bearings VI – Hanover G
6H Lubrication Fundamentals IV – Novel Additives – Regency V
6I Wear II – Regency VI
6J Grease III – Regency VII
6L Non-Ferrous Metals II (Rolling) – Dunwoody
6M Gears II – Courtland
6N Condition Monitoring III – Baker (ends at 3:00pm)
6O Biotribology I – Baker (starts at 3:30pm)
6P Engine & Drivetrain II – The Learning Center (TLC)

Beverage Break – 10 - 10:30 am – Grand Hall
Beverage Break – 3 - 3:30 pm – Grand Hall Foyer

Thursday, May 25, 2017

Registration
7 am – 12Noon – Grand Hall Foyer

Speakers Breakfast
7 – 7:45 am – Centennial II

Certification Exams
8:30 am – 12:30 pm – Hanover A/B

Technical Sessions - 8 am - 12Noon

7B Metalworking V- Hanover C
7C Rolling Element Bearings III – EHL and Friction – Hanover D
7D Tribochemistry II – **Joint Session** - Hanover E
7E Seals I – Hanover F
7F Power Generation I – Hanover G
7G Lubrication Fundamentals V – EHL Modeling and Evaluation – Regency V
7H Wear III – Regency VI
7I Synthetics & Hydraulics II – Regency VII
7J Engine & Drivetrain III – The Learning Center (TLC)
7K Non-Ferrous Metals III – (Biobased) – Dunwoody
7M Biotribology II – Baker

Technical Sessions - 1:30 pm - 5:30pm

8B Metalworking VI – Hanover C
8C Rolling Element Bearings IV – Rolling Contact Fatigue II – Hanover D
8D Tribochemistry III – Joint Sesssion - Hanover E
8E Seals II – Hanover F
8G Lubrication Fundamentals VI – Regency V
8H Wear IV – Regency VI
8I Synthetics & Hydraulics III – Regency VII
8J Engine & Drivetrain IV – The Learning Center (TLC)
8M Biotribology III - Baker

Beverage Break - 10 – 10:30 am – Grand Hall Foyer
Beverage Break - 3 – 3:30 pm - Grand Hall Foyer

1B Hanover C

Commercial Marketing Forum I

8:00 am - 8:30 am - Functional Products, Inc.

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

9:00 am - 9:30 am - Sea-Land Chemical Company

9:30 am - 10:00 am - Croda, Inc.

10:00 am - 10:30 am - Break

1C Hanover D

Metalworking I

Session Chair:
Session Vice Chair:

8:00 am - 8:30 am
Multiple Light Scattering for the Analysis of Physical Stability of Concentrated Dispersions
Matt Vanden Eynden, Formulaction, Inc, Worthington, OH, Christelle Tisserand, Mathias Fleury, Yoann Lefeuvre, Pascal Bru, Gerard Meunier, Formulaction, L'Union, France

Products such as emulsions, dispersions and foams will eventually undergo destabilization processes related to sedimentation, creaming, clarification, flocculation or coalescence thus giving a product that may exhibit a reduction in product performance. In order for formulators to optimize the development a quality material the investigation of the product in its native state is up utmost importance in order to produce a quality product within a reasonable time frame.
We present here a technique based on Multiple Light Scattering (MLS) to fulfill this purpose. It has proven to be a useful technique to characterize the dispersion state of concentrated samples and the mean diameter of the particles in the dispersion. By detecting and predicting the stability of the product, overall product quality and shelf-life predictions can be made in a fraction of the time that would be seen by the naked eye.

8:30 am - 9:00 am
The Role of the Pin & Vee Block Torque Curve for Aluminium Alloys
Kathy Helmetag, Henkel, Warren, MI, Dirk Drees, Emmanuel Georgiou, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium

The torque curve measured during continuous load increase in a Falex Pin-and-Vee Block test (ASTM D3233) was used in the past to evaluate lubricant performance in the transition boundary - extreme pressure regimes. By recording frictional torque during increasing load, sudden increase in torque ('torque pop-up') can be correlated with damage events in forming operations. These incipient artifacts give insight

into conditions that could present problems in the field. Previous tests were done with standard steel described in the ASTM method. This work will explore the continuous load technique using light alloy Pins and/or Vee blocks, with standard machining coolant formulations to show how the torque curve can be used to explore the limits of lubricity on these surfaces. Two aluminium alloys, an extrusion and a cast alloy, are compared with respect to the lubricant efficiency. The additional information that can be gathered from recording the load and torque curves, will be analysed.

9:00 am - 9:30 am
Clean & Green: Improving Process Life for Induction Quenching Auto Parts Production
Eduardo Lima, FASB - Fhilosophy and sciences college, São Paulo, São Paulo, Brazil

An innovative improvement to quenching system process life could create significant economic benefits as well as address other critical technical challenges for the metalworking fluids process chain. This novel solution could extend the process life of quenching baths and prevent contamination with oil/alkaline soap (tramp oil phenomenon) and darkening due to fluid aging.

9:30 am - 10:00 am
Statistical Interpretation of Twist Compression Test (tct) Results on Metal Deformation Fluids
Joseph Schultz, The Lubrizol Corporation, Wickliffe, OH, Elizabeth Schiferl, Lubrizol Corporation, Wickliffe, OH, Johnnie Thomlison, Brett Wessler, The Lubrizol Corporation, Wickliffe, OH

The twist compression test (TCT) is a tribotest that is used for evaluating fluids in boundary and EP lubrication conditions. It is typically used for evaluating and comparing metal deformation fluids and measures coefficient of friction (COF) over time. A fluid that provides effective lubrication in this test typically demonstrates a low, level COF for a certain period of time. In previous work, the time vs. COF plot has been used as a surrogate for metalworking application severity. Fluids that show a low COF for the duration of the test would be considered suitable for the most severe applications. In most cases the lubricant fails, the film breaks down and metal-to-metal contact occurs; this is typically referred to as the “failure time." An algorithm for estimating failure time will be discussed. In addition, there is a need for a more statistically driven interpretation of TCT results. The application of statistical sciences to TCT results will be discussed in this presentation.

10:00 am - 10:30 am - Break

1D — Hanover E

Materials Tribology I

Session Chair: N. Argibay, Sandia National Laboratory, Albuquerque, NM
Session Vice Chair: D. Haidar, University of Delaware, Newark, DE

8:00 am - 8:30 am
Selecting Powder Steel for Manufacturing Valve Seats on Diesel Engines
Nelly Alba de Sanchez, Andres Saavedra, Gustavo Agudelo Ospina, Andres Torres, Juan de Jesus Galindo, Faber Correa Ballesteros, Pedro Arango, Andres Rodriguez, Universidad Autónoma de Occidente , Cali, Colombia

This work was aimed at characterizing and selecting an alloy of pulvimetallurgical steel which complies with the specifications, to manufacture valve seats for diesel engines. Powder materials such as M2 and M3 steel, which contain high percentage of different elements.The wear on the seats was analyzed through the pin-on-disk test in order to determine the loss of material and to obtain the friction coefficient. Optical microscopy was carried out, to analyze the microstructure and porosity percentage of the

materials; scanning electron microscopy (SEM) was used to study the wear mechanism by pin-on-disk test. Finally, the dimensional stability of the valves seats was determined by simulating a cylinder head where the seats were placed and which was subjected to different temperatures, similar to the working temperatures of diesel engines. The analysis of the results led to recommend the use of the alloy M3 steel for manufacturing valve seats for diesel engines to the company.

8:30 am - 9:00 am
Friction Behaviors of Interfaces Between Friction Components and Copper Matrix in Copper-based Composites
Taimin Gong, Pingping Yao, Central South University, Changsha, Hunan, China

Copper-based friction composites manufactured by powder metallurgy have been widely applied to braking pads and clutches, which always contain friction components to get desired friction coefficient. In current work, chromium metal and silicon dioxide were added into copper matrix as friction components respectively. Friction behaviors of interfaces between friction components and copper matrix were investigated by a micro-scratch testing instrument. The results demonstrate that the friction coefficient behaved an obvious decreasing trend during the scratching from matrix to friction components. The fluctuation of friction coefficient in the interface between silicon dioxide component and copper matrix was more significant than that in the interface between chromium component and copper matrix due to their different characteristics. Meanwhile, model was established to discuss the friction mechanism of interfaces between the friction components and the copper matrix in composites.

9:00 am - 9:30 am
The Origin of Microstructural Discontinuities Underneath a Tribologically Loaded Surface
Christian Greiner, Zhilong Liu, Reinhard Schneider, Lars Pastewka, Peter Gumbsch, Karlsruhe Institute of Technology, Karlsruhe, Germany

Frictional loading of a metal surface induces microstructural changes underneath the surface. A typical tribo-induced microstructure displays distinct discontinuities parallel to the surface separating the surface layer from the bulk. By systematically decreasing the number of passes of a sapphire sphere sliding over high-purity copper, we find that the origin of the microstructural discontinuity is already laid after the first sliding pass. A distinct dislocation structure is formed 100-150 nm under the surface. This dislocation self-organization is attributed to a sign change in the stress field underneath the sphere. The dislocation structure evolves into the known microstructural features with increasing number of sliding passes. Consequently, the microstructure and mechanical properties of the surface layer are determined in the very first loading pass. Control of the initial tribological loading could be exploited to precondition interfaces for superior tribological properties.

9:30 am - 10:00 am
Nanocrystalline PtAu MEMS Electrical Switches
Michael Dugger, Nicolas Argibay, David Adams, Christopher Nordquist, Alejandro Grine, Michael Henry, Sandia National Laboratories, Albuquerque, NM

MicroElectroMechanical Systems (MEMS) relays have orders of magnitude higher figure of merit compared to semiconductor devices, along with lower power consumption and insertion loss. Unfortunately MEMS switches have not penetrated high volume applications partly due to contact adhesion, contamination, high cycle switch life and microstructural evolution leading to performance drift. A new alloy of Pt and Au may provide solutions to several challenges preventing greater adoption of MEMS switches. Nanocrystalline as-deposited grains are stabilized by the presence of gold at grain boundaries, presenting the possibility of reduced creep and relaxation in the electrical contacts and structural elements of a MEMS switch. Sputtered PtAu has been used to construct a MEMS switch, and initial results suggest performance improvements relative to baseline switches made from gold. MEMS switch performance and associated material evolution mechanisms will be discussed.

10:00 am - 10:30 am - Break

1E Hanover F

Environmentally Friendly Fluids I

Session Chair: B. Sharma, University of Illinois, Champaign, IL
Session Vice Chair: S. Erhan, Industrial Oils, ADM, Decatur, IL

8:00 am - 8:30 am
Addressing the Thermo- Oxidative Stability of Environmentally Friendly Biobased Lubricants
Ashok Cholli, Polnox Corporation, Lowell, MA

Oxidation caused by oxygen and heat results in the deterioration of a wide range of materials including oils and lubricants. Improving thermo-oxidative stability of biobased lubricants is a key industry issue. Oils used in these environment friendly lubricants include plant oils like canola oil, soy, palm oil, and synthetic esters. Potent antioxidants are required to improve their stability. Polnox has developed potent antioxidants based on its proprietary DT-mPM technology to address this critical stability issue of bio-oils. Evaluations of these novel antioxidants using industry standard ASTM methods suggest that their performance is multiple times better compared to commercial antioxidants. In this presentation the novel technology behind these new antioxidants and their performance will be presented. Compared to current industry antioxidants, these novel antioxidants have significantly improved material protection due to their enhanced antioxidant activity.

8:30 am - 9:00 am
The Growing Benefits of the Estolide
Jacob Bredsguard, Biosynthetic Technologies, Irvine, CA

Estolides have gained much recognition over the years as an environmentally acceptable lubricant. Companies all over the globe test estolides and do work on creating formulations with them in anticipation of commercial availability. These companies are excited by the estolide for both its low impact on the environment and its unique performance capabilities, allowing the formulation of environmentally friendly products. This presentation will detail the new properties and uses of the estolide that has been investigated over the last two years. New research on estolides has given light to strong performance properties, even without the help of additives. The environmental benefits of the estolide have been further proven both as a base oil and in formulations. New developments have been made in the technology, giving rise to new products and different viscosity grades, opening the environmental benefits to new applications.

9:00 am - 9:30 am
Polyalkylene Glycols as Enablers of Polyol Esters in Environmentally Acceptable Lubricants
Lauren Huffman, Gagan Srivastava, Andrew Larson, Martin Greaves, The Dow Chemical Company, Midland, MI

Natural and synthetic esters are important building blocks in formulating environmentally acceptable lubricants since many are biodegradable and derived from renewable feedstocks. They are especially preferred when formulating lubricants that need to meet the requirements of the Vessel General Permit and the European Eco-label. One known technical challenge with esters is they are prone to hydrolysis which can shorten fluid life. One way of improving their hydrolytic stability is to include polyalkylene glycols as additives into the ester formulation thereby reducing the rate of hydrolysis. Different polyalkylene glycol structures and chemistries yield different performance. Examples will be shared and how this combination can be used in formulating modern environmentally acceptable lubricants.

9:30 am - 10:00 am - Available Slot

10:00 am - 10:30 am - Break

1F Hanover G

Fluid Film Bearings I

Session Chair: A. Cristea, Tecnitas SAS, Levallois-Perret, France
Session Vice Chair: J. Zhou, R&D, Waukesha Bearings Corp., Pewaukee, WI

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

8:30 am - 9:00 am
Two Magnetorheological Elastomer Devices for the Control of Aerostatic Thrust Bearing: Thru Regulating Air Flow or Surface Curvature
Sy-Wei Lo, Tsung-Ti Shu, Jyun-Lin Li, National Yunlin Univ of Science & Technology, Douliu City, Yunlin County, Taiwan, Tsuo-Fei Mao, Chienkuo Technology University, Changhua, Taiwan

In this paper two novel controlling elements made of magnetorheological elastomer (MRE) for aerostatic thrust bearing have been developed. An electromagnet was integrated in the bearing to trigger the contraction of the elastomer. In the mode of “flux control”, the performance of the bearing depends on the air flux flowing through the gap between a MRE ring and the central mandrel. While in the mode called “curvature control,” changing the magnetic field can bend the MRE orifice shape and deepen the recess of the bearing. The air pressure distribution and the load capacity of the bearing are altered accordingly. A series of static experiments was conducted to measure the load capacity at various elevation of the bearings. It revealed that the load-elevation relationships can be manipulated. A simple dynamic test showed that the MRE bearings have both amplitude and frequency of resonance less than that of the typical design.

9:00 am - 9:30 am
Rotor Trajectory Control in the Lubricant Film of Journal and Thrust Fluid-Film Bearings
Alexander Babin, Denis Shutin, Leonid Savin, Oryol State University n.a. I.S. Turgenev, Oryol, Russian Federation

Active introduction of intellectual technologies to the elements of machines has become a modern tendency in pushing the limits of rotating machinery. In the high-speed and high-load machines of newest generation, control of rotor’s dynamic behavior is one of the actual tasks. Here, the object of the studies are trajectories of rotor motion in a bearing. The configuration of a trajectory defines energy efficiency of the operational process of a rotor machine, and thus is subject to optimization. In the present paper, the influence of a control system on the characteristics of fluid-film bearings has been investigated. The obtained trajectories of rotor motion have been analyzed in terms of energy efficiency by means of evaluating the friction processes in the fluid film. Conclusion has been made on the possibility of increasing the energy efficiency of rotor-bearing systems with adjustable parameters of fluid-film bearings.

9:30 am - 10:00 am
Effective Methods for Monitoring PEEK Bearing Temperature: Metal Versus Oil
Jie Zhou, Barry Blair, Donald Pitsch, Waukesha Bearings Corp., Pewaukee, WI
Bearings using engineered plastic, such as PEEK, can operate at much higher loads than babbitt-lined

bearings of the same size, mostly due to PEEK's higher working temperature and higher strength at elevated temperatures. With PEEK bearings, for example, turbomachinery can be upgraded for high power density without increasing bearing size. PEEK's other properties, such as fluid compatibility, corrosion resistance, and tribology characteristics, make it a good bearing material for process lubricated applications. The low thermal conductivity of PEEK, however, raises concern with monitoring PEEK bearings through pad metal temperature, as is the standard practice for monitoring babbitt bearings. This paper presents experimental work monitoring PEEK bearing temperature measurements by pad metal and by oil over a range of operating loads and speeds.

10:00 am - 10:30 am - Break

1G Regency V

NanoAdditives Joint Session I – Nanotribology & Lubracation Fundamentals

Session Chair: H. Khare, University of Pennsylvania, Philadelphia, PA
Session Vice Chair: M. Patel, Vanderbilt Chemicals, LLC, Norwalk, CT

8:00 am - 8:30 am
Tribological Properties of an Industrial Lubricant Containing Inorganic Fullerene-like Tungsten Disulfide (if-ws_2) Nanoparticles.
Roger Soto-Castillo, Nanotech Industrial Solutions, Avenel, NJ

The study refer to an tribological properties of an industrial lubricant formulation based on *IF*-WS_2 nanoparticles that results in significant improvement in extreme pressure (EP) properties while decreasing micropitting, friction and wear. Tribological properties were measured by ASTM D4172, ASTM D2783, FVA Proc No. 54. Morphology and deagglomeration state of *IF*-WS_2 nanoparticles were analyzed by Environmental Scanning Electron Microscopy (ESEM). Also, the lubricant containing IF-WS_2 was tested for copper corrosion according to ASTM D130 and was found to be non-corrosive for yellow metals (obtained 1A). Studied *IF*-WS_2 based lubricant can be used in extreme gear applications that may be subject to EP and micropitting fatigue, especially heavily loaded gearboxes with surface-hardened tooth metallurgies under extreme operating conditions such as high and ultra-low temperatures, high pressure and high vacuum, high load, high rotating speed, high radiation and corrosion conditions.

8:30 am - 9:00 am
Interactions of IF-MeS_2 (Me=Metal) Nanoparticle Additives With Lubricant Co-Additives
Fabrice Dassenoy, Ecole Centrale de Lyon, Ecully, France, Paula Ussa, TOTAL , Lyon, France, Pierre Rabaso, PSA, Velizy, France, Fabrice Ville, INSA Lyon , Lyon, France, Benoit Thiebaut, TOTAL , Lyon, France, Moussa Diaby, PSA, Velizy, France

Inorganic fullerene-like (IF) nanoparticles composed of metal disulphides (MoS_2/WS_2) are known to present very promising tribological properties. Dispersed in base oil, they reduce considerably the friction coefficient up to a level that competes with conventional lubricant additives. However, their lubricative properties can be strongly changed when they are dispersed in fully formulated lubricants. The reason for this is the compatibility of the nanoparticles with some of the additives present in the lubricant. While the nanoparticle performances are enhanced in presence of ZDDP, they become inactive in presence of the dispersants commonly used in engine oils. In this work, we present a possible explanation to the origin of these behaviors.

9:00 am - 9:30 am
The Performance of Translucent Silicon-Oxide Nanoparticle Lubricant Additives
Zoe Tucker, Robert Jackson, Mohammed Hossain, German Mills, Auburn University, Auburn University,

AL

The objective of this work is to observe the wear and friction performance of the translucent silicon-oxide (silica) nano-particle infused lubricants. The lubricants tested included these silica nanoparticle-additives at different weight percentages and a control of the isolated base fluid. The lubricated ball-on-disk testing was performed in a UMT machine over the two-hour testing period with friction being recorded and wear being observed before and after testing. The additive-infused lubricants were compared with the base oil control, and no significant differences in performance were observed.

9:30 am - 10:00 am
Surface-Modified Silver Nanoparticles as Lubricant Additives
Chanaka Kumara, Huimin Luo, Jun Qu, Oak Ridge National laboratory, Oak Ridge, TN

Several groups of organic modified silver nanoparticles (NPs) were synthesized with different thiolated ligands, ranging 1-6 nm in size, and characterized using electron microscopy and optical spectroscopy. The organic surface layer protects the metallic core, prevents the nanoparticle aggregation, and enhances the solubility in lubricating oil. Stable suspension of NPs was achieved in a PAO 4 cSt base oil, depending on the particle size and the molecular structure of the organic layer. Tribological tests were performed with ball-on-flat reciprocating sliding and cylinder-on-flat unidirectional sliding configurations. The addition of NPs produced significant friction and wear reductions in boundary lubrication. This is attributed to a deposition layer of silver NPs on the contact area, as confirmed by surface morphology and composition characterization. An interesting relation between the particle size and surface roughness was observed, which provides insight for future development.

10:00 am - 10:30 am - Break

1H Dunwoody

Tribotesting I

Session Chair: G. Krauss, Engineering, Harvey Mudd College, Claremont, CA
Session Vice Chair:

8:00 am - 8:30 am
Material Hardness Evaluations at Elevated Temperatures
Michael Moneer, Peter Lee, Southwest Research Institute, San Antonio, TX, Steven Shaffer, Bruker Nano Surfaces Division, San Jose, CA

A material’s hardness is an indication of its strength and resistance to plastic deformation. The standard Rockwell indentation tester is an industry recognized tool for evaluating material hardness at room temperatures. However, materials are often subjected to elevated temperatures thus changing their physical properties in terms of dislocation mobility, grain structure, precipitate aging, or other microstructural changes which affect hardness properties. For this reason, a method is being developed to measure hardness at temperatures far above ambient.
This presentation will provide an overview of the developing method of determining material hardness at elevated temperatures using a standard tribometer.

8:30 am - 9:00 am
The Use of Novel Specimen Designs in Reciprocating Line Contact Tests
George Plint, Phoenix Tribology Ltd, Kingsclere, United Kingdom

The limitations of the sliding hertzian point contact tests as models of real-world contacts are well established, as are the reasons for their lack of sensitivity to parameters such as additive concentration. However, despite obvious limitations, tests involving a ball sliding on a flat, have the merit of being easy to set up and that they generate wear scars that are nominally easy to measure.
The tribological advantages of a reciprocating line contact over a reciprocating hertzian point contact test are obvious, however, with the resulting wear distributed over a larger area, simple optical techniques for measuring wear scars are no longer feasible. If the experiment ends up being more complicated, it must deliver more information. The current work focuses on experiments with line contacts with plate specimens with curved edges, both parallel and non-parallel, and explores simple and cheap techniques for increasing the information content of each test.

9:00 am - 9:30 am
Advanced Characterization Method to Investigate Friction, Wear and Surface Morphology Change With Time
Tushar Khosla, Rtec-Instruments, San Jose, CA

Reliable measurement of wear and friction on surfaces with micron and nano scale roughness is challenging due to the inherent complexities in sample topography, preparation and handling. We present an advanced characterization technique that combines traditional tribological tests with high-resolution inline imaging techniques (confocal profilometer). An exploratory study showing wear characterization and friction measurements on a chrome alloy against a tungsten carbide ball (WC ball) using Rtec instruments' tribometer MFT-5000 is discussed. The presented method can be used to investigate the sample wear with surface morphology change within one setup, eliminating the need to wait for visible wear and significantly reducing variations during sample handling. These advanced characterization capabilities have the potential to significantly enhance studies of wear initiation and mechanism in a wide range of systems.

9:30 am - 10:00 am
Effect of Running-in Conditions on Repeatability of Friction and Wear Testing Results
Howard Benade, Philip de Vaal, University of Pretoria, Pretoria, Gauteng, South Africa

Friction and wear properties of liquid lubricants can be screened by performing laboratory-based standard test methods (ASTM D 5707 and ASTM D 6425). These tests are conducted at constant loads and require repeatable results with regard to friction coefficient, wear volume and surface appearance. A running-in process is carried out at the start of a test to prepare the surfaces for high loads. The running-in process consists of a constant low load for a specified period followed by a step increase to the operating load. The repeatability of the results improved when the step increase was replaced with a gradual increase. A reduction in the deviation of the friction coefficient was also observed at the end of the running-in period. This indicates that the gradual load increase improves the consistency of the real contact area, since the friction coefficient is a function of the friction force, which in turn is a function of the real contact area.

10:00 am - 10:30 am - Break

1I Courtland

Wind Turbine Tribology I

Session Chair: B. Gould, Mechanical Engineering, University of Delaware, Wilmington, DE
Session Vice Chair: A. Greco, Argonne National Laboratory, Argonne, ILA. Richardson, University of Southampton, Southampton, United Kingdom

8:00 am - 8:30 am

Generation of Electric Current in Tribocontact and Electrically Caused Microstructure Alterations

Mihails Scepanskis, University of Latvia, Riga, Latvia, Benjamin Gould, University of Delaware, Wilmington, DE, Aaron Greco, Argonne National Laboratory, Lemont, IL, Viktorija Smelova, University of Southampton, Southampton, United Kingdom, Ling Wang, Southampton University, Southampton, United Kingdom, Imants Kaldre, Andris Jakovics, University of Latvia, Riga, Latvia

White etching cracks (WEC) are subsurface initiated cracks associated with altered microstructure, which appears white in a nital etched sample. It is likely that energy is accumulated during the failure-free period as local microstructure alterations in multiple points, which fails by cracking upon further loading. Electrical current was recently mentioned as possible energy source with high localization potential at micro-inhomogeneities of steel like carbides. The present investigation reports the empirical observations of voltage generation in a lubricated tribocontact with different oils altering load, sliding and temperature. Tested oils of different additive packages found completely different electrical behavior. The oil, which is known to produce WECs in laboratory tests, demonstrated significant voltage generation. The separate experiment demonstrated altered microstructure in the sample, which was loaded by multiple electrical impulses. The altered regions appeared dark.

8:30 am - 9:00 am

Formation of White Etching Cracks (WECs) in Rolling Bearing Steel and Their Relationship to Premature Bearing Failures

Francesco Manieri, Pawel Rycerz, Tribology Group, Imperial College London, London, United Kingdom, Kenred Stadler, SKF, Schweinfurt, Germany, Amir Kadiric, Tribology Group, Imperial College London, London, United Kingdom

Over the last decade there has been a considerable debate about the causes of premature failures that have been observed in rolling bearings used in wind turbine applications. Such failures are generally associated with the appearance of white etching cracks (WECs) in failed bearings. A number of theories have been proposed to explain the formation and growth of WECs but there is currently no consensus amongst researchers on the most significant influencing factors. This study uses a triple-contact rolling fatigue rig to systematically investigate the influence of contact conditions, including stresses, slide-roll ratio, contact geometry and film thickness, as well as lubricant composition, on the formation of WECs in AISI 52100 bearing steel specimens. Based on these investigations, and the associated evolution of steel microstructure, this paper attempts to explain the root causes for the formation of WECs, and discusses their relationship with observed premature bearing failures.

9:00 am - 9:30 am

A Study on the Evolution of Microstructure Alterations in White Etching Cracks

Viktorija Smelova, University of Southampton, Southampton, United Kingdom, Alexander Schwedt, RWTH Aachen University, Aachen, Germany, Ling Wang, University of Southampton, Southampton, United Kingdom, Walter Holweger, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany, Joachim Mayer, RWTH Aachen University, Aachen, Germany

Formation of the subsurface White Etching Crack (WEC) has been identified as a cause of detrimental failures in a wide range of rolling contact applications. One of the characteristics of WEC is that the cracks are bordered by transformed microstructure, known as White Etching Area (WEA). Recent studies have shown that WEA has a complex microstructure containing varied size grains, hardness heterogeneity and chemical elements redistribution. Despite the significance of the problem and the amount of efforts over decades, the mechanisms of the microstructure transformation leading to the formation of WEA and WEC is still unclear. This study, presents the results from detailed microstructural analyses on WECs, formed in a series of rolling bearing test conditions, using a combination of SEM, EBSD, EDX, and TEM techniques revealing the evolution of WEC formation.

9:30 am - 10:00 am

Influence of Calcium Sulfonate on the Diffusion of Hydrogen and Formation of White Etching Cracks (WECs) in Rolling Contact Fatigue Tested 100Cr6 Bearing Steels
Alex Richardson, Ling Wang, Martin Evans, Robert Wood, University of Southampton, Southampton, United Kingdom, Marc Ingram, Afton Chemical, Bracknell, United Kingdom, Zachary Rowland, University of Southampton, Southampton, United Kingdom

White structure flaking (WSF) is a premature failure mode experienced by wind turbine gearbox bearing steels due to the formation of white etching cracks (WECs). Initiation and propagation mechanisms for WSF/WECs are highly debated. Hydrogen diffusion into the bearing during operation is thought to be one driver of WSF. A number of additives found in lubricants have been shown to influence the occurrence of WSF, these including formulations of Calcium sulfonate (CaS) detergent and zinc dithiophosphate (ZDDP) antiwear additives. The effect of CaS on the diffusion of hydrogen into rolling contact fatigue tested 100Cr6 bearing steel and the formation of WECs has been investigated. Thermal desorption analysis (TDA) has been used to measure diffusible hydrogen concentrations, metallographic analysis to quantify WEC damages and energy-dispersive X-ray spectroscopy (EDX) and Auger electron spectroscopy (AES) to analyse the structural and chemical composition of the tribofilm during operation.

10:00 am - 10:30 am - Break

2A Hanover AB

Nanotribology I

Session Chair: U. Ramasamy, University of California Merced, Merced, CA
Session Vice Chair: B. Noble, Mechanical Engineering, University of Utah, Salt Lake City, UT

1:30 pm - 2:30 pm - Invited Lecture
Interlayer Elasticity and Dissipation in 1D and 2D Van der Waals Materials
Elisa Riedo, Yang Gao, CUNY Advanced Science Research Center and City College New York, New York City, NY, Angelo Bongiorno, CUNY Graduate Center , New York City, NY

One-dimensional (1D) and two-dimensional (2D) Van der Waals materials, such as Carbon nanotubes and graphene, are a-few-atomic-layer thick tubes or films characterized by strong in-plane bonds and weak interactions between the layers. The study of the elastic and frictional properties of nanotubes and 2D films is extremely important for their applications and presents beautiful and sometimes unexpected new science. Here, we will present a new method to perform sub-Å-resolution indentation measurements of the perpendicular-to-the-plane elasticity in 2D materials and nanotubes [1], and its implications for graphene films. Furthermore, we will discuss our recent work on the interplay between mechanical deformations, chirality, number of layers, structure, defects and friction in nanotubes [2], and in MoS_2 films.

2:30 pm - 3:00 pm
Rheology in Nanometer-confined Liquid and Boundary Shearing
Hongyu Gao, Martin Müser, Saarland University, Saarbrucken, Germany

When liquids are confined to nanometer-scale gaps, their intrinsic molecular density correlations lead a layering structure. This phenomenon is observed when an atomic force microscopy (AFM) tip approaches the substrate surface in a liquid system. The dynamic response of the tip is largely dependent upon confinement, and thermally activated jumps occur as the tip-sample distance decreased. In this research, we model the confinement of hexadecane on graphene by an AFM tip using molecular dynamics (MD) simulation, and the tip shearing in boundary lubrication is discussed associated with liquid layering. We

observe the dissipation and shear stiffness exhibit step-wise increase from layer to layer, upon which the load-bearing capacity is quantified.

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

4:00 pm - 4:30 pm
Simulation, Rheology, and Efficiency of Polymer-Enhanced Hydraulic Fluids
Uma Shantini Ramasamy, Ashlie Martini, University of California Merced, Merced, CA, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI

Viscosity modifiers (VM) are used to optimize the viscosity of hydraulic fluids, but the effect of VMs on the overall efficiency of hydraulic components is still not completely understood. In this study, we attempt to bridge the gap between the fundamental behavior of polymer-enhanced fluids and the performance of complex fluid power systems using molecular dynamics (MD) simulations, a bench top rheometer, and a hydraulic dynamometer. MD simulations are used to understand the relationship between molecular structure and viscosity of hydraulic fluid blends. MD-predicted viscosity is then validated using a benchtop rheometer. Lastly, the efficiency of polymer-enhanced fluids is evaluated using a hydraulic dynamometer. Ultimately, this approach will provide a fundamental understanding of the effect of VMs on hydraulic fluid efficiency and enable the design of efficient hydraulic fluid systems.

4:30 pm - 5:00 pm
Friction Behavior of Cyclohexane Film Under Nanoconfinement
Yongsheng Leng, The George Washington University, Washington, DC

The structural and shear properties of cyclohexane molecules confined between two mica surfaces are studied by molecular dynamics simulations. Tthe force-distance profiles obtained from simulations are qualitatively similar to the SFA force measurement. Our results demonstrate that nanoconfined cyclohexane fluids undergo an abrupt, liquid-to-solid phase transition. The characteristic stick-slip pattern is clearly observed when the solidified film is under shear. We find that during the stick-slip motion, boundary slips at the mica-cyclohexane interfaces and interlayer slips within the cyclohexane film are always observed, in contrast with the common idea that stick-slip friction is associated with shear melting and recrystallization of the confined film. The ordered solidified structure of cyclohexane film is well maintained during repeated stick-slip cycles. Individual cyclohexane molecules under shear are also investigated during the stick-slips.

5:00 pm - 5:30 pm
Niti Bearing Alloys: Mechanisms Governing Lubrication, Resilience and Hardness
Christopher DellaCorte, NASA, Cleveland, OH

Nickel-rich Ni-Ti alloys are emerging candidate materials for bearing applications that encounter shock loads and corrosive environments. NiTi alloys exhibit high hardness yet have a relatively low elastic modulus resulting in extraordinarily high resilience and resistance to denting. They are also intrinsically impervious to aqueous corrosion. The unique combination of these positive attributes makes NiTi alloys ideally suited for highly loaded ball bearings and gears used in corrosive applications. Over the last decade, focused R&D has revealed the underlying fundamental reasons for NiTi's unusual characteristics. Atomic level bonding imparts chemical inactivity leading to good tribological response and the in-situ formation of nano-scale phase precipitates leads to remarkable elastic and hardness properties. In this paper, the state-of-art of nickel-rich NiTi alloys will be introduced and the materials science driving their intriguing behavior will be addressed.

Commercial Marketing Forum II

1:30 pm - 2:00 pm - Munzing

2:00 pm - 2:30 pm - Sasol North America, Inc.

2:30 pm - 3:00 pm - ExxonMobil Chemical Company

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

4:00 pm - 4:30 pm - Novitas Chemical Solutions, LLC

4:30 pm - 5:00 pm - Chemtura Corporation

5:00 pm - 5:30 pm - Emery Oleochemicals

5:30 pm - 6:00 pm - Evonik Oil Additives, Inc.

2C Hanover D

Metalworking II

Session Chair:
Session Vice Chair:

1:30 pm - 2:00 pm
Effects of Filtration on Defoamer Performance in Aqueous Metal Removal Fluids
Ernest Galgoci, Joseph Panzariello, James Sullivan, Justin Mykietyn, Munzing, 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.

2:00 pm - 2:30 pm
Boundary Lubricant Additive Response Comparisons on Various Metals Using Twist Compression Tests (TCT)
Ted McClure, Sea-Land Chemical - 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 evaluate the boundary and E.P. performance of lubricants designed for severe operations. This current work utilizes this test to compare additive responses on various difficult workpiece materials, including titanium and austenitic stainless steels. Boundary and E.P. additives evaluated include chlorine, sulfur and phosphorus bearing E.P. additives and polar boundary additives. The aim is to provide useful data for formulation of lubricants for severe applications.

2:30 pm - 3:00 pm

Critical Examination of Foam Test Methods for Aqueous Metal Removal Fluids

Justin Mykietyn, James Sullivan, Ernest Galgoci, Joseph Panzariello, Munzing, Bloomfield, NJ

There are many test methods employed to evaluate the foam tendency of metal removal fluids. These range from standardized tests to customized, in-house versions that each company has internally-developed. Ideally, the test method should accurately reflect the end-use conditions; however, these conditions might not be readily scalable to the laboratory, so accommodations for scale are usually necessary. Since the ideal test may not be amenable to the timely completion of numerous screening experiments, multiple tests may have to be utilized for a comprehensive defoamer evaluation. This paper will describe various test methods, which include shaking, sparging, blender mixing, and recirculation, plus a critical examination of the interpretation of results and how improvements to interpretation and test method design can be made to better correlate with the field.

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

4:00 pm - 4:30 pm

The Influence of Neutralizers/pH Adjusters in Water-Dilutable Metalworking Fluids on Lubrication of 6061 Aluminum

Patrick Brutto, Bonnie Pyzowski, Soraya Kraszczyk, ANGUS Chemical Co., Buffalo Grove, IL

Several types of acid-functional lubricant additives are used in metalworking operations, to maximize tool life, produce parts with the required tolerance and finish, and to minimize energy consumption. Examples include fatty acids and phosphate esters, which require neutralization for water solubility or emulsification. Although the effects of these additives on lubrication are well recognized, the influence of neutralization chemistries including amino alcohols has not been reported. This presentation will discuss the effects of neutralizer choice, as quantified by tapping torque on 6061 aluminum alloy. We will also quantify the effect on lubrication of naphthenic oil emulsions formed using tall oil fatty acid neutralized with various materials, and their relationship with emulsion particle size.

4:30 pm - 5:00 pm

Biofouling Control in Metalworking Fluids

Brian Corbin, Dow Microbial Control, Collegeville, PA

Metalworking fluids are susceptible to contamination by various types of bacteria and fungi. Microbial growth in these fluids can cause a variety of problems ranging from odors, pH drop, emulsion splitting, fluid discoloration, enhanced corrosion, filter plugging, sump and tool life reduction, and potential health effects. Problem-causing microorganisms may be free-floating in the bulk fluid or attached to surfaces growing as complex differentiated communities known as biofilms. In this report we discuss the selection of biocides for concentrate and tankside treatment to control biofouling. Factors that must be considered include biocide stability, chemical compatibility, efficacy and environmental fate. In addition, we will discuss formaldehyde-free options and key problem causing microorganisms. The results are presented that demonstrate the efficacy of varying biocides in synthetic, semi-synthetic and soluble oil fluids.

5:00 pm - 5:30 pm

Microbial Misconceptions II
Nicole Webb, ANGUS Chemical Company, Buffalo Grove, IL

Testing for fluid longevity in a metalworking fluid (MWF) is a constant challenge for the industry. Currently, the determination of fluid longevity is done using variations of standard test methodologies. These numerous challenge test variables, including temperature, mechanisms for mixing, tramp oil usage, amount, rate and type of microbial contamination, etc., create a unique opportunity to customize multiple aspects of the testing environment. However, these variations can greatly impact the test results and the next challenge becomes understanding the effects of each test parameter and ensuring these conditions are repeatable and representative of the MWF environment in which the fluid will be used. This presentation addresses key aspects of microbial challenge testing and proposes a method for ensuring accurate and reproducible microbial data.

5:30 pm - 6:00 pm
Chemo-Mechanical Magnetorheological Polishing of Bearing Steel Substrate
Wenpeng Jia, Yu Tian, State Key Laboratory Of Tribology, Beijing, Beijing, China

In some cases, an ultra-smooth surface of AISI 52100 steel is needed.
Chemical mechanical polishing (CMP) is one of the most used polishing methods to getting ultra-smooth surface of AISI 52100 steel. Related researchers have successfully reduced the surface roughness Ra of AISI steel from 188nm to 1.8nm by using dedicated CMP fluid (CMPF).
Chemo-mechanical magnetorheological polishing (CMMRP) combines advantages of CMP and magnetorheological polishing (MRP). However, polishing bearing steels by this multiple polishing process hasn't been researched yet. In this work, CMMRP was employed to polish AISI 52100 steel. In details, the MRP fluid (MRPF) is added with components of CMPF. On one hand, MRPF will change to a viscoelastic body under a magnetic field, above which are abrasives and CMPF. On the other hand, the rough micrographs of the surface will be removed by chemical effects. The influences of different concentrations of CMPF in MRPF polishing performance were studied in this work.

2D — Hanover E

Materials Tribology II

Session Chair: G. Sawyer, University of Florida, Gainesville, FL
Session Vice Chair: B. Krick, Lehigh University , Bethlehem, PA

1:30 pm - 2:00 pm
Faked Adhesion Caused by Material Viscoelasticity in None Fully Detaching Test
Zheyu Liu, Hongyu Lu, Dashuai Tao, Xiangjun Zhang, Yonggang Meng, Yu Tian, The State Key Laboratory of Tribology, Tsinghua University, Beijing, China

Detachment of adhesive pair is an interesting problem in tribology that is strongly related with the mechanical property of the materials. In many occasions, the detachment procedure is divided into a few steps to accomplish, which was called in this research, none fully detachment (NFD). Few researches focused the adhesive behaviors of materials during this process. We discovered that in NFD mode sphere-plate detaching experiment might demonstrate a faked adhesion force, which even went beyond the zero force level which disobeyed our common sense. Analysis showed that the recovery of sphere delayed to the moving of stage due to the viscoelasticity so that the state of double cantilever changed alternatively. The shape and value of this force peak were related to the radius of sphere, the viscoelasticity of material and detaching velocity. This research helps a more profound comprehension of the NFD procedure and the tribological property of materials.

2:00 pm - 2:30 pm

First Contact: Adhesion Hysteresis in Soft Interfaces
Kyle Schulze, Alexander Bennett, Yongliang Ni, Greg Sawyer, University of Florida, Gainesville, FL

Characterization and contact mechanics of soft materials continue to be of extreme importance to the world of medicine and health. Many studies in the recent past have thus been conducted on soft materials such as tissues and their proxies at the micro, meso, and macro scale to better understand the materials of life. Here we examine a soft tunable material that can be used as a proxy for soft biotribological interfaces that have adhesion considerations with PDMS. Specifically, we examine that by systematically changing the contact indentation experiment conditions the mechanical property predictions from traditional contact theories such as JKR can be readily manipulated. By in situ observation of real area of contact of PDMS indentation we examine rate, geometry, indentation, and modulus dependence on the contact hysteresis of the system.

2:30 pm - 3:00 pm
Elastic-Plastic Sinusoidal Contact Under Combined Normal and Tangential Loading
Xianzhang Wang, Yang Xu, Robert Jackson, Auburn University, Auburn, AL

The behavior of an elastic plastic contact between a deformable three-dimensional sinusoidal asperity and a rigid flat under combined normal and tangential loading is investigated using the finite element method. The sliding inception is determined by the maximum shear stress criterion. The resulting junction growth and static friction coefficient are investigated. It is found that for a general case, at the low dimensionless contact pressures ($0.0001 \leq p_{ave}/p^*_{ep} < 0.05$) the static friction coefficient decreases sharply with increasing contact pressure. However, at the medium contact pressure ($0.05 \leq p_{ave}/p^*_{ep} \leq 0.3$), the static friction coefficient nearly approaches a constant value (around 0.23). Nevertheless, as the contact pressure further increases, the static friction coefficient keeps on reducing at a linear rate. The effects of material properties, geometric properties and critical shear strength on the static friction coefficient are also studied.

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

4:00 pm - 4:30 pm
Illuminating Pressing Problems with Rough Contacts
Alex Bennett, University of Florida, Gainesville, FL, Kathryn Harris, Kungliga Tekniska Högskolan, Stockholm, Sweden, Kyle Schulze, Juan Manuel Uruena, Angela Pitenis, Sean Niemi, Samantha Marshall, Samuel Hart, Thomas Angelini, Greg Sawyer, University of Florida, Gainesville, FL

A method to measure contact area between complex, random, multiscale surfaces is presented. A 100 × 100 × 10 mm scale (x1000) replica of a computer generated surface with self-affine fractal roughness was 3D printed using an opaque polymethylmethacrylate (PMMA). The surface was pressed into contact with flat, transparent polydimethylsiloxane (PDMS) sheets using dead weight load. Indentation experiments using hemispheres of a similar acrylic were conducted against the samples in order to estimate modulus and work of adhesion.The modulus of the PDMS samples spanned two orders of magnitude. A total internal reflection imaging technique was used to measure the evolving contact area between the printed surface and the PDMS samples with increasing pressure. Within experimental uncertainty, the experimental and computational predictions of contact area as a function of reduced pressure are in agreement.

4:30 pm - 5:00 pm
In situ and In silico Study of Adhesion, Deformation, and Area of Contact Between Nanoscale Asperities
Sai Bharadwaj Vishnubhotla, University of pittsburgh, Pittsburgh, PA, Rimei Chen, Unversity of California Merced, Merced, CA, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Shelly Hu, Ashlie Martini,

Unversity of California Merced, Merced, CA, Tevis Jacobs, University of Pittsburgh , Pittsburgh, PA

Continuum contact mechanics models are used routinely to describe the deformation and the contact area of the nanoscale bodies, but the underlying assumptions of these models may not hold true at these scales. Thus, there is a need for new techniques to test the validity of contact mechanics models at the nanoscale. Here, *in situ* transmission electron microscopy (TEM) and molecular dynamics simulation were used to study the contact between a flat diamond indenter and a sharp silicon tip. The TEM enabled real-time imaging of the contact tests, while the simulations provided atomic-scale information. The experiments and simulations were matched in terms of geometries, crystallographic orientation, load, adhesion and surface amorphization. The combined experiments and simulations enabled the investigation of the adhesion, deformation, and area of the nanocontact. The results demonstrated the limits of the continuum contact mechanics for describing nanoscale contacts.

5:00 pm - 6:00 pm - The Contact Mechanics Challenge

2E Hanover F

Environmentally Friendly Fluids II

Session Chair: S. Erhan, Industrial Oils, ADM, Decatur, IL
Session Vice Chair: B. Sharma, University of Illinois, Champaign, IL

1:30 pm - 2:00 pm
Evaluation of Environmentally Acceptable Lubricants for Arctic Thruster Systems
Ichiro Minami, Bharath Sundararajan, Lulea University of Technology, Lulea, Sweden, Arto Lehtovaara , Matti Savolainen, Tampere University of Technology, Tampere, Finland

According to Vessel General Permission (VGP) by the United States Environmental Protection Agency, lubrication systems in ships have to operate with environmentally acceptable lubricants (EAL). Several types of EAL based on synthetic esters are commercially available. This work focuses on the tribological properties of EAL in thruster systems for ships, especially to be operated under arctic climate, as a part of research consortium on Arctic Thruster Ecosystem (ArTEco). Laboratory tribo-tests (ball-on-flat and twin-disc types) were employed to compare conventional (petroleum-derived) lubricants and EAL. Changings in tribological properties as a function of ageing stage were also emphasized, since the durability of EAL has not been well investigated. The results will be discussed on the basis of lubricant chemistry. The importance of lubricant maintenance which conforms to the concept of green chemistry will be also highlighted.

2:00 pm - 2:30 pm
Evaluation of IF-WS_2 in Ester Lubricants
Bryan Bergeron, Hicham Saade, A.W. Chesterton, Groveland, MA

There is a commercial need for fluid lubricant technologies with improved tribological performance using environmentally safe components. Specifically, superior levels of efficiency must be attained by lowering friction coefficients and increasing load carrying capability. Furthermore, high levels of biodegradability and low toxicity must exist for compliance with various regulations. Here, we present compelling laboratory results derived from evaluation of several esters including high oleic oil and polyolester oil comprising various treatment levels of fullerene-like tungsten disulfide nanoparticles (IF-WS_2). Measurements from four ball wear, four ball weld, Pin & Vee Block, Cannon Fenske viscometer, SEM/EDAX, and XPS instrumentation will be presented. This study expands the potential utility of IF-WS_2 beyond use in PAO base stock typically focused upon gear and bearings, and instead demonstrates applicability of IF-WS_2 in esters for chain and wire rope applications.

2:30 pm - 3:00 pm
Selecting the Right GpV Base Stock to Achieve Friction Reduction
Matthias Hof, Emery Oleochemicals GmbH, Monheim, NRW, Germany

Lubricants are used in a wide variety of applications. While each application has its own set of requirements which need to be met, friction reduction is a common need for all lubricating oils. This is important not only for equipment protection but also for the overall behavior and workability of the fluid. Friction reduction is now gaining higher priority due to the growing interest in more fuel-efficient and energy-efficient lubricants. At STLE 2016, Emery Oleochemicals presented a comprehensive study of various frictional properties of ester base stocks. Through further testing of this basic evaluation of synthetic base stocks, additional properties have been identified and compared with both conventional and unconventional petrochemical base stocks. Also, the impact of additives on frictional behavior has been tested to better understand the value of the intrinsic lubrication that ester base stocks can provide.

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

4:00 pm - 4:30 pm
Synthesis and Characterization of Biolubricant Based on Poliesterification of the Ricinoleic Acid/oxalic Acid/ethylene Glycol
Paulo Suarez, University of Brasilia, Brasilia, DF, Brazil, Eduardo Peres, IFB, Brasilia, DF, Brazil

In this work we developed a new biolubricant based on the polyesterification of ricinoleic acid with oxalic acid and ethylene glycol leading to different ester compounds. The formation of ester and consumption of acid and hydroxyl groups were confirmed by Infrared (IR-FT) and Nuclear Resonance Magnetic (^{1}H-NRM) spectroscopy. Properties like thermal stability, viscosity, viscosity index, pour point, oxidative stability were properties measured to assess your use as lubricant. The biolubricant synthesized in this work has shown a potential to substitute petroleum-based lubricants.

4:30 pm - 5:30 pm - Panel Discussion

5:30 pm - 6:30 pm - EFF Business Meeting

2F Hanover G

Fluid Film Bearings II

Session Chair: J. Bouyer, Mechanical Engineering and Complex Systems, Pprime Institute, Futuroscope Chasseneuil Cedex, France
Session Vice Chair: Y. Henry, Tribolub, Pprime, Angoulême, France

1:30 pm - 2:00 pm
Impact of Measurement Uncertainties on the Validation of Mixed Lubrication Simulation
Sebastian Fricke, Sergey Solovyev, Ulrich Stolz, Johannes Bette, Jürgen Vdovak, Robert Bosch GmbH, Renningen, Germany, Matthias Wangenheim, Jörg Wallaschek, Institute of Dynamics and Vibration Research, University of Hanover, Hanover, Germany

The validation of the simulation of a journal bearing in mixed lubrication conditions is presented with focus on the friction force. The major difficulty are the measurement uncertainties of the boundary conditions during the experiment such as surface roughness or the temperature in the contact. This complicates the validation since the boundary conditions of the experiment and the simulation have to be equal.

As solution, the measurement uncertainties are considered in the validation based on the theory of the uncertainty quantification. The determination of a friction scattering based on simulation results is proposed, instead of computing only one friction value. The probability distribution of the computed interval is determined using a Monte-Carlo-Simulation. The measured scattering of the boundary conditions of the experiment are used as input. The presented approach delivers suitable results and allows evaluating the accuracy of the simulation models.

2:00 pm - 2:30 pm

Comparison of Cavitation Models Within the Solution Framework of Both the Reynolds and Navier-stokes Equations on The Static Performance and Dynamic Properties of Journal Bearings
Troy Snyder, Minel Braun, The University of Akron, Akron, OH

In this paper, several Reynolds-based cavitation models are compared with one another and are also compared with Navier-Stokes-based (CFD) cavitation models. Comparison is made between the predicted loads, static equilibrium positions, pressure maps, and linearized dynamic coefficients for varying eccentricities and speeds of a hydrodynamic journal bearing with length-over-diameter ratio of 1. The hydrodynamic bearing is assumed to be isothermal and laminar with a rigid bushing. The Reynolds-based cavitation models investigated include: half-Sommerfeld, mass-conserving JFO, and coupled Reynolds-Rayleigh-Plesset (RE-RP) models. The Navier-Stokes-based cavitation models investigated include: Kunz, Schnerr-Sauer, and Merkle models. Parametric variations of the cavitation model surface dilatational viscosity and evaporation/condensation rate parameters are performed and recommendations made as the parameter values for hydrodynamic journal bearing analysis.

2:30 pm - 3:00 pm
Comparison of Reynolds Equation and CFD Simulations for Evaluation of a Grooved Journal Bearing with Injection.

Kristopher Pierson, Minel Braun, Troy Snyder, The University of Akron, Akron, OH
A physics based, transient pseudo-cavitation model using variable properties Reynolds (RE), Rayleigh-Plesset-Scriven (RPS) and Energy equations has recently been proposed by the authors. The RPS equation calculates a time dependent change in bubble radius (variable void fraction) which is then used to determine the homogenous, two-phase fluid's density and viscosity for use in the RE equation; concomitantly the energy equation determines the homogeneous fluid's temperature and provides corresponding adjustment in the already mentioned transport properties. Thus both pressure and temperature effects are incorporated in the bubble (void) growth process. The effect of oil injection on cavitation development and the performance of a grooved journal bearing is then evaluated on a comparative basis between the proposed Reynolds based model and the full Navier-Stokes CFD solution. The effects of groove position and geometry on bearing's operational characteristics will also be presented.

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

4:00 pm - 4:30 pm
Design of Cooled Tilting-pad Bearings Obtained with Additive Manufacturing Technology
Steven Chatterton, Paolo Pennacchi, Phuoc Dang, Andrea Vania, Politecnico di Milano, Milan, Italy

A lot of rotating machines are nowadays equipped with both thrust and journal tilting-pad bearings. The thermal aspect is critical for applications at high speed and load where high temperatures originates due to shear stresses in the oil-film or by the surroundings. In these cases, the minimum oil-film thickness and the pad thermal crowning must be taken into account. Leading edge groove bearings solve partially the problem by controlling the oil inlet temperature in the shoe. Another approach is based on cooling the pad by means of a suitable internal circuit for the cooling fluid. The manufacturing issues due to the pad

drilling can be solved with the additive manufacturing technology. In the paper the results of the numerical simulations for a cooled pad bearing obtained with this technology will be described.

4:30 pm - 5:00 pm
Efficient Numerical Analysis of Textured Hydrodynamic Bearings
Daniel Gropper, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom, Klaus-Dieter Meck, Vladimir Gviniashvili, John Crane UK Ltd, Manchester, United Kingdom

A successful application of surface texturing in hydrodynamic bearings relies heavily on efficient numerical models. In this work, several ways to enhance the computational performance of models based on the Reynolds equation are presented and compared to conventional techniques. The present approach is based on a Finite Volume discretization of the Reynolds equation and takes into account mass-conserving cavitation as well as thermal effects. It is shown that applying special discretization schemes to handle discontinuities, using non-uniform and adaptive meshes, taking advantage of multicore processing and strategically utilising different algorithms to find the bearing equilibrium are ways to study textured bearings most efficiently. Furthermore, using the results of an equivalent untextured bearing as first approximation for the textured bearing is shown to significantly reduce computation times. Results are validated through CFD data and correlated with laboratory test results.

5:00 pm - 5:30 pm
Computational Aspects of Iterative Solution Method for Reynolds Equation
Nenzi Wang, Hsin-Yi Chen, Chang Gung University, Tao-Yuan, Taiwan

This study presents a general view of computing-performance related issues when Reynolds equation is being solved by parallel iterative methods. The major factors considered in this study are (1) the clock-speed, number of cores, and cache size of the multicore CPU (central processing unit); (2) the clock-speed, number of cores, and cache size of the many-core GPU (graphics processing unit); (3) the parallel iterative methods selected; (4) stopping criterion of the iterative methods; and (5) the communication overhead in parallel computing. The OpenMP and OpenACC directives in Fortran programming are applied in the parallel iterative method for solving Reynolds equation. The comparison of the computational performance of various approaches is presented. The limitations of the approaches tested are also discussed.

2G Regency V

NanoAdditives Joint Session II – Nanotribology and Lubrication Fundamentals

Session Chair: M. Patel, Vanderbilt Chemicals, LLC, Norwalk, CT
Session Vice Chair: H. Khare, University of Pennsylvania, Philadelphia, PA

1:30 pm - 2:00 pm
Quartz Crystal Microbalance and Atomic Force Microscope Study of Atomic Scale Polishing and Roughening of Surfaces Exposed to Nanoparticle Suspensions of Diamond, Al_2O_3 and SiO_2.
Biplav Acharya, Melanie Chestnut, Antonin Marek, NCSU, Raleigh, NC, Olga Shendarova, Adámas Nanotechnologies, Inc., Raleigh, NC, Alex Smirnov, Jacqueline Krim, NCSU, Raleigh, NC

Nanotribological properties of nanparticle lubricant suspensions of diamond, Al_2O_3 and SiO_2 dispersed in water and/or oil (PAO6) were studied in real time by means of a Quartz Crystal Microbalance (QCM) technique, with a focus on how the suspensions impacted the nanoscale surface roughness of the QCM electrode. The frequency and dissipative properties of QCM's with both Au and Ni surface electrodes were first studied for immersed samples upon addition of the nanoparticles. Nanodiamonds resulted in increased mechanical resistance while addition of Al_2O_3 and SiO_2 nanoparticles resulted in decreased mechanical resistance, indicating reduced resistance of the fluid to the motion of the QCM. Atomic Force

Microscope measurements were then performed on the QCM electrodes to explore potential polishing and/or roughening effects. The rms roughness increased with exposure time to the suspensions, with significant variation in the etching rate from one system to another.
*Work supported by NSF

2:00 pm - 2:30 pm
Water Soluble Carbon Nanodot as Lubricant Additive for Ceramic-on-Ceramic and Ceramic-on-Steel Contacts
Huaping Xiao, Shuhai Liu, Quan Xu, China University of Petroleum-Beijing, Beijing, China

Water soluble carbon nanodot was prepared and was used as lubricant additive in DI water. The impacts of carbon nanodots on tribological properties of water were evaluated using a ball-on-disk tribometer for both SiN-on-steel and SiN-on-SiN contacts. Experimental results show that the coefficient of friction (COF) was effectively reduced in the two types of tribopairs after the addition of carbon nanodot additive. The maximum reduction in COF are 30% and 14% for SiN-steel contact and SiN-SiN contact, respectively. For SiN-steel contact, the width of wear track (200 μm) was half of that in dry environment on steel disk surface. The roughness of the surface decreased as the concentration of carbon nanodot increased. The surface roughness of worn surface reduced from 21μm under dry condition to 7μm with the present of carbon nanodots. This research opens the door of application of carbon nanodot as an promising additive in water-based lubricant.

2:30 pm - 3:00 pm
The Tribological Properties of Silica Nanoparticles as Additives for Aqueous Lubrication
Tianyi Sui, Bin Lin, Tianjin University, Tianjin, China

During the past few decades, silica nanoparticles have been broadly investigated as lubricant additives because of their economic efficiency, eco-friendliness and excellent tribological properties. In this study, we investigated the anti-wear and friction reduction properties of silica nanoparticles as additives for aqueous lubrication. Silica nanoparticles were synthesized using stöber method and characterized by variety of method. Silica nanoparticles with different sizes and concentrations were added into water and their tribological performances were examined. It was found that silica nanoparticles could improve the load carrying capacity of water significantly and reduced both friction and wear. Silica nanoparticles were found forming a protect film on the substrate after examining the wear surface.

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

2H Dunwoody

Tribotesting II

Session Chair: G. Krauss, Engineering, Harvey Mudd College, Claremont, CA
Session Vice Chair:

1:30 pm - 2:00 pm
On the Load Dependence of the Friction Coefficient
Kenneth Budinski, Bud Labs, Rochester, NY

Some experimentalists use multiple normal forces in friction testing and use the slope of a plot of friction force versus normal force as the coefficient of friction. The direct proportionality of friction force to normal force in Amonton's law (μ= F/N) suggests that this is the proper way to measure friction coefficient. It was proposed that this methodology be made an ASTM standard. Standardization requires tests on the repeatability and reproducibility of a test. In performing tests to allow standardization, it was determined

that this methodology may only work in a limited force range. This study as well as historical data on tribosytems where the force variations spanned three or more orders of magnitude showed that there is no longer a direct proportionality of friction force to normal force and the slope concept does not apply.

2:00 pm - 2:30 pm
Fretting Wear of Nuclear Fuel Claddings in High-Temperature High-Pressurized Water
Jun Qu, Sladjan Lazarevic, Oak Ridge National Laboratory, Oak Ridge, TN, George Plint, Phoenix Tribology Ltd, Kingsclere, United Kingdom, Roger Lu, Westinghouse Electric Company, Hopkins, SC, Peter Blau, Blau Tribology Consulting, Enka, NC

Fuel rods in a pressurized water nuclear reactor experience flow induced vibration, which causes fretting wear against the grid support features. If the wear is not well controlled, the cladding wall of the rod could be worn through to leak the fuel. In order to simulate the grid-to-rod fretting (GTRF) wear, an autoclave-enclosed fretting bench tribometer (AFBT) has been designed and fabricated. The AFBT enables one to conduct fretting, impact, and fretting plus impact tests in pressurized (1-24 bars) water with temperatures up to 220 ^{o}C. Samples from actual zirconium alloy cladding, in as-received and pre-oxidized conditions, were rubbed against samples from actual zirconium and stainless steel grids under controlled contact stress and motion frequency and amplitude. The effects of water temperature, pre-oxidation treatment, contact geometry, water chemistry, and synergy between fretting and impact on the wear behavior have been explored.

2:30 pm - 3:00 pm
Testing Study of Fretting for Involute Spline
Yuanqiang Tan, Huaqiao University, Xiamen, China

There are three kinds of facts, including angular misalignment, parallel misalignment and combined misalignment, to affect the fretting behavior of involute spline. In this study, FEM analysis was carried out for the fretting of spline firstly. Then a wear test rig was established to investigate the fretting parameters of the involute spline coupling in the angular misalignment. It’s found that when the normal force was increased, the friction force of spline became larger, the fretting displacement decreased, and the fretting wear was reduced. The materials treatment process, such as Nitriding, Carburizing, as well as lubrication can improve the fretting wear resistance properties of the materials of spline.

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

4:00 pm - 4:30 pm
Experimental Study of the Influence of Contact Conditions and Lubricant Properties on the Onset of Scuffing Using a New Contra-rotation Test Method
Bo Peng, Guoquan Huang, Amir Kadiric, Imperial College London, London, United Kingdom

Scuffing is a type of severe surface damage that occurs due to excessive adhesion between contacting surfaces that are subjected to a significant amount of sliding. Owing to its sudden onset, rapid progression and influence of both fluid and boundary lubricant films, scuffing is difficult to study in a systematic, repeatable manner. This paper presents an experimental study of scuffing using a recently developed test method in which two metal surfaces are rubbed together in contra-rotation while the sliding speed is increased step-wise under constant load. The method enables the effects of fluid film and boundary film to be isolated, while also minimising the changes in the contact area as the test progresses. Results are presented to study the influence of contact conditions and surface finish on scuffing onset, as well as to compare the scuffing resistance of a series of base and fully formulated oils and compare the observations to equivalent Ryder gear scuffing tests.

4:30 pm - 5:00 pm
A Screening Test Method for Evaluation of Energy Efficiency of Industrial Gear Oils
R Mahapatra, M K Dubey, R Meshram, IOCL R&D Centre Sector 13 Faridabad, Faridabad, Haryana, India, A. Bhardwaj, IOCL R&D Centre, Faridabad, Harayana, India, Ajay Harinarain, IOCL R&D Centre Sector 13 Faridabad, Faridabad, Haryana, India, S K Mazumdar, IOCL R&D Centre, Faridabad, India

A laboratory test method using a mini traction machine (MTM) has been developed for assessment of energy efficiency characteristics of gear oils. This is a 3X3X4X4 test matrix carried out at a wide range of load, temperature, speed and sliding to rolling ratio under controlled conditions. This paper gives details of the test method and test results obtained for two commercial gear lubricants. The tests were carried out under a back to back sequence of R-C-R (reference oil-candidate oil-reference oil). With this controlled test condition, the test is not only able to discriminate between the two oils but also gives an excellent repeatability with back to back reference oil test, thus justifying the energy efficiency of candidate oil vis-a-vis reference oil. The test results were further validated by a simulating gear contact in a modified FZG test rig having the provision of torque sensor to precisely differentiate energy efficiency under wide range of load stage, speed and temperature.

5:00 pm - 5:30 pm
Prediction of Friction Coefficients and Mechanical Power Loss of Spur Gears
Jie Cheng, Yuxu Geng, Zhangjiang Wang, Chongqing University , Shapingba District, Chongqing, China, Qian Wang, Northwestern University, Evanston, IL

Twin-roller testing is an effective approach to tackle the gear problem. The work reported in this presentation simulates gear contacts by rollers of different sizes and with different surface roughnesses in a group of twin-roller experiments subjected to controlled SRR and a wide range of operating conditions. An empirical friction coefficient formula is developed through a multi-variable regression analysis of the measured data. Combining the friction formula with a gear meshing analysis leads to a mechanical-loss predication method that computes instantaneous mechanical power loss at any given operating position for a spur gear pair. The results are validated by the well-agreed comparison between the measured and calculated power losses.

5:30 pm - 6:00 pm
Crossing the Boundary of Static Friction - An Experimental Study
Charlotte Reppich, Kartik Pondicherry, Anton Paar GmbH, Graz, Austria

As per Newton’s First Law, an object at rest will remain at rest unless acted upon by an unbalanced external force. Therefore, in order to set a body at rest into motion, the external force applied should be sufficient enough to overcome its static (or limiting) frictional resistance. Accurate characterization of limiting friction is a tough task, as it involves precise measurement of forces and displacements with nanoscale resolution. In this current study, we demonstrate a methodology to determine limiting friction of both dry and lubricated contacts. Rotational and oscillatory tests were carried out on an MCR Tribometer to obtain values of limiting friction of these contacts, which include polymers, food items, and other industrial applications such as metalworking flluids, greases, engine lubricants, etc. The tribological data is substantiated with *in situ* microscopic observations. The study also illustrates the importance of limiting friction in our day-to-day applications.

2I Courtland

Wind Turbine Tribology II

Session Chair: B. Gould, Mechanical Engineering, University of Delaware, Wilmington, DE
Session Vice Chair: A. Greco, Argonne National Laboratory, Argonne, ILA. Richardson, University of Southampton, Southampton, United Kingdom

1:30 pm - 2:00 pm

Using Tomography Techniques to Investigate the Development of White Etching Cracks in Bearing Steel

Benjamin Gould, University of Delaware, Wilmington, DE, Aaron Greco, Argonne National Laboratory, Lemont, IL, Kenred Stadler, SKF GmbH, Schweinfurt, Germany, Erik Vegter, SkF B.V., Nieuwegein, Netherlands

Steels used in roller bearings consists of highly tailored microstructures that are developed to withstand high load and harsh conditions. In large industrial gearboxes or drive train applications, bearings are often subjected to a wide variety of operating conditions which ultimately results in cracking decorated by nano-grained microstructural alterations referred to as White Etching Cracks (WECS). By combining the tomography results of prematurely failed field bearings performed at Argonne National Lab with SKF in-house investigations of tested bearings, a better understanding of the typical metallurgical occurrences in failed bearing steels will be given. Based on the results obtained, an admissible hypothesis for the development of WECs can be derived. The results support the idea that the microstructural alterations form secondary to any cracking, suggesting that the white etching alterations are simply a symptom of a pre-existing failure, not the root cause.

2:00 pm - 2:30 pm

Investigating the Dominant Drivers of White Etching Crack Formation in Accelerated Benchtop Testing

Benjamin Gould, Aaron Greco, Argonne National Laboratory, Lemont, IL

White etching cracks (WECs) have been identified as a dominant mode of premature failure within wind turbine gearbox bearings. Though WECs have been reported in the field for over a decade, the conditions leading to this failure, and the process by which this failure culminates, are both highly debated. In order to fully understand the wide variety of inputs which could lead to WECs within wind turbines, a highly accelerated benchtop test capable of recreating the conditions seen by bearings in this application is necessary. This includes but is not limited to load transients, electrical application, sliding, and various lubricant formulations. The authors will discuss their findings pertaining to the influence that some of these aforementioned drivers have on the formation of WECs within 52100 test samples.

2:30 pm - 3:00 pm

Wear Analysis of Main Bearings

Arnab Ghosh, Sentient Science, Indianapolis, IN

Main bearings in wind turbine are prone to wear and micropitting. These failure modes cause premature failure of these bearings in wind turbine. A systematic approach is required to predict the main bearing wear rates. Major differentiation between the main bearings can be made in terms of suppliers and design differences. The goal of this presentation is to show a systems approach to wear modeling. The approach presented here considers the effect of wind loads on main shaft and bearing dynamics to evaluate contact pressures and sliding velocities. It is shown that the wear rates of main bearings are dependent on multiple macro and micro scale parameters and suggestions are provided to increase wear resistance of main bearings based on extensive computational modeling.

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

4:00 pm - 4:30 pm

New Grease Technology and Synthetic Base Oils for Wind Turbines

James Dimas, Koetsu Wada, Idemitsu, Southfield, MI

The customer-orientated philosophy of IDEMITSU is to develop products based on the customer's requirements in one of the largest research complexes in the world. Higher efficient Wind turbines are pushing their lubricants to temperatures and conditions that have never been seen in the market. By working with Japanese OEM's, IDEMITSU has engineered and developed new grease type additives coupled with highly refined synthetic base oils to create a grease with high resistance to oxidation and prevention of deterioration under these ever more demanding circumstances. IDEMITSU has conquered grease related issues that have plagued wind turbines due to inferior greases. New additive technology and synthetic type base oil will be discussed in this paper, along with new Japanese methods in monitoring grease performance based on test results.

4:30 pm - 5:00 pm

Measurements of Individual Contacts in Wind Turbine Rolling Bearings: Experience from the Field

Rob Dwyer-Joyce, Gary Nicholas, University of Sheffield, Sheffield, United Kingdom

Ultrasonic reflection can be used to determine oil film thickness, surface deflection, and contact load in rolling element bearings. In this work we have installed piezoelectric transducers on the main shaft bearing of a Vestas V42 600 kW wind turbine operating in the Barnesmore field in Northern Ireland. The nature of .the contact geometry meant that careful location of the transducer was required to ensure direct pulse-echo reflection. Passage of each roller was clearly visible as a drop in reflection signal. Converting to oil film thickness is qualitative because the film is thin compared to the surface roughness. However, reflection results correlate well with the shaft speed and load. The load directly imparted by the roller onto the raceway was deduced from the change in the ultrasound time of flight, which is only a few nanoseconds. Loads on each roller in te compliment were determined and results were consistent with expectation.

5:00 pm - 6:00 pm - Panel discussion

6:00 pm - 6:30 pm - Wind Tribology Business meeting

Nanotribology II

Session Chair: H. Ghaednia, Ford Motor Company, Dearborn, MI
Session Vice Chair:

8:00 am - 8:30 am
Atomic Scale Simulation of Friction Reduction and Wear Protection of Monolayer MoS_2
Yang Liu, Yuhong Liu, Jianbin Luo, Tsinghua University, Beijing, China

Layered materials, such as graphite and molybdenum disulfide, are frequently used as solid lubricant or additives of lubricating oil to achieve low friction and enhance the lifetime of mechanical parts. Experiments have shown that Monolayer MoS_2 can greatly reduce the coefficient of friction and improve the extreme pressure of lubricant oil. We use molecular dynamics simulations to research the mechanical properties of MoS_2 monolayer supported by Pt(1 1 1), during indentation and scratching process. We find that MoS_2 monolayer can protect Pt below, until the monolayer ruptures, and three stages exist during the indentation process: elastic deformation, plastic deformation and final rupture of MoS_2 monolayer. In plane stretching of MoS_2 monolayer and contraction between Mo and S atom layers are two dominating reasons for the excellent load bearing property of MoS_2 monolayer.

8:30 am - 9:00 am
An Examination of DLC Adhesion using MD and In-situ Nanoindentation
Judith Harrison, US Naval Academy, Annapolis, MD, J Schall, Oakland University, Rochester, MI, Rodrigo Bernal, University of Pennsylvania, Philadelphia, PA, Polun Chen, Ping-Chi Tsai, Yeau-Ren Jeng, National Chung Cheng University, Chiayi County, Minxiong Township, Taiwan, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Adhesion between DLC tips and diamond counterfaces was examined using a nanoindentor coupled to TEM and molecular dynamics (MD). Strong interactions between the surfaces in vacuum led to gradual nanoscale wear of the DLC. Force-separation curves show an approximate correlation between pull-off force and applied load for various contact points, while pull-in force was fairly constant for all contact points and independent of applied load. MD simulations were designed to replicate experiment as closely as possible and used the AIREBO and the REBO+S potentials. DLC tips with the same general shape (which often deviated from the assumed paraboloidal tip geometry due to wear) were brought into contact with diamond surfaces. MD results demonstrate that pull-off force is correlated with bonds formed during contact, providing an explanation of the trends observed in the TEM data. The effects of contact point and hydrogen-termination on pull-off and pull-in forces will also be discussed.

9:00 am - 10:00 am – Invited Lecture
Probing the Mechanisms of Small-Scale Deformation with Nanoindentation
George Pharr, Texas A&M University, College Station, TX

Since its development in the mid-1980's, nanoindentation has led to the discovery of a variety of unique small-scale deformation phenomena. Among these are the indentation size effect, in which hardness at small indenter penetration depths increases; indentation pop-in, in which sudden displacement excursions are caused by homogenous nucleation of dislocations; and micro-pillar compression testing, in which the nanoindenter is used as a small-scale compression testing apparatus to explore deformation phenomena in samples small enough to probe single dislocation events. One common theme in these observations is that "smaller is stronger", with much research over the past decade focusing on the

physical origin of these effects. In this presentation, an overview of the state-of-the-art in nanoindentation testing is given along with the ways in which experimental observations obtained in such tests can be used to improve our understanding of small-scale contact and tribological behavior.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Surface Topography Across Length Scales: The Experimental Characterization of Ultrananocrystalline Diamond from Angstroms to Centimeters
Abhijeet Gujrati, Subarna Khanal, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Surface roughness has a strong effect on properties such as adhesion, contact stiffness which are critical for the performance of many small-scale devices. Recently, the mechanical behavior of rough surfaces has been described using the mathematics of self-affine (fractal-like) topography. The central quantity to describe roughness in these theories is the power spectral density. The PSD contains a complete statistical description of the surface, yet it is challenging to accurately measure experimentally. To fill this gap, the topography of ultrananocrystalline diamond surfaces has been characterized across an unprecedented 8 orders of magnitude – using optical interferometry and surface profilometry (cm-μm), AFM(μm-nm) and TEM (nm-Å) – to achieve a more-complete statistical description of these surfaces. The results demonstrate the limitations of conventional measurement techniques. The implications for topography characterization and prediction of contact properties will be discussed.

11:00 am - 11:30 am
Testing the Limits of Continuum Contact Mechanics at Small Scales and High Loads
Tevis Jacobs, University of Pittsburgh , Pittsburgh, PA, Sai Bharadwaj Vishnubhotla, University of pittsburgh, Pittsburgh, PA, Rimei Chen, Unversity of California Merced, Merced, CA, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Shelly Hu, Ashlie Martini, Unversity of California Merced, Merced, CA

Continuum contact mechanics models provide convenient closed-form expressions to describe the behavior of bodies in contact. It is known that these models should break down at small scales and high loads; yet the limits of their applicability are not well quantified. This talk will present the findings of a systematic investigation into the contact behavior between silicon and diamond. Contact tests were performed using *in situ* transmission electron microscopy experiments with matched molecular dynamics simulations to probe two orders of magnitude in size scale (radii of 1-100 nm) and three orders of magnitude in load scale (1-1000 nN). The results demonstrate a transition in behavior with increasing load, and suggest an empirically-derived limit for the applicability of contact mechanics. Additionally, the examination of the surfaces before, during, and after contact suggests mechanistic causes for the break down of these models.

11:30 am - 12:00 pm
Nanoscale In-situ Friction Test With Nanoparticles in the TEM: See What You Are Doing
Fabrice Dassenoy, Istvan jenei, Ecole Centrale de Lyon, Ecully, France

A fine understanding of tribological phenomena requires the use of advanced *in-situ* characterization techniques able to track in real time the structural, mechanical, chemical changes of the interfacial material during friction. *In-situ* TEM is a powerful technique as it allows the visualization of the tribological interface when mechanical stress is applied on the material. First *in-situ* observations of the behavior of nanoparticles during compression and sliding have been carried out using a sample holder that combines TEM and AFM. Thanks to these experiments significant progresses have been made in the understanding of the lubrication mechanism of MoS_2/WS_2 nanoparticles. However, until now, only the normal force could be measured and controlled. New *in-situ* friction tests were recently carried out on WS_2 nanoparticles using a new picoindentor with a so called 2D transducer. For the first time, the friction

coefficient involving a single nanoparticle in a sliding contact was recorded.

3B Hanover C

Commercial Marketing Forum III

8:00 am - 8:30 am - Evonik Oil Additives, Inc.

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

9:00 am - 9:30 am - Ingevity

9:30 am - 10:00 am - Savant Labs

10:00 am - 10:30 am - Break

10:30 am - 11:00 am - ANGUS Chemical Company

11:00 am - 11:30 am - King Industries, Inc.

11:30 am - 12:00 pm - Novitas Chemical Solutions LLC

3C Hanover D

Metalworking III

Session Chair:
Session Vice Chair:

8:00 am - 8:30 am
Friction Control and Coolant Separability of Slideway Lubricants
Marc Ingram, Paul Norris, Carl Williams, Gabriel Clarke, Afton Chemical Ltd, Bracknell, United Kingdom

Slideways/guideways are used in manufacturing machines to ensure the accurate positioning and movement of a tool relative to a work piece. This low speed, low pressure contact is lubricated with a specialist slideway lubricant. The two most important features of the slideway lubricant are its ability to eliminate stick-slip in the slideway and separate quickly from the metalworking fluid. This ensures accurate machining by suppression of stick-slip, and allows continuous MWF performance through fast separation. These two fluid properties are not independent since they are both controlled by the surfactant-type additives used in the slideway lubricant. In general surfactants that are good at reducing friction and stick-slip can inhibit slideway lubricant/MWF separability. In this paper we discuss the sensitive balance between friction performance and MWF separability, and how good performance in both attributes can be achieved through the use of special lubricant formulations.

8:30 am - 9:00 am
Cutting Tools - Investigation of Materials, Coatings and Coolant for Effective Cutting Tool Life
Peter Lee, Southwest Research Institute, San Antonio, TX, Thomas Stinnett, Lockheed Martin, Austin, TX, Michael Moneer, Southwest Research Institute, San Antonio, TX

A pin-on-disk machine was adapted to enable testing of carbide pins both coated with a range of coatings and uncoated. Two disk materials were used; Titanium and Stainless Steel. This work was undertaken using a traditional machining fluid and liquid nitrogen. The presentation will descirbe the test design and show the results obtained from the test matrix.

9:00 am - 9:30 am
Study of the Hot Corrosion Process and the Influence of Metalworking Fluid Properties on Hot Corrosion of Aluminium 2024-T3
Chelsea Good, Robert Evans, Quaker Chemical Corp, Conshohocken, PA

Materials that are critical for use under high mechanical stress and high temperature conditions can prematurely fail due to cracks and pitting formed as a result of corrosion. The corrosion process can be initiated by various environmental contaminates. These include those often found in metalworking fluids as well as cleaners used during the fabrication of a part. For this reason, it is important to understand the corrosion process and how the components and properties of industrial fluids impact a material's susceptibility to corrode. This presentation will discuss the hot corrosion process on aluminum 2024-T3, the role of the microstructural features in the onset of hot corrosion and the influence of certain fluid properties on the hot corrosion with this metal.

9:30 am - 10:00 am
Toxic Metal Emissions from Dry Machining Operations
John Burke, Houghton International, Inc., Valley Forge, PA, Michael Pearce, W. S. Dodge Oil, Inc., Maywood, CA, Alan Cross, Houghton International, Inc., Valley Forge, PA

Companies are investigating the use of dry machining in an effort to reduce environmental, health and safety issues associated with the use of flood application of metal removal fluids. Flood application of metal removal fluid provides benefits such as cooling and lubricating at the point of cut, flushing chips away from fixtures, dust suppression and in-process corrosion protection. Measurements conducted by the California South Coast Air Quality Management District identified levels of nickel and chromium in the immediate neighborhood of a manufacturing plant conducting dry grinding of metal alloys. Of interest was the identification of hexavalent chromium in air and solid waste samples at various locations on this property. There was no hexavalent chromium in the base metal alloys where dry grinding was conducted. This paper will discuss these recent findings and concerns going forward with dry machining and minimum quantity lubrication applications in metal removal processes.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Pine Chemistry Derived Esters as Additives for Metalworking Fluids
Eric Olivier, Monica Ford, Ingevity, North Charleston, SC

Pine chemicals serve as the backbone for a wide range of derivative chemistries, many of which are commonly used as metalworking fluid additives. One of the most widely varied classes of pine chemical derivatives are esters. These products are extremely popular as lubricant additives in metalworking fluid formulations; tall oil esters have been used in the industry for decades. Fluid technology is evolving to keep up with increasingly demanding metalworking applications and lubricant additive chemistry is too. This talk will discuss the characteristics of esters derived from pine chemistry, and will touch on the performance benefits of the new wave of tall oil derived performance lubricity additives.

11:00 am - 11:30 am
Optimizing Metalworking Fluid Performance with Primary and Tertiary Amines.
Guy Verdino, Eastman Chemical, Elk Grove Village, IL

In this study, typical metalworking fluid formulations that contain secondary amines will be replaced by combinations of primary and tertiary amines. Metalworking fluid formulators are familiar with replacing Diethanolamine (DEA) with combinations of Monoethanolamine (MEA) and Triethanolamine (TEA). The stoichiometry is straight forward. One mole each of MEA & TEA will replace two moles of DEA and yield the same Base Value so that the acid/base ratios remain the same in the two formulas. Other amine combinations are not so obvious and require knowledge and juggling of base values plus balancing against the inherent acid values of the total components in the formulation. To facilitate these kinds of calculations, a spreadsheet has been developed to handle the calculations so that at a glance, the proper levels of the replacement primary & tertiary amines can be adjusted.

11:30 am - 12:00 pm
Optimizing Mineral Oil-Free Metalworking Fluid Tapping Performance with Design of Experiment
Jason Pandolfo, Quaker Chemical Corp., Conshohocken, PA
Mineral Oil-Free metalworking fluids are known to experience difficulty when tapping aluminum alloys.

Ethoxylated/propoxylated surfactants and esters are well-known classes of lubricants for this product matrix which can have a significant impact on tapping performance. With many commercially available EO/PO surfactants and esters available, it can be difficult and time-consuming to find the right combination for acceptable lubricity. With the aid of a tapping torque test system and design of experiment, it is possible to systematically screen lubricants and quantify their performance in a reasonably short period of time. The results of a laboratory effort to improve the tapping performance of a mineral oil-free product will be presented and discussed.

3D — Hanover E

Materials Tribology III

Session Chair: G. Zeng, Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA
Session Vice Chair: S. Vishnubhotla, University of Pittsburgh, Pittsburgh, PA

8:00 am - 8:30 am
Tribology Performance and Adhesive Strength Evaluation of $Ti_{1-x}Al_x$-N Coatings
Lan Yan, Tao Zhang, Feng Jiang, Huaqiao University, Xiamen, China

Scratch test and friction test were respectively performed to evaluate the interface behavior of $Ti_{1-x}Al_x$-N coatings with x value 0.3, 0.5 and 0.7 respectively. The critical compressive and shearing stress of coating failure during scratch test were calculated. The average friction coefficients of $Ti_{1-x}Al_x$-N coating against 30Cr steel were presented under different sliding velocity of 50, 100, 150 and 200m/min. The elements diffusion was analyzed by energy dispersive spectrometer (EDS). The oxidation decreases with the increase of sliding speed, but the adhesion increases with the increase of sliding speed.

8:30 am - 9:00 am
Scratch Resistance and Indentation Hardness of Nanoporous Structures
Diana Berman, University of North Texas, Denton, TX, Elena Shevchenko, Argonne National Laboratory, Argonne, IL

Porous materials have shown their effectiveness for being used in a wide range of practical applications, such as catalysis, batteries, and water purification. Recently, it was demonstrated that porous materials also exhibit excellent optical properties and thus can be used as a base for anti-reflective coatings;However, in order to be practically reliable, there is one extra challenge to overcome. In addition to needed optical performance, excellent mechanical properties, in particular scratch resistance and indentation hardness, are highly desirable. In this talk we will demonstrate how porosity introduction to the material affects its mechanical and tribological properties. We will experimentally highlight the change in the properties with increasing the pore size from nanoscale up to macroscale. Clear understanding of the porous material performance will allow careful prediction and manipulation of the structure geometry.

9:00 am - 9:30 am
Wear Mechanisms in Annealed Atomic Layer Deposited Alumina Thin Films
Zakaria Hsain, Guosong Zeng, Nicholas Strandwitz, Brandon Krick, Lehigh University, Bethlehem, PA

Atomic layer deposited (ALD) alumina is a promising candidate for use as a wear-resistant and protective coating in MEMS and other applications. The tribological properties of ALD alumina are affected by numerous factors related to processing, environment, and operating conditions, yet its wear behavior is neither quantified nor well understood. In this study, ALD alumina is annealed at different temperatures, then subjected to tribological testing in dry nitrogen and humid air environments. Friction coefficient and wear rate appear to be heavily influenced by annealing temperature. Surprisingly, wear rate dropped by more than two orders of magnitude after annealing at 1000 C. We hypothesize that this increase in wear resistance is due to crystallization and densification of the ALD coating. Other factors contributing to wear mitigation include tribochemical reactions and favorable changes in the coating/substrate interface due to thermally-activated diffusion.

9:30 am - 10:00 am
Performance of Wear Resistant Resin Bonded Solid Film Lubricants on 6000-Series Aluminum with Deposited Ceramic Surface Modification through Plasma Electrolytic Oxidation Process
Aureliano Perez, Texas High Energy Materials, LLC, Austin, TX

Solid film lubricants are used in applications where oils and greases cannot be employed. Early dry film lubricants (DFL) contained toxic materials and hazardous solvents. Some DFL manufacturers continue to use these compounds which are under increasing environmental restrictions. We prepared a water-based DFL to replace a solvent-based analogue, for use in a mechanical application with contacting parts composed of flat, square geometries. The application consists of stainless steel and 6000-series aluminum which slide against each other, under moderate pressure, in a cyclic and linear mode. The aluminum was pre-treated *via* Plasma Electrolytic Oxidation (PEO), a process that deposits a ceramic layer onto the surface of aluminum. The ceramic layer was then coated with solid film lubricants. We subjected our waterborne DFL, and the incumbent solvent based product, to a series of lubricant tests to determine coefficient of friction, wear resistance and endurance life of each product.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Tribochemistry of ta-C Coatings in Base Oil: The Key-role of Counterface Material
Stéphanie Lafon-Placette, Julien Fontaine, Maria-Isabel De Barros Bouchet, Laboratoire De Tribologie Et Dynamique Des Systèmes, Ecole Centrale De Lyon, Ecully, France, Christophe Heau, Ireis Hef, Andrézieux-Bouthéon, France

Diamond-like carbon coatings (DLC) are of interest for tribological applications thanks to their ability to reduce friction and wear of mechanical parts. Their wear mechanism in boundary lubrication and how they interact with the lubricant and the counterface are still not well understood. Preliminary results

showed that high hardness of DLC coating does not prevent from wear. Tetrahedral carbon coating (ta-C) with high hardness showed typically higher wear than amorphous hydrogenated carbon coating (a-C:H) when sliding against steel in base oil, preheated to 110°C. To go further, several metal coatings were deposited on the steel counterface. Tribological experiments showed that the counterface nature plays a significant role on the wear of ta-C and suggested that iron could promote the formation of a heterogeneous carbon based tribofilm on the steel surface, as observed by TEM. Experiments also revealed that the tribochemical wear of ta-C is strongly activated by temperature.

11:00 am - 11:30 am
Effects of load and Humidity on Friction Fade-out in Dlc Films Sliding Against ZrO_2 Pins in an H_2 and N_2 Gas Environment
Takahisa Kato, Masataka Nosaka, The University of Tokyo, Tokyo, Japan, Atsushi Murase, Mamoru Tohyama, Toyota Central R&D Labs., Inc., Nagoya, Japan, Masahiro Suzuki, JTEKT CORPORATION, Nara, Japan

Friction tests using fully hydrogenated DLC film against ZrO_2 pins under H_2 gas or N_2 gas containing small amount of ethanol vapor were conducted. The test procedure consisted of a step-increase in applied load then followed by a decrease in ethanol vapor. The results showed that the friction coefficient dropped to the tribometer noise level as low as 0.0001, which we termed friction fade-out (FFO). It will be shown that FFO depended a great deal on an applied load. In addition, it was found the onset of FFO was controlled by the humidity of environmental H_2 of N_2 gas. For more information of FFO, the tribofilm made on ZrO_2 surface was investigated using FT-IR and TOF-SIMS measurements, where deuterated ethanol was used. It was found that a large amount of D^- and OD^- ions were included in the tribofilm, suggesting that the ethanol was dehydrated by a catalytic action of ZrO_2 and remained C_2H_4 contributed to form the tribofilm on ZrO_2.

11:30 am - 12:00 pm
On The Solid Lubrication Processes of Silicon Oxide Containing Hydrogenated Amorphous Carbon Coatings
Julien FONTAINE, Ecole Centrale de Lyon, Ecully Cedex, France, Medard Koshigan, Ecole Polytechnique Montreal, Montreal, Quebec, Canada, Filippo Mangolini, University of Leeds, Leeds, United Kingdom, Brandon McClimon, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Diamond-Like carbon (DLC) coatings are successful solid lubricants, which lubrication processes are not well understood. They combine good wear resistance, due to their high hardness, with low friction behavior, implying an easy-to-shear sliding interface. However, their use is limited by their high sensitivity to the sliding environment. Doping the carbon matrix with silicon and oxygen is known to reduce such issue. In this work, the tribological behavior of silicon oxide-containing amorphous hydrogenated carbon (a-C:H:Si:O) was studied from high vacuum to varying pressures of H_2, O_2 or H_2O. For all gases, a minimum pressure is necessary to obtain low friction and wear. The stabilized friction coefficients decrease from 1 to less than 0.1 at these thresholds, with a change in the direction of material transfers. Based on NEXAFS and Raman measurements, a simple phenomenological model is proposed to account for these observed behaviors.

3E Hanover F

Surface Engineering I

Session Chair: A. Saeed, GCET, Muscat, Oman
Session Vice Chair: M. Nazir, Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom

8:00 am - 8:30 am

Experimental Investigation of Surface Film Finish Time and Curing Finish Time of Replicating Materials Microset 101 RT
Harold McCormick, C-K Engineering, Inc., Ellisville, MO, Jianfeng Ma, Changqing Qiu, Saint Louis University, Saint Louis, MO

Microset 101 Fluid Compounds are two part silicone polymers with high resolution designed to replicate metal surfaces and they are very suitable for replicating rough surfaces, tubes, threaded holes, and cavities. In this research, experiments are conducted to investigate the surface film finish time and curing finish time of Microset 101 RT at different commonly used operating temperatures (55, 65, 75, 85, 95, 105 degree F). Duometer is used to measure the curing hardness and incubator is employed to maintain the replicate bar and Microset 101 RT to the specified operating temperatures. The curing hardness measuring is conducted in the environment that has the same temperature as that the replicate bar and replicating material are maintained at. The experimental results of the surface film finish and curing finish time of this compound provide insightful guidance for people in industry to better replicate the profile of the rough surfaces using Microset 101 RT.

8:30 am - 9:00 am
Inhibitory Effect of the Sliding Surface Damage Due to the Discharge
Kenji Matsumoto, Honda R & D, Haga, Tochigi, Japan, Naoaki Yoshida, Kyushu University, Kasuga, Japan, Akira Sasaki, Maintek Consultant , Yokohama, Japan

The discharge traces on the surfaces of components, which are used in environments where oil or grease are abundantly supplied, are sometimes observed. It is a well-known fact that charge accumulation by the electric double layer is formed in the sliding surface, and that causes the discharge. Discharge causes small damage and promotes wear on the sliding surface. We developed a new DLC（Diamond-like Carbon）coating, and found that the coating had the effects of the damage suppression by discharge. This time, we report the results of detailed analysis of the tested DLC coating by TEM (Transmission Electron Microscope).

9:00 am - 9:30 am
Elasto-plastic Contact of Non-Conformal Rough Surfaces
Itzhak Green, Georgia Tech, ATLANTA, GA, Leander Reinert, Sebastian Suarez, Saarland University, Saarbruecken, Germany

It is well known that the Greenwood-Williamson model or its variants have largely assumed flat rough surfaces. That simplifies such analyses as global variations in geometry, or macro substrate deformations, have no consequence. While indeed the method that is presented here build upon the Greenwood-Williamson or the Jackson-Green models, the non-conformal nature of the contact along with substrate deformations compels a change in the methodology so that both effects are taken into account. The numerical examples given herein are taken from an electrical contact application in which a hemispherical punch is forced into contact with carbon nanotubes (CNT) impregnated flat surface. The flat surface is laser textured to reduce wear and adhesion, while the electrical conductance remains largely intact. Both surfaces, that of the hemispherical punch and that of the textured flat, are rough and deformable.

9:30 am - 10:00 am
Effect of Laser treatment on Plasma Sprayed WC-12%Co Cermet Coating Using Fe and Ni Base Substrates
Mohammad Ajmal, mohammad Mughal, Mohammad Afzal, UET, Lahore, Pakistan

Laser re-melting techniques is to fuse completely pores within the coatings and results in a homogeneous modified surface reduce inherent defects such as porosity and inter-splat boundaries. In the present study, the WC-12% Co coating was produced by Air Plasma Spraying (APS) technique on SS-321and

Monel-400 at 100 mm optimized standoff distance. The coated samples were treated with CO_2 laser under the shroud of nitrogen atmosphere and the effect of laser re-melting on microstructures and interface of both substrate were investigated. It was observed that the modified surfaces have defect free surfaces and have better mechanical properties as compared to plasma sprayed coatings on both the substrates. The increase in surface hardness of the substrate was attributed to the formation of metallurgical bond between the coating and substrate.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Experimental Study of the Permanent Deformation Patterns After the Low Speed Collision of a Rigid Rod with an Elastic-plastic Lubricated Flat
Hamid Ghaednia, Dan Marghitu, Robert Jackson, Auburn University, Auburn University, AL

It has been shown recently that the permanent deformations after collision can be used to analyze the contact forces during the collision. In this study low speed impact of a rounded ended stainless steel rod with an aluminum flat has been analyzed. The rod has been dropped with different angles from 0 to 70 deg with initial normal speeds up to 3 m/s. The motion of the rod has been captured using a high speed camera and analyzed using image processing techniques. A profilometer has been used to measure the permanent deformations on the flat . The results for the normal permanent deformations on the flat and the motion of the rod have been compared for dry and lubricated flat and for different lubricants and initial normal velocities.

11:00 am - 11:30 am
Spreading Dynamics of Liquid Droplets Under Different Ambient Pressure
Lichun Shi, Tsinghua University, Beijing, China, Roger HORN, Deakin University, Melbourne, Victoria, Australia, Yu Tian, Tsinghua University, Beijing, China

Spreading dynamics of liquid droplets on a rigid flat surface is a fundamental phenomenon usually happens in time scale from milliseconds to seconds in nature and industry, such as in raining, spin coatings, painting, liquid adhesion, and inkjet printing. The spreading is drove by the capillary force and hindered by inertial and viscous force. Most studies about liquid droplet wetting were carried out in air environment and the researchers did not pay attention to the effect of ambient pressure on liquid droplet wetting. Generally, surface tension and viscosity of liquids, which are not easy to evaporate at vacuum pressure, are unaffected by the pressure of the environment. In this manuscript, we study the spreading under different ambient pressure and reveal that the velocity of droplet wetting is related to the air pressure. This research could be significant for further understanding of droplet wetting in different ambient pressure.

11:30 am - 12:00 pm
The Use of Graphene and DLC to Reduce Friction and Wear in Automotive Engines
Stephen Hsu, Lawrence Li, Kalyan Mutyala, The George Washington University, Washington, DC

Controlling friction and wear between the sliding surfaces of engine components in engines has gained attention recently due to the drive to improve fuel economy and reduce carbon emission. Technologies such as surface textures, thin films and coatings are being studied worldwide. We have investigated the use of diamond like carbon, bonded chemical films, and graphene thin films on textured surfaces of piston rings to evaluate their effectiveness. Characterization of these films in terms of scratch hardness, SEM, Raman spectroscopy was carried out. Coated piston rings are tested in a ring and liner (Plint TE 77) tribometer under various lubrication modes to measure their friction reduction properties and durability.

Session Chair: B. Bou-Said, INSA, Villeurbanne, France
Session Vice Chair: M. Braun, University of Akron, Akron, OH

8:00 am - 8:30 am
Coupled Poroviscoelasticity and Hydrodynamic Lubrication in Thrust Bearings
Patrick Smyth, Itzhak Green, Georgia Institute of Technology, Atlanta, GA

As the state-of-the-art pushes triboelements toward greater capabilities and longevity, the need for evolving triboelement technology exists. The following work explores a novel coupling of phenomena inspired by biomimetics. A poroviscoelastic substrate, coupled to a fluid film load is modeled and compared to its rigid counterpart. It is hypothesized that poroviscoelasticity can improve triboelement properties such as damping and wear resistance, and have utility in certain applications where flexibility is desired (e.g. biomechanical joint replacements, flexible rotordynamic bearings, and mechanical seals). This study provides the framework for the analysis of flexible, porous viscoelastic materials and hydrodynamic lubrication in thrust bearings.

8:30 am - 9:00 am
On Optimum Geometry for a Thrust Bearing Operating on a Polyurethane Foam Slider Imbibed With Liquid
Sergey Kunik, Aurelian Fatu, Jean Bouyer, Pprime Institute, Futuroscope Chasseneuil Cedex, France

It has been previously showed that self-sustained fluid films generated within highly compressible porous layers imbibed with liquids are a high-performance alternative for classical lubrication systems. The mechanism was named eX-Poro-Hydro-Dynamic (XPHD) lubrication and it is characterized by very soft porous materials where the lift forces generated by the compression of the solid matrix can be neglected. Using a numerical model based on the Darcy-Brickman equation, a parametric study is made in order to optimize a thrust-bearing geometry in terms of lifting force and friction torque. Two optimal geometries are retained to be tested on a simple experimental test rig. The experimental results are then used to show the significance of the numerical model.

9:00 am - 9:30 am
Analysis of Couple-Stresses and Piezo-Viscous Effects in a Layered Connecting-Rod Bearing Using a Global Thermal Approach
Benyebka Bou-Said, INSA, Villeurbanne, France

In this work, the combined effects of couple-stresses and piezo-viscosity on the dynamic behaviour of a compression ignition engine big-end connecting-rod bearing with elastic layer are investigated using a global thermal approach based on the “effective temperature” concept. It is assumed that the journal (crankpin) is rigid and the big-end bearing consists of a thin compressible elastic liner fixed in an infinitely stiff housing. On the other hand, the Walther’s law is included in the simplified model in order to account the viscosity variation with respect to effective temperature. The governing Reynolds’ equation and the viscous dissipation appearing on the RHS of energy equation are modified using the V. K. Stokes micro-continuum theory. The non-Newtonian effect is introduced by a new material constant which is responsible for couple-stress property.

9:30 am - 10:00 am
Quantitative Elastohydrodynamic Film-Forming for an Oil/Refrigerant System
Scott Bair, Georgia Tech, Atlanta, GA, Wassim Habchi, Lebanese American University, Byblos, Lebanon, mark Baker, CPI Fluid Engineering, Midland, MI

The first calculations of film thickness for an oil/refrigerant system using quantitative elastohydrodynamics are reported in this work. An unusual response to lubricant inlet temperature is revealed wherein the film thickness may increase with temperature as a result of decreasing refrigerant solubility in oil when the inlet pressure is high. There is competition between the reduction in viscosity of the oil and the reduction of refrigerant concentration with increased temperature. For high inlet pressure, the dilution effect is dominant, whereas for low inlet pressure, the temperature dependence of the viscosity of the solution dominates over the range of inlet temperatures considered. It seems that only central film thicknesses have been experimentally measured for oil/refrigerant systems leaving these calculations as the only means of assessing the minimum.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Combined Effects of Couple Stress and Poro-Elasticity on Squeeze Film Between Parallel Plates
Benyebka Bou-Said, INSA, Villeurbanne, France

This work deals with a numerical simulation of combined effects of couple stress and poro-elasticity on hydrodynamic performances of squeeze film between infinitely long parallel plates. The lower plate is a poro-elastic matrix saturated by a Newtonian fluid and its poro-elasticity is taken into account by the homogenization method. The modified Reynolds equation accounting for the couple stress, the elasticity of the poro-elastic plate and the slip velocity condition at the film – poro-elastic plate interface is derived. The partial differential equations in the fluid film and poro-elastic plate are discretized by finite differences method and iteratively solved using Gauss-Seidel method. The fluid film and poro-elastic plate coupling is managed using the iterative fixed point technique. The numerical results, presented for different couple stress parameters, flexibility parameter and permeability parameter, are promising.

11:00 am - 11:30 am
Dynamic Modeling of a Dual Clearance Squeeze Film Damper Operating with Air Entrainment
Laurentiu Moraru, University Politehnica of Bucharest, Bucharest, Bucharest, Romania, Theo Keith Jr., The University of Toledo, Toledo, OH, Florin Dimofte, The University of Toledo at NASA GRC, Toledo, OH, Sorin Cioc, The University of Toledo, Toledo, OH, David Fleming, NASA Glenn Research Center (retired), Cleveland, OH

Squeeze film dampers (SFD) are devices utilized to control the shafts of high-speed rotating machinery. A dual squeeze film damper (DSFD) consists of two squeeze film bearings that are separated by a sleeve which is released only within abnormal operating conditions. In this part of our study of DSFD we analyze the case when both the inner and the outer oil films are active and air entrainment is allowed. We present computed and measured unbalance responses of a shaft supported in DSFD

11:30 am - 12:00 pm - Available Slot

3G — Regency V

Lubrication Fundamentals I - Additives & Additives degradation

Session Chair: B. Miller, Chevron Oronite Co. LLC, Richmond, CA
Session Vice Chair: R. Mourhatch, Chevron Oronite, LLC, Richmond, CA

8:00 am - 8:30 am
Lubricant Shear Stability Mechanism Study

Philip Ma, Shouxun Zhao, Andreas Minke, BASF, Tarrytown, NY

Higher viscosity index (VI) lubricants are desired for their ability to maintain their viscosity under a wide range of temperature for modern day machinery, however, high VI lubricant experiencing high load and low speed boundary lubricating conditions often result in the breakdown of portions of the high molecular weight polymer molecules within the lubricant formulation. This paper uses commonly used high viscosity Polyalphaolefin thickened Wind turbine type gear lubricant as example to examine the mechanism involved during the KRL Tapered Roller Bearing Test shear process and the potential influences on the lubricant properties. This understanding provide guide on improving the stability of the polymer thus prolong the lubricant life as a whole.

8:30 am - 9:00 am
A New Approach to Probe the Interactions Between Viscosity Modifiers and Waxes Present in Engine Oil
Solmaz Pirouz, University of Waterloo, Waterloo, Ontario, Canada

An engine oil formulation is usually a mixture of base oils and oil-additives. Oil-additives such as viscosity modifiers (VMs) are long chain, high molecular weight polymers used to reduce the decrease in viscosity of the base oil upon increasing temperature without excessively increasing the viscosity of the oil at lower temperatures. The long ethylene sequences of ethylene-propylene copolymer VMs crystallize in solution and shrinks the overall dimension of the polymer coil and, consequently, reduces the viscosity. While reduced viscosity is desired, the crystallized macromolecule becomes less soluble in oil which could lead to uncontrolled polymeric aggregation and eventually polymer precipitation. Unlike traditional methods, this research will introduce a new methodology based on pyrene excimer fluorescence to quantitatively measure the actual level of intermolecular association between EP copolymers in the absence and presence of wax.

9:00 am - 9:30 am
ZDDP Tribochemistry Influenced by Oxidative Degradation
Nicole Doerr, Christoph Gabler, Andjelka Ristic, Marcella Frauscher, AC2T research GmbH, Wiener Neustadt, Austria

Tribochemistry of ZDDP antiwear additives is reported by numerous publications. However, the impact of lubricant deterioration – especially due to oxidative stress – on the long-term properties still remains widely hidden on the molecular scale. In this work, a model oil containing ZDDP was artificially altered by a lab-based method. Oil in fresh condition and oil samples obtained during oxidative stress were analysed for degradation products by mass spectrometry for a proper description of the oil condition. Selected samples were tribometrically assessed using an oscillating steel-steel contact. Wear scars were analysed by mass spectrometry and XPS to account for organic and inorganic moieties on the surface. ZDDP tribolayer chemistry is discussed with regard to oxidative degradation observed.

9:30 am - 10:00 am
Microencapsulation of Friction Modifiers for Engine Oils
Stephen Hsu, Shanhong Xu, Fei Zhao, The George Washington University, Washington, DC

With poly (methyl methacrylate) (PMMA) as shell and friction modifiers as core substances, microcapsules were prepared based on solvent evaporation method. The lubrication effect of the capsules for engine oil were examined by four ball friction test. The reduced coefficient of friction of engine oil containing capsules was attributed to release of friction modifiers from the capsules by breakage of the shell. The effect of the process conditions such as temperature, shell/core ratios, nature and concentration of emulsifiers on the release of friction modifier was studied. The morphology, particle size and surface charge for microcapsules were characterized by SEM, light scattering and zeta potentiometer. Other polymeric materials as shell for microcapsules with controlled release of friction modifiers were also investigated.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Base Oil and Antioxidant Selection - The Role of Secondary Antioxidants and Base Oil Sulfur Content.
Thomas Norrby, Nynas AB, Nynashamn, Sweden, Ann-Louise Jonsson, Naphthenics Reseach, Nynas AB, Nynashamn, Sweden

Different base oil Sulfur levels are known to be correlated to Antioxidant (AO) treat rate response. We have studied new base oils designed to be Group I base oil replacements. As these are based on highly refined Naphthenic and Group II base oils, the Sulfur levels are low compared to traditional solvent refined Group I base oils. Thus, these new base oils have somewhat lower response to conventional primary antioxidants compared to reference Group I base oils. In order to elucidate the relative contribution of base oil Sulfur, and the addition of Secondary Antioxidants, an oxidation stability study was performed using HP-DSC. Results show good correlation between base oil Sulfur, primary and secondary AO and the Oxidation Induction Time (OIT) by HP-DSC, and by RPVOT.

11:00 am - 11:30 am
Aged Oil Frictional Properties of Organometallic and Organic Rriction Modifiers
Mihir Patel, Brian Casey, Vincent Gatto, Vanderbilt Chemicals, LLC, Norwalk, CT

Friction reduction mechanism of MoDTC based friction modifiers(FM) in oil have been well studied. But, little is known about the sulfur free molybdenum-based FM such as the molybdenum ester-amides. While extensive work has been done studying the properties of FMs in fresh engine oils, much less has been reported on their effectiveness after the aging of engine oil. Understanding FMs performance under aged oil conditions is a critical component towards developing effective and durable FMs. Hence, study was conducted to understand the frictional properties of molybdenum ester-amides and their combination with organic FMs under both fresh and aged engine oil conditions. The frictional properties of commercial molybdenum ester-amide FMs were compared to commercial and experimental organic FMs in prototype 0W-20 engine oil. Based on the friction retention benefits, an optimized FM additive was synthesized that effectively combines the chemistries of molybdenum & organic FM.

11:30 am - 12:00 pm

Effect of Urban Automobile Running Parameters on Lubricating Oil Properties
Lei Wei, Haitao Duan, Song Chen, Bingxue Cheng, Jian Li, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China

This study focused on an urban running automobile and two kinds of lubricating oils to research the effect of running parameters on lubricating oil properties. The running parameters contained speed, mileage, idle time, running time, number of starts, etc. were obtained from the On-Board Diagnostic system. The lubricating oil samples were obtained about every 30 days and its properties were analyzed in lab. The improved grey relational analysis method were used to analyze the inner relationship between running parameters and oil properties. The change law of lubricating oil properties in actual application directly affects whether the oil change interval can be determined scientifically. The results show that average speed, idle time and idle ratio have significant influence on lubricating oil properties. The scientificalness of commonly used oil change interval which was determined according to mileage needs to be further researched.

Session Chair: P. Cusatis, BASFCorporation, Tarrytown, NY
Session Vice Chair: D. Kohler, Evonik Oil Additives, Horsham, PA

8:00 am - 8:30 am
The Role of Interfacial Forces in Non-aqueous Foam Stability and Rupture
Abhishek Kar, Shell Global Solutions US Inc., Houston, TX

Foams are found in lubricants from the release of dissolved gas that can be detrimental to machinery efficiency due to economic loss from sweeping of oil droplets in the gas stream and damages to equipment hardware from poor lubrication. Antifoams or defomants are often used to mitigate foaming in lubricants. However, fine filtration and lack of mechanistic insight into bubble rupture have left the antifoams prone to separation from the oil. In this talk, we will present the study on a single bubble rupture mechanism through a dynamic fluid-film interferometer (DFFI) that can measure and understand the fate of bubbles as they approach the interface of lubricating oils. Through DFFI, we can gain mechanistic information on the evolution of entrained film volume, the drainage rate of the film and the minimum film thickness before bubble rupture. Our results indicate that Marangoni flows are critical to foam stability and are at the heart of solving the foaming problem in lubricants.

8:30 am - 9:00 am
Foaming and Antifoaming of Lubricating Fluids. Part I. Fundamentals of Foaming in Lubricating Oils and the Chemistry of Antifoams Used in Them
Kalman Koczo, Mark Leatherman, Momentive Performance Materials, Tarrytown, NY, Kevin Hughes, Don Knobloch, The Lubrizol Corporation, Wickliffe, OH

Antifoams are important, although often overlooked, components of lubricating fluids. In this comprehensive review series we will discuss many aspects of antifoam agents, based on the literature and our research. In Part I, we will review the foaming properties of lubricating fluids, including effects from base oils, additives, and contaminants, as well as the chemistry and key physical properties of antifoaming agents used in lubricants. Antifoams act by breaking the thin liquid films that make up a foam. The most important criteria for effective foam control are that the antifoam agent should have a lower surface tension than the foamant (i.e., the lubricating fluid); it has to be insoluble in the foamant and should be dispersible into small droplets. Three types of silicones (polydimethylsiloxane, organomodified silicones and fluorosilicone) and polyacrylates can meet these conditions and their structures, properties and limitations will be discussed.

9:00 am - 9:30 am
Foaming and Antifoaming of Lubricating Oils. Part II. Mechanisms of Antifoaming Action and Air Entrainment
Kalman Koczo, Mark Leatherman, Momentive Performance Materials, Tarrytown, NY, Kevin Hughes, Don Knobloch, The Lubrizol Corporation, Wickliffe, OH

Much of what is known about the fundamentals of antifoam agents comes from experiments using water-based systems, so less is understood about how antifoams act in hydrocarbon based lubricants. We will begin Part II of this two part series by describing the general theories for water-based systems and then highlight key differences between water- and oil-based systems. The most important differences involve the magnitudes of the interfacial forces between the foaming fluid, air, and the antifoam (surface/interfacial tensions and interfacial rheology). We will also review the thermodynamic conditions of foam control, the role of the so-called pseudoemulsion film, the importance of drop size, and then discuss the possible mechanisms by which antifoam agents work in lubricants. Air entrainment is also a critical phenomenon in lubricating oils. The mechanisms leading to air entrainment, the possible role of antifoams, and the role of molecular weight and solubility will be also discussed.

9:30 am - 10:00 am

Experimental Study on the Effect of Hygroscopic Properties on Lubrication Performance of Refrigeration Oil

Ruihong Kong, Jin Zhu, Yihong Sun, Shuo Zhang, Shanghai Hitachi Electrical Appliances CO.,LTD, Shanghai, China

As the environment-friendly Refrigerants are proposed as substitutes for R22 in refrigeration system, the relevant refrigeration oils are chosen from single Mineral Oil to different synthetic oils for the refrigerants. However, there are significant differences in the hygroscopic properties of different refrigeration oils. In the experiments, the difference of hygroscopic properties in short time was evaluated, of the current common refrigeration oils such as Mineral oil, Alkyl benzene, PVE, straight and branched chain POE. The result shows the PVE and POE has more highly hygroscopic. Then the friction tests of PVE VG68 and POE VG68 with different water contents were carried out by the Bruker UMT-III system. It is studied of the friction and wear between the friction pairs with the increase of the water content of the refrigeration oil at the compressor operating temperature.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am

Newly Synthesized Ionic Liquids (ils) as Friction Modifier Additivies for Lubricants

Pankaj Baghel, Hirofumi Kondo, Kouki Hatsuda, Nobuo Tano, Dexerials Corporation, Kanuma, Tochigi, Japan, Shinya Sasaki, Shouhei Kawada, Tokyo University of Science, Tokyo, Japan

This paper deals with effects of the molecular structure of newly synthesized ILs on the tribological properties. ILs containing multiple long alkyl chains introduced on Imidazolium (IM) ring were synthesized. The tribological properties were investigated on steel/steel contact at various temperatures by using the Optimol SRV oscillating friction tester. Addition of 1 wt.% of 1-octadecyl-2-undecyl IM sulfonylimide showed reduction in friction coefficient compared to additive free Poly Alpha Olefine by 38% at 40^{o}C. Scanning Electron Microscopy (SEM) and X-ray photoelectron spectroscopy revealed the boundary film made of ionic liquid's elemental composition, which leads to the low abrasion on the surface of disk specimen. Mechanism of low friction and wear thus obtained are further discussed in detail.

11:00 am - 11:30 am

Performance Additives to Improve Tribological Properties of Ionic Liquid as Base Fluids

Erik Nyberg, Luleå university of technology, Luleå, Sweden, Mattias Grahn, Chemical Engineering, Luleå, Sweden, Ichiro Minami, Luleå university of technology, Luleå, Sweden

Room temperature ionic liquids (RTILs) have several properties which make them interesting candidates as base fluids for extreme conditions. However, a lack of compatibility with tribo-improving additives combined with an often overly aggressive nature is limiting their use as base fluids. To overcome these drawbacks, hydrocarbon-mimicking RTIL base fluids have recently been developed. These lubricants aim for a more balanced interaction with metal surfaces while enabling compatibility with common additives, so that the reactivity with the lubricated surface can be tuned in a manner similar to hydrocarbon base oil–additive systems. In this work, the effects of several common additives in the novel RTIL were examined by laboratory tribotesting. Surface analysis was performed in order to study the lubrication mechanisms.

11:30 am - 12:00 pm

Compatibility Between Ionic Liquids-based Lubricant Additives and Bronze and Aluminum Bearing Alloys

Yan Zhou, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Tribological compatibility between anti-wear additives and non-ferrous bearing alloys has been investigated. The anti-wear additives are ZDDP and ionic liquids (ILs). The two tested material pairs are AISI 52100 steel balls sliding against 932 bronze and A380 aluminum flats, respectively. The lubricating performance is highly dependent on the compatibility between the IL chemistry and material composition. The addition of ZDDP or phosphonium-carboxylate IL resulted in effective wear protection on both the bronze and Al alloy surfaces. Phosphonium-phosphate IL had little effect on the bronze but reduced wear for the aluminum surface. On the contrary, phosphonium-sulfonate IL worked well with the bronze surface but caused significant wear increase on the aluminum surface. Surface characterization showed little tribofilm on the bronze or aluminum surface, suggesting very different protection mechanisms of anti-wear additives for non-ferrous alloys compared with that for steel or iron.

3I The Learning Center (TLC)

Engine & Drivetrain I

Session Chair: M. Plumley, US Coast Guard Academy, New London, CT
Session Vice Chair: K. Sinha, Chevron Oronite Co. LLC, Bellaire, TX

8:00 am - 8:30 am
Study of Effects of Boundary Lubrication on Piston Pin/Bore Scuffing Failure
Chao Zhang, Shanghai University, Shanghai, China

Effects of engine oil additives and boundary lubrication conditions including surface roughness, clearance, engine loads and speeds, oil temperature, and oil feeding rate on scuffing behavior of piston-pin/bore bearings are investigated. QMERA is a program that allows combined quantum mechanical (QM) and molecular mechanics (MM) forcefield calculations to be performed using the ChemShell environment. QMERA is used to simulate tribochemistry reactions in boundary films. A lubricant-chemistry kinetic model of boundary film formation and removal based on structure-oriented lumping (SOL) approach is used. Piston and piston pin are production components. The piston pin is a hollow cylinder made of steel and the piston are made of aluminum alloy and steel respectively. Both fixed pins and floating pins are used. The simulation results are compared with the bench and engine test results. XANES methodology is used.

8:30 am - 9:00 am
Fuel Efficient Low Viscosity Lubricants
Stephen Hsu, Fei Zhao, Xiangyu Ge, The George Washington University, Washington, DC, Gefei Wu, Amol Savant, Valvoline LLC, Lexington, KY, Timothy Cushing, GMC LLC, Warren, MI

A new generation of fuel efficient lubricants designated as GF-6 is being developed with associated ASTM Engine Dynamometer Sequence Tests. While the engine tests are being developed, we examine some experimental GF-formulations for testing. Using low viscosity lubricants to reduce the pumping loss and hydrodynamic friction requires stable low viscosity base oils and special attention to viscosity modification. We have developed a set of laboratory bench test procedures to screen friction modifiers, supplemental antiwear additives to maximize fuel economy while trying to maintain or enhance durability. We have conducted Seq. VI engine tests to validate the fuel economy gains.

9:00 am - 9:30 am
The Effect of the Driving Cycle in the Fuel Economy Measurement With MoDTC in Low Viscosity Engine Oils
Kenji Yamamoto, ADEKA Corporation, Tokyo, Japan, Sascha Heiden, ADEKA Europe GmbH,

Dusseldorf, Germany, Yukiya Moriizumi, ADEKA Corporation, Tokyo, Japan

Applying low viscosity engine oil is one well known approach for improving fuel economy of vehicles. On the other hand, it is concerned that low viscosity engine oil possibly increase the frequency of surface contact and increase the friction losses in sever condition. Lubrication condition in engine will be changed on its operation such as driving speed and oil temperature which are defined by fuel economy measurement procedure. The influences of driving cycle, lubricant viscosity and molybdenum dithiocarbamate (MoDTC) as friction modifier in fuel economy performance measurement by chassis dynamo test are studied. The result indicates lubrication condition is affected by driving cycles significantly, and severer condition of WLTC than NEDC is expected by the effect of viscosity and MoDTC in this study.

9:30 am - 10:00 am
Correlating the Effect of Lubricant Temporary Shear Thinning to Shear Rates in Engines and its Impact on Lubricant Design for Improved Fuel Economy
Priyanka Desai, Shell Global Solutions (US) Inc., Houston, TX

Efforts to improve fuel economy have led us to better understand the impact of shear rates on viscosity and rheology of lubricants so that we can “design viscosity” targets instead of just lowering viscosity to achieve fuel economy. Typically, shear thinning of an engine lubricant has been characterized by the viscosity loss of the lubricant at a shear rate of 1 million reciprocal seconds, as measured by ASTM D4683 High Temperature High Shear (HTHS) Viscosity. But in order to further improve fuel economy predictions and to help in the formulation of fuel efficient lubricants, a more complete measurement of viscosity versus shear rate is needed to better correlate with typical shear rates/temperatures seen in engine valve trains, piston rings, and journal bearings. This talk focuses on the variation of lubricant viscosity with temperature and shear rates, correlating it to typical engine conditions and its implications for fuel economy.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Improving Vehicle Fuel Efficiency Through High VI Engine Oils
Boris Eisenberg, Evonik Oil Additives, Darmstadt, Germany

Optimizing fuel economy requires constant improvement both in hardware as well as in lubricant performance. In an innovative step in VII design, the PAMA chemistry has been combined with polyolefin chemistry to defined comb polymers. Comb polymers allow for significantly reduced low temperature viscosity and reduced internal friction, which directly translates into fuel economy. The presentation shows the potential to optimize the relationship between viscosity and operating temperature. Depending on VII-design and chemistry it is possible to tailor the oil viscosity to engine requirements, which results in fuel economy advantages for comb polymers when compared to OCP based lubricants. Selected VMs have been tested with regard to fuel economy performance in different formulations.

11:00 am - 11:30 am
The Effect of Friction Modifiers and Additive Packages on Friction Reduction Potential of Next Generation Engine Oils: Part I Fresh oils
Zhiqiang Liu, Arup Gangopadhyay, Steven Simko, Ford Motor Company, Dearborn, MI, Bill Lam, Mark Devlin, Afton Chemical Corporation, Richmond, VA

Three additive packages were blended in SAE 5W-20 and 0W-16 viscosity grades. A motored cranktrain assembly from a GDI engine has been used to evaluate them, in which FMEP as a function of engine speed and temperature is measured. Results show that additive package plays a significant role in friction reduction. Results from the MTM2 provide detailed information on traction coefficient in boundary, mixed and elastohydrodynamic lubrication regimes. Results from the cranktrain rig are fairly consistent with

MTM2 results for the oils tested. Analytical studies suggest that the traction coefficient increase in mixed lubrication regime is associated with the lubricant starvation due to the tribofilm formation. Oil film thicknesses have been measured as a function of rolling speed and temperature using EHD2 rig. Analytical study indicated that the observed higher film thickness at low speeds and high temperatures can be explained by surface roughening or plastic deformation of the surface.

11:30 am - 12:00 pm
The Effects of Friction Modifiers and Additive Package on Friction Reduction Potential of Next Generation Engine Oils: Part II Aged Oils
Arup Gangopadhyay, Zhiqiang Liu, Steven Simko, Ford Motor Company, Dearborn, MI, Bill Lam, Mark Devlin, Afton Chemical Corporation, Richmond, VA

Following a companion study on fresh oils in Part I, the friction behavior of friction modifier and additive package combinations on rubbing ferrous surfaces with 5K-mile aged oils has been studied. Using a cranktrain rig with an I-4 GDI engine block, we found that aged oils either improved or maintained but did not degrade friction at low speeds and high temperatures while showing somewhat higher friction at high speed regime than that observed with fresh oils. The latter is consistent with EHD2 results showing enhancement of oil film thickness. Aged oil also pushed mixed lubrication regime to lower engine speed at high temperatures. Using MTM2 in conjunction with SLIM, the topography and thickness of tribofilms on worn tracks and wear have been periodically recorded. The relationship in friction results between MTM-SLIM and the cranktrain rig is discussed. The tribo-films on wear tracks from MTM-SLIM tests were analyzed for better understanding of friction and wear behavior.

3J Dunwoody

Tribotesting III

Session Chair: S. Rappaport, Shell Global Solutions, Houston, TX
Session Vice Chair:

8:00 am - 8:30 am
Abrasive Wear of Advanced Polymeric Coatings at Elevated Temperature for Oil & Gas Drilling Applications
Pixiang Lan, Andreas Polycarpou, Texas A&M University, College Station, TX

From our previous research, we concluded that ATSP-based coating has extremely low wear rates (4.15x10-8 mm^3/Nm) under boundary lubrication simulating tilting pad bearing in harsh conditions. It was acknowledged that coatings' resistance to abrasive particles is very critical; its abrasive wear resistance is studied in this work by a pin-on-disk experimental configuration which submerged in drilling mud from field (about 55wt. % solid particles) at elevated temperature (Room, 75°C and 125°C) and high chamber pressure(500PSI Nitrogen gas) condition. For comparison, experiments on bare metal without ATSP coating were also carried out. Experiments showed that ATSP coating could great reduced the coefficient of friction in boundary lubrication condition and ATSP had good abrasive wear resistace. The abrasive wear mechanism of ATSP was studied by SEM and micro scratch.

8:30 am - 9:00 am
Tribological Testing of Food: Mouthfeel and Stribeck Curves
Charlotte Reppich, Kartik Pondicherry, Anton Paar GmbH, Graz, Austria

Food tastes and feels the way it does due to its complex rheological and tribological properties, such as its viscosity, consistence, texture, stickiness, etc. The current study attempts to show as to what can be read out from simplified Stribeck curves in terms of oral sensory attributes for simple foods and beverages. Here, tests were carried out on various food elements such as chocolates, milk, soft drinks,

cheese, etc. In select cases, the effect of saliva, both human and artificial, on the frictional behavior of foods has also been studied. The tests were carried out on an MCR Tribometer with a ball-on-three-pin configuration. Polydimethylsiloxane (PDMS) and glass were used to simulate soft contact conditions that exist in the human mouth. Results indicate that certain aspects of the Stribeck curve can offer an insight into the correlation between the frictional behavior of food to their sensory feel.

9:00 am - 9:30 am
Investigation of Stick-slip of Steel-polymer Contacts
Kartik Pondicherry, Florian Rummel, Anton Paar GmbH, Graz, Austria, Florian Summer, Montanuniversität Leoben, Graz, Austria

We present a methodology which enables precise observation of stick-slip behaviour of selected steel-polymer tribopairs.Tribological tests were carried out on a rotational tribometer and the contact interface was observed with the help of a microscope during the tests. These tests were carried out under both dry and lubricated conditions. The applications in focus are automotive components and, food and beverages. While stick-slip behaviour is in most cases to be avoided in the former, it is believed to be essential in the latter in order to enhance mouthfeel of food and beverages. In the case of food and beverages, "Exetended" Stribeck curves were also plotted to correlate stick-slip with the slope of the Stribeck Curve. Results show that the test methodology applied here is very much suitable for studying stick-slip behaviour of steel-polymeric contacts.

9:30 am - 10:00 am
The Tribology Laboratory: A Handy Environment for Failure Analysis?
Philip De Vaal, University of Pretoria, Pretoria, South Africa

A well-equipped tribology laboratory can make meaningful contributions towards the identification of malfunctioning lubricants. In addition, interesting conclusions related to component failure analysis can also be made. Several examples will be discussed related to the following: Lubricants used not conforming to specification, Failure analysis based on trace element identification, Insufficient detail in lubricant specifications and Interpretation of laboratory test results Laboratory-based lubricant performance testing devices can be a great help when results are carefully studied. When used with surface analysis, spectroscopic, optical- and electron-microscopic support, a new world of understanding unfolds.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Seizure Load Determination as a Challenge in Modern Model Tests on the Translatory Oscillation Tribometer (SRV®)
Gregor Patzer, Optimol Instruments Prueftechnik GmbH, Munich, Germany

When looking in detail at analyses of the tribological load-carrying capacity of lubricants, it becomes apparent that an exclusive evaluation of the development of the coefficient of friction cannot provide any sufficient criteria for determining the occurrence of adhesive failure. This is due on the one hand to the increasing complexity of lubricant formulae, and on the other hand to the increasing frictional power capacity of modern drive and control concepts in the construction of tribometers. For this reason, it is urgently needed to examine the adhesive processes and their detection in more detail with the help of appropriate tribological values and criteria. Aside from new criteria for adhesive failure, which were compiled by the work group for the relevant ISO, DIN, and ASTM standards, this talk also presents a discussion of further parameters.

11:00 am - 11:30 am

An In Situ Approach to Study Tribocorrosion of a Supermartensitic Steel
Renata Soares, Vanessa Lins, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil, Hong Liang, Texas A&M University, College Station, TX

Tribocorrosion plays an important role in applications such as in off-shore industry and biomedical engineering. One of the scientific gaps in tribocorrosion study is that standard methods are scarce. The objective of this work is to develop a novel in situ methodology to characterize surfaces under triboelectrochemical conditions. A potentiodynamic anodic polarization is employed to rubbing in order to analyze the synergistic interactions of corrosion and wear. A new triboelectrochemical setup was developed in order to study effects of mechanical abrasion on corrosion. The setup contains third-body abrasive wear through a tribometer, and an electrochemical monitoring. A supermartensitic steel was used in this study. The wear scars produced indicated that three-body abrasion was the dominant wear mechanism. During tribocorrosion, more pits were initiated, so called tribo-pits, than those without rubbing.

11:30 am - 12:00 pm
Experiments on the Mechanism of Liquid Penetration into Nut and Bolt Contacts and the Effect on Frictional Torque.
Rob Dwyer-Joyce, Cyrus Parikhaah, Robin Mills, University of Sheffield, Sheffield, United Kingdom

Every engineer's toolbox contains a can of liquid penetrant such as WD40 to release seized nuts and bolts. Penetrants typically consist of a solvent that helps transmit the lubricating additives direct to the seized contact inside the thread. In this work we have developed an ultrasonic method for measuring the rate of penetrant flow into the gaps between the nut and bolt threads. We have been able to deduce interesting aspects of how the fluid flows and how deep it penetrates into the threads. We show how the fluid flows helically down the loose side of the thread and then penetrates radially into the tight side. The surface tension and viscosity are important parameters, and small defects in the thread, and the presence of vapour bubbles effect penetration. In parallel we measured the frictional tightening and loosening torque and relate this to the rate of penetration of the fluid.

3K Courtland

Ceramics & Composites I

Session Chair: A. Dorri Moghadam, University of Wisconsin Milwaukee, Milwaukee, WI
Session Vice Chair: W. Dai, Texas A & M University, College Station, TX

8:00 am - 8:30 am
Lubrication and Drag Reduce of Coiled Tubing in Hole Cleaning
Yanbao Guo, Huaping Xiao, China University of Petroleum, Beijing, China

The requirement for intervention operations in long laterals continues to grow with the development of horizontal and extended reach well. Coiled tubing is commonly used as an intervention tool for treatment delivery in long horizontal wells. Extended reach completion has presented new challenges to the CT industry by pushing the operational limits of current CT capabilities. The primary obstacle associated with extended reach environments is overcoming frictional forces applied to the CT over thousands of meter while still maintaining sufficient weight to perform the intended function at the downhole tools. Friction between well casing and CT are apparent in every CT job. This become a pivotal restriction factor to the CT applied in extended reach environments. In this study, the lubricant and friction properties of water-based well-cleaning fluid were investigated to understand the CT friction and show prospect of lubricant additives in extending the reach of lateral wells.

8:30 am - 9:00 am

Manufacture of Bio-Inspired Surface Texture Gradients Using Laser Processing to Enhance Tribological Performance
Michael Carrillo, Sydney Hale, Mathew Kuttolamadom, Texas A&M University, College Station, TX

The objective of this project is to create snake scale-inspired surface topology features and their gradients on select materials in order to enhance their tribological performance. For this, first, topologies of scaled reptilian skin will be investigated using microscopy and non-contact white-light interferometry to elucidate the core principles that enable its frictional and wear performance. Then, the micron-range features will be imparted onto aluminum steel, titanium, and carbide candidate materials using a combination of micro milling and Ytterbium fiber laser processing in the subtractive manufacturing regime, and selective laser melting (SLM) in the additive regime. A number of surface texture variations will also be created for comparative study. Finally, friction and scratch tests will be conducted to evaluate their tribological performance. Results from this project will help shed light on the design and manufacture of tribologically-robust synthetic surfaces.

9:00 am - 9:30 am
Tribological Performance of Advanced Carbon-Ceramics Composite Materials
M. Cinta Lorenzo Martin, Oyelayo Ajayi, Dileep Singh, Argonne National Laboratory, Lemont, IL

Carbon-carbon (C/C) composite are currently used for tribological applications because of their high mechanical strength, light weight, and high temperature resistance. These properties are further enhanced by adding ceramic materials. The carbon ceramic composites are specially used for severe tribological conditions. This paper presents the results of friction and wear performance evaluations of three carbon-ceramic composite materials under unidirectional and reciprocating sliding contacts using a ball-on-flat contact configuration. Significant differences were observed in the friction and wear mechanisms of the three materials when sliding against silicon nitride and 52100 steel balls under dry conditions. These differences are attributed to differences in the materials microstructures. Transitions in the wear rate with increasing loads are also connected with each material microstructure.

9:30 am - 10:00 am - Ceramics & Composites Business Meeting

10:00 am - 10:30 am - Break

4A Hanover AB

Nanotribology III

Session Chair: P. Egberts, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada
Session Vice Chair:

2:00 pm - 3:00 pm
Full Information Acquisition and Chemical Imaging in Scanning Probe Microscopy: What Happens on the Tip Surface Junction?
Sergei Kalinin, Oak Ridge National Laboratory, Oak Ridge, TN

In 30 years since invention, force-based scanning probe microscopy (SPM) techniques have become the mainstay of nanoscience and nanotechnology. However, despite the wealth of SPM studies, fundamental phenomena at the tip-surface junction remain explored only weakly, as a result of preponderant signal processing routines and lack of chemical specificity. Here, I will introduce the general data acquisition mode (GMode) of SPM, based on full data capture and subsequent information theory and physics based

analysis of the data stream. I will further delineate the applications of *in-situ* SPM – time of flight secondary ion mass spectrometry (ToF SIMS) to map the changes in surface chemistry during tribological and local electrochemical experiments, including ferroelectric switching and pressure-induced resistance changes in oxides.

This research is supported by the Scientific User Facilities Division, BES DOE, and is performed at the Center for Nanophase Materials Sciences at ORNL.

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

4:00 pm - 4:30 pm
Measurements of Thicknesses Dependent Friction on Few-layer MoS_2, WS_2, and WSe_2
Liang Fang, Dameng Liu, The State Key Laboratory of Tribology,Tsinghua University, Beijing, China

The thicknesses dependent friction of two-dimensional materials has been widely studied due to its perspective future in nano-applications. However, traditional FFM measurements are highly influenced by puckering effect on 2D materials, leading to decreasing friction with thicknesses and concealing the intrinsic friction. Using pre-worn tip with circular truncated cone like peak configurations, we suppressed effect of puckering and measured the thicknesses dependent friction on few-layer MoS2, WS2, and WSe2 with FFM. The friction was found to monotonically increase in most cases for all three materials with the only exception that friction on monolayer MoS2 was higher than bilayer. These results correspond to the friction variation trend we calculated by DFT methods, and the little differences between experiments and calculations are attributed to the residual effect of puckering.

4:30 pm - 5:00 pm
Water-Induced Friction Hysteresis on Two Dimensional Films
Philip Egberts, Peng Gong, Lin Yuan, University of Calgary, Calgary, Alberta, Canada

The friction reducing properties of two-dimensional lubricants, such as graphene, boron nitride, and molybdenum disulphide, have shown to have a number of interesting properties, such as a dependence on the number of layers of the lubricant present, an exceptional dependence on the surface adhesion properties of the underlying substrate, and environmental stability. In this experimental work, we explore the friction reducing properties of these two-dimensional films under varying relative humidity of the laboratory air. In particular, the hysteresis in friction observed in load-dependent friction measurements between loading and unloading are correlated with the relative humidity of the environment. Furthermore, it will be shown that the surface energy of the two-dimensional film in the presence of humid air has a significant influence on the degree of hysteresis observed, with respect to the unlubricated substrate.

5:00 pm - 5:30 pm
Humidity and Material Dependence of Nanoscale Friction for 2D Solid Lubricants
Robert Carpick, Kathryn Hasz, Han Ye, University of Pennsylvania, Philadelphia, PA, Zhijiang Ye, Miami University, Oxford, OH, Ganghee Han, A.T. Johnson, University of Pennsylvania, Philadelphia, PA, Ashlie Martini, UC-Merced, Merced, CA

We discuss novel friction effects for nanoscale single asperity contacts on 2D or layered solid lubricants measured with atomic force microscopy (AFM) and compared with molecular dynamics (MD) simulations. We first examine how humidity affects friction between amorphous carbon tips sliding on graphite. AFM and MD results both show a non-monotonic trend of friction vs. humidity, indicating that water plays a stochastic role. We then examine heterogeneous 2D material samples. Samples with both graphene and molybdenum disulfide (MoS_2) regions on a Si substrate were prepared. We found that friction sliding on graphene/Si was lowest, on MoS_2/graphene/Si intermediate, and on MoS_2/Si the highest. MD results show a similar trend. The differences between graphene/Si and MoS_2/Si are explained by the Prandtl-Tomlinson (PT) model. The reduction of friction for MoS_2/Si by inserting a layer of graphene is discussed

in terms of the interfacial bonding between the MoS_2 and graphene.

5:30 pm - 6:00 pm
Lubricity of Gold Nanocrystals on Graphene Measured using Quartz Crystal Microbalance
Masahiro Ishigami, Michael Lodge, Brandon Blue, University of Central Florida, Orlando, FL, Ashlie Martini, University of California, Merced, Merced, CA

In order to test recently predicted ballistic nanofriction (ultra-low drag and enhanced lubricity) of gold nanocrystals on graphite at high surface speeds, we use the quartz microbalance technique to measure the impact of deposition of gold nanocrystals on graphene. We analyze our measurements of changes in frequency and dissipation induced by nanocrystals using a framework developed for friction of adatoms on various surfaces. We find the lubricity of gold nanocrystals on graphene to be even higher than that predicted for the ballistic nanofriction, confirming the enhanced lubricity predicted at high surface speeds. Our complementary molecular dynamics simulations indicate that such high lubricity is due to the interaction strength between gold nanocrystals and graphene being lower than previously assumed for gold nanocrystals and graphite.

4B — Hanover C

Commercial Marketing Forum IV

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

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

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

4:00 pm - 4:30 pm - Sasol North America, Inc.

4:30 pm - 5:00 pm - Chemtura Corporation

5:00 pm - 5:30 pm - Available Slot

5:30 pm - 6:00 pm - Vanderbilt Chemicals, LLC

4C — Hanover D

Metalworking IV

Session Chair:
Session Vice Chair:

2:00 pm - 2:30 pm
Sum-times Added Measures Make all The Difference: A Study of Additives in Mixture Formulation

Emil Schnellbacher, Lockhart Chemical - Additives International, Flint, MI

You are what you measure! To develop effective formulations, one must determine the most important characteristics and then select the best testing methods. This paper how to evaluate, measure, and select the best ingredients for formulations. Potential rust preventives (RP) and metal working fluid additives for will be considered as an illustration. Formulation methods to develop and formulate projects from conception through laboratory testing will be discussed. Once the project design characteristics are determined, ferrous RP additive ingredients will be evaluated and compared in different base fluids. The experiment results will be reviewed, summary comparisons of the additive ingredients will be discussed. This paper has practical applications for formulators and also persons interested in an analytical approach to problem-solving, by exploring the development process of additive ingredients in mixture formulations.

2:30 pm - 3:00 pm
Self Emulsifier Lubricity Booster for Metalworking Fluid
Keihann Yavari, Arthur Coen, Oleon, Compiègne Cedex, France

Biobased MWFs compositions are gaining momentum in the metalworking industry. In that context, Oleon offers a self-emulsifier ester (Self Emulsifier Lubricity Booster) that can be used into a broad range of MWFs to improve performance characteristics. Due to the careful selection of raw materials, we have brought superior technical performances and sustainability together. Our high molecular weight ester combines both polymeric and self-emulsifying chemistries. Its inherent polar structure makes it easy to use in a wide range of formulations giving possibilities to replace traditional additives with a product showing better performances. Indeed, in comparison to existing products, it shows superior emulsion stability as well as low foaming tendency, hydrolytic stability and excellent lubricity that will be presented.

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

4:00 pm - 4:30 pm
Water Soluble *IF*-WS_2 Nanoparticle Base Lubricant for Metalworking Applications
Girija Chaubey, George Diloyan, Nanotech Industrial Solutions, Avenel, NJ

Inorganic fullerene like tungsten disulfide (*IF*-WS_2) nanoparticles are known to be high performing AW/AF/EP additive for lubricant applications. These nanoparticle can be designed to be used in more specific application by tuning several parameters such as particles size and shape, surface chemistry and dispersing media. The nature of interaction between the particles and metal surface play important role in determining the performance of the particles. The current work presents an experimental evaluation of water base IF-WS_2 nanoparticles in cutting, drilling, and metal forming applications. Developed formulation show competition between extreme pressure and lubricity. Extreme pressure as well as anti-wear properties were tested using four ball tester and EP was further confirmed by Falex pin-on-vee block test. Friction coefficient was evaluated using ball-on-disk test. Efficiency of the fluid for metal forming application was further evaluated using Twist compression test.

4:30 pm - 5:00 pm
Coefficients of Friction Between Chip and Cutting Tool in Near-dry Milling Processes
Feng Jiang, NIngchang Wang, Lan Yan, Huaqiao University, Xiamen, China

Cutting fluid is the most common method to control the cutting temperature. However, it is usually harmful to the environment and personal healthy. Near-dry cutting could be an effective substitute of cutting fluid. Most researchers focus on steady friction conditions during different near-dry cutting processes. However, the unsteady friction conditions are popular in the interrupted cutting processes, such as milling process. In this study, coefficients of friction (COFs) of different cooling/lubrication methods, including nature cooling, compressed air cooling, compressed cold air cooling and minimal quantity lubrication (MQL)

cooling, have been estimated by the cutting forces of milling process. Cutting temperature, temperature of coolant carrier, velocity of coolant carrier have great effect on the COFs in the near-dry cutting processes.

5:00 pm - 5:30 pm
Study of Contamination and Performance of Biodegraded Cutting Fluids
Marcília Finzi, Alisson Rocha Machado, Federal University of Uberlandia, Uberlandia, Brazil, Emmanuel O. Ezugwu, Air Force Institute of Technology, Kaduna, Nigeria, Rosineide M. Ribas, Paulo P Gontijo Filho, Federal University of Uberlandia, Uberlandia, Brazil

The metalworking fluids (MWF) due to their lubri-cooling properties reduce tool wear, increase tool life, lower cutting forces, power consumption and improve surface roughness. MWF are highly susceptive to physical, chemical agents and biodegradation, reducing tool life, lowering productivity, harming the machine tool operator and the environment. In the present study the profile of the microbiological contamination (time and origin; biofilm composition; and biome) was raised after samples of in-use water base MWFs were collected in two metal-mechanical sectors. Bacteria recovered from the industries were used to biodeteriorate a fresh MWFs (vegetable and mineral base) and their lubri-cooling performance were studied and compared to the fresh ones. The collected samples showed high level of contamination (10^8 CFU/mL) composed predominantly by Gram-negative bacilli and almost immediate contamination when new samples of MWFs is introduced in the machine tool.

5:30 pm - 6:00 pm
Tribological Properties of Titanium Alloys Under Lubrication of Oil and Aqueous Solutions
Ye Yang, Jianbin Luo, State Key Laboratory of Tribology, Tsinghua University, Beijing, China

The tribological behaviors of titanium–tungsten carbide and aluminum–tungsten carbide friction pairs lubricated by oil or aqueous lubricants are investigated using universal tribotester. Titanium is more difficult to be lubricated than aluminum. The results show that self-emulsifying ester (SEE), either oil phase or aqueous solution, has good friction reduction performance on titanium alloys while the commonly used paraffin and PAO fail to lubricate the system. Furthermore, it demonstrates that SEE aqueous solution with 1wt% concentration presents better anti-wear property than the oil phase for titanium alloys. SEE water solution can decrease the adhesive wear and abrasive wear greatly. The high polarity of molecules and good thermal conductivity of the aqueous solution lead to the excellent lubricating and anti-wear properties for titanium alloys.

6:00 pm - 6:30 pm - MWF Business Meeting

4D — Hanover E

Materials Tribology IV

Session Chair: J. Curry, Mechanical Engineering & Mechanics, Lehigh University, Bethlehem, PA
Session Vice Chair: T. Scharf, Materials Science and Engineering, The University of North Texas, Denton, TX

2:00 pm - 2:30 pm
Sliding Speed Dependent Tribochemical Wear of Single Crystal Silicon in Humid Air and in Water
Lei Chen, Tribology Research Insititute, Chengdu, China, Seong Kim, Department of Chemical Engineering and Materials Research Institute, Univeristy Park, PA, Linmao Qian, Tribology Research Insititute, Chengdu, China

Tribochemical reaction is a complex process which is very susceptible to many extrinsic factors, such as environments, interface chemical activity and experimental parameters. Here, we introduce the effect of

water and sliding speed on tribochemical wear of single crystalline silicon (Si) at nanoscale. When contact pressure is too low to induce Si yield, material removal only occurs at the atmosphere with water molecules and its volume increased dynamically with relative humidity or decreases logarithmically to constant as sliding speed increased both in humid air and in water. Transmission electron microscope observations show that the removal of Si substrate at the given speed conditions are consistent with the tribochemical wear. We explain the results with a model where the dynamics of rupture and reformation of interfacial bonding bridges results in the variation of tribochemical wear of Si with sliding speed.

2:30 pm - 3:00 pm
Tribochemistry of GaN
Guosong Zeng, Lehigh University, Bethlehem, PA, Xiaofang Yang, Princeton University, Princeton, NJ, Damir Borovac, Lehigh University, Bethlehem, PA, Chee-Keong Tan, Clarkson University, Potsdam, NY, Bruce Koel, Princeton University, Princeton, NJ, Nelson Tansu, Brandon Krick, Lehigh University, Bethlehem, PA

Surface chemistry of GaN has been studied for decades. Understanding GaN's surface chemistry will help in surface cleaning/preparation, reducing luminescence and polarization effects, etc., to obtain better performance of GaN-based devices. However, most of these studies are based on static chemical/physical reactions. By applying tribological test on GaN coating, we can look into the surface chemistry of GaN responding to external load under different environments. Several state-of-the-art characterization techniques, including XPS, TEM, SEM, etc., have been employed to analyze the surface after wear testing. DFT has also been applied here to find out the possible materials forming during the wear test, as well as to understand the stress effect on tribochemical reaction. This study focuses on how sliding interactions affects surface chemistry of GaN semiconductors. Specifically, the comparison of surface chemistry modification on the unworn and worn surfaces will be presented.

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

4:00 pm - 4:30 pm
Nanoscale Tribocatalytic Reaction Driven Superlubricity at Macroscale
Anirudha Sumant, Diana Berman, Badri Narayanan, Subramanian Sankaranarayanan, Mathew Cherkara, Alexander Zinovev, Ali Erdemir, Argonne National Laboratory, Argonne, IL

In this study, we observe an interesting phenomenon of generating a solid lubricant *in-situ* at the tribological interface during sliding leading to superlubricity at macroscale in dry environment. We demonstrate that two dimensional (2D) layered materials such as molybdenum disulfide (MoS_2) and boron nitride (BN) are capable of demonstrating superlubricity (friction coefficient: 0.005) through unique tribocatalytic reaction with carbon leading to *in-situ* formation of onion-like carbon (OLC) directly at the tribological interface. Our initial experimental and theoretical investigations suggest that formation of OLCs is possible through tribocatalytic reaction facilitated by these 2D materials at the tribological contact due to the high contact pressure. These OLCs behaves in a similar way described earlier in our previous studies(Science,348, 6239, 1118 (2015) providing reduced contact area and incommensurability with respect to the sliding DLC surface leading to superlubricity.

4:30 pm - 5:00 pm
Effective Solid Lubrication via In-situ Formation Of Ws_2 Tribofilms
Vladimir Totolin, Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria

We propose an innovative in-situ method for generating tungsten disulphide (WS_2) tribofilms at the sliding interface. The WS_2 tribofilms formed via a tribochemical reaction between tungsten carbide particles embedded in a steel surface and an extreme pressure lubricant additive, and led to extremely low friction and negligible wear. This outstanding tribological performance was achieved at relative humidities of up to 70 %, thus showing that this novel approach is more effective than conventional transition metal

dichalcogenide films prepared by magnetron sputtering. The presence of the WS_2 tribofilms was confirmed by XPS and TEM and their tribochemistry was discussed. The friction behaviour was influenced by the rate of WS_2 tribofilms formation, EP additive concentration and normal load applied. The results showed that low-friction tribofilms can be prepared by a fast, cost-effective and robust process that has the potential to be used in several future engineering applications.

5:00 pm - 5:30 pm
Effects of Microstructure and Environment on the Run-In of MoS_2
John Curry, Lehigh University, Bethlehem, PA, Tomas Babuska, Nicolas Argibay, Michael Chandross, Sandia National Laboratories, Albuquerque, NM, Brandon Krick, Lehigh University, Bethlehem, PA

Run-in performance of MoS_2 typically exhibits high initial friction and wear, especially in environments containing water and oxygen. Recent studies have shown that highly basally oriented MoS_2 coatings exhibit lower initial friction than sputtered coatings in dry and humid environments, with sputtered MoS_2 exhibiting nearly twice the initial friction coefficient as compared to dry conditions. These results suggest that water does not poison friction behavior of established films of highly oriented MoS_2, but it does poison the ability to form long range order and sintering of crystallites. The present study builds upon these previous findings in order to develop a better mechanistic understanding of the run-in processes for pure MoS_2 coatings. Spiral orbit tribological experiments were carried out to in dry and humid nitrogen environments to assess the effect of prolonged sliding on purely amorphous MoS_2 with and without formation of a transfer film, as well as oriented, sprayed films.

5:30 pm - 6:00 pm
Self-Adaptive Friction Behavior and Thermal Stability of $MoS_2/Sb_2O_3/C$ Coatings
Thomas Scharf, Tyler Torgerson, The University of North Texas, Denton, TX, Andras Korenyi-Both, Tribologix, Inc., Golden, CO

$MoS_2/Sb_2O_3/C$ is a composite coating used as a solid lubricant in satellites due to its self-adaptive properties. The coating's self-adaptive sliding friction behavior during thermal cycling to elevated temperatures is currently unknown. Thus, the friction behavior was tested in ambient air from room temperature (RT) to 350°C. Lowering of friction coefficients (μ) from ~0.1 to ~0.01 occurred as the temperature increased from RT to 200°C, respectively, due to water desorption from the coating, while μ increased back to ~0.1 at RT. Thermal cycling to 300°C resulted in the formation of some MoO_3 in the wear track leading to higher μ of ~0.1 but low friction was recovered with decreasing temperature. Thus, the coating exhibits self-adaptive friction behavior to 300°C. However, cycling to 350°C resulted in increased amounts of MoO_3 in the wear track with $\mu > 0.3$ and low friction did not return with decreasing temperatures.

6:00 pm - 6:30 pm - Materials Tribology Business Meeting

4E — Hanover F

Surface Engineering II

Session Chair: Z. Khan, Faculty of Science & Technology, Bournemouth University, Bournemouth, United Kingdom
Session Vice Chair: M. Nazir, Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom

2:00 pm - 2:30 pm
Mechano-chemical Surface Modification With Cu_2S: Inducing Superior Lubricity
Michael Varenberg, Georgia Institute of Technology, Atlanta, GA, Grigory Ryk, Alexander Yakhnis, Yuri

Kligerman, Technion - Israel Institute of Technology, Haifa, Israel, Neha Kondekar, Matthew McDowell, Georgia Institute of Technology, Atlanta, GA

Advances towards low-friction surfaces are in growing demand from many economic sectors for energy efficiency and environmental safety. However, the traditional approach of multi-grade oil formulation is limited by its inability to induce pollution-free generation of uniform oil-retaining films needed to improve surface lubricity. Here, a direct route to the formation of a surface layer of superior lubricity is presented as an alternative to the use of oil additives for friction reduction. The deformation-induced generation of a surface film consisting of low-shear-strength oil-retaining compounds is obtained via supplying chemically beneficial elements during a widely used surface-finishing mechanical treatment. An ultra-low friction coefficient of about 0.01 is obtained with base oil lubrication after tailoring the surface chemistry by shot peening using a mixture of Cu_2S and Al_2O_3; this result opens new horizons for surface engineering.

2:30 pm - 3:00 pm
Elastic-Plastic Axisymmetric Sinusoidal Surface Asperity Contact
Swarna Saha, Robert Jackson, Auburn University, Auburn, AL

Closed-form finite-element empirical solutions are available for elastic-plastic spherical and sinusoidal contact. However some of these models do not consider the effect of interaction with adjacent asperities or require extensive numerical resources because they employ a full 3-D model. The present work has considered these factors during modeling. The current finite element model (FEM) represents an axisymmetric elastic-plastic sinusoidal surface in contact with a rigid flat for a wide range of material properties and different values of the amplitude to wavelength ratio. Empirical equations are derived for the critical pressure and contact area at which two surface will reach complete contact. An equation for the critical value of the amplitude of the sinusoidal asperity below which it will deform completely elastically from initial to complete contact is also established. The results are applicable for almost all kinds of metallic materials.

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

4:00 pm - 4:30 pm
Experimental Research on Transient Behavior of Cavitation Bubbles and Cavitation Pressure in Textured Thrust Bearings
Linqing Bai, Yonggang Meng, Tsinghua University, Beijing, China, Varian Zhang, Shell (Shanghai) Technology Ltd., Shanghai, China

Cavitation is recognized as an important phenomenon in liquid hydrodynamic lubrication, which causes lubricant film rupture and affects tribology performance of mechanical devices significantly. The transient behavior of cavitation phenomenon in textured thrust bearings with oil lubricant were experimentally investigated. During experiments, the cavitation phenomenon in different surface textures was observed directly with a high-speed camera. It is shown that cavitation shape and area change according to texture patterns. The bubbles within cavitation zones increase with running time in the beginning, and gradually reach to a steady state, meaning that a transient period is needed to get equilibrium. Then, the cavitation pressure in textures was measured under different operation conditions. The relationships between the cavitation pressure and geometrical parameters, rotational speed and lubricating oil viscosity were also investigated.

4:30 pm - 4:30 pm
In-depth Studies of the I*n-Operando* Formation of Amorphous Carbon Tribofilms at Lubricated Interfaces
Giovanni Ramirez, Osman Eryilmaz, Argonne National Laboratory, Argonne, IL, Badri Narayanan, Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL, Yifeng Liao, Argonne National Laboratory, Argonne, IL, Ganesh Kamath, Subramanian Sankaranarayanan, Center for Nanoscale

Materials, Argonne National Laboratory, Argonne, IL, Ali Erdemir, Argonne National Laboratory, Argonne, IL

Aiming to improve the durability of the components in mechanical systems, we have been developing a new generation of catalytically active nanocomposite coatings that can interact very well with the unformulated lubricants, opening up new possibilities for the replacement of traditional antiwear additives. In this presentation, we focus on this coating concept, that when rubbed in the presence of base oils, can extract amorphous carbon tribofilms from the oil molecules. Here, we explain the mechanisms involved in the scission of the hydrocarbon molecules and how they recombine to form a protective solid tribofilm with similarities to DLC. To study the tribofilms, we analyzed them using Raman, TOF-SIMS and TEM. In an attempt to fully understand the tribocatalysis process and to prove our theory, we used computational simulations.

4:30 pm - 5:00 pm
Tribological Studies of Lubricated ECM-Textured Point Contacts in Rolling
Glenn Gyimah, Zhongning Guo, Guangdong University of Technology, Guangzhou, Guangdong, China, Ping Huang, South China University of Technology, Guangzhou, Guangdong, China, Shuzhen Jiang, Guangdong University of Technology, Guangzhou, Guangdong, China, Gary Barber, Oakland University, Rochester, MI

In this study, research was carried out on the friction and wear behavior of concentrated point contacts between a ball and a plate. In particular, the tribological performance of lapped GCr 15 bearing balls and lapped/electrochemical machined (ECM)-textured flat bearing materials which were produced under different heat treatment conditions was studied. The topographical features of these ECM textures were characterized by both optical and scanning electron microscopy and studied in the fully-flooded EHL lubrication regime under pure rolling conditions. Three electrochemical micro-textured surfaces were compared with three non-textured surfaces. The experimental results showed that the geometry (textured, untextured) and the densities of the micro-texture played an important role in the tribological behavior when run against the lapped GCr 15 steel bearing balls. Significantly lower friction and wear was observed for the textured surfaces as compared to the untextured surfaces.

5:00 pm - 5:30 pm - Surface Engineering Business Meeting

4F Hanover G

Fluid Film Bearings IV

Session Chair: M. Fillon, Instut Pprime, Futuroscope, France
Session Vice Chair: M. Braun, University of Akron, Akron, OH

2:00 pm - 2:30 pm
Case Study on Resolving Oil Whirl Issues on Gas Compressor
John Yu, GE Oil & Gas Digital Solutions, Atlanta, GA, Sergey Drygin, Nicolas Peton, Pisut Lertsongkram, General Electric, Moscow, Russian Federation

This case is a site vibration issue on a Gas compressor module. The Machinery Diagnostics Engineer was requested on site to collect startup and steady state data Gas compressor. When machine was running at partial load condition, vibration at compressor DE and NDE suddenly increased and tripped the machine. The dominant of extremely high vibration level – 346 um pp, higher than nominal bearing clearances was subsynchronous (0.37X component forward precession). Significant shaft centerline thermal influence was detected. Oil Whirl condition was diagnosed for Compressor DE bearing [1, 2]. Bearing and seals, piping support inspection and alignment check were recommended. Even after proper unit alignment the subsynchronous component wasn't decreased significantly. L/D (Length/Diameter)

bearing ratio was decreased by pads machining from both sides. Future tests after bearings modification confirmed Oil Whirl condition absence and normal unit operation at different load condition.

2:30 pm - 3:00 pm

Investigation of the Effect of a Non-Isothermal Flow of the Non-Newtonian Fluid in a Thin Layer on the Dynamics of a Flexible Rotor of the Turbo-Machinery

Elena Zadorozhnaya, Igor Levanov, Nadezhda Khozeniuk, Vlad Khudyakov, South Ural State University , Chelyabinsk, Russian Federation

Modern lubricants have non-Newtonian properties. Mathematical models that account for these properties in the calculation of rotor dynamics, presented in the report. At the same time, the thermal state of each multilayer bearing should be taken into account. Solution of non-isothermal fluid flow problem in a thin layer is made. The turbo-machine rotor is flexible and asymmetric. Estimated rotor model represents the five of the masses, which are connected by elastic rods. Trajectory of moving elements, the elastic rotor line and hydro-mechanical bearing characteristics are provided as the calculation results.

3:00 pm - 3:30 pm - Available Slot

3:30 pm - 4:30 pm - Exhibitor Appreciation Break

4:30 pm - 5:00 pm

Study on the Dynamics and Tribology Coupling Modeling of Three-screw Pump

Shuaiyu Zhou, Xiqun Lu, Hanfeng Lu, Wanyou Li, Harbin Engineering University, Harbin, Heilongjiang, China

Abstract: Due to the working theory of the three-screw pump, there is a close coupling relationship between movement rules and tribological problems of central screw and idle screws. In this study, based on the theory of hydrodynamic lubrication, the dynamics and tribology coupling modeling of central screw and idle screws of three-screw pump is established in the working process, so as to analyze the regular rule of oil film thickness, and load distribute at the contact area between central screw and idle screws. During the study, the effects of geometry parameters (e.g. central angle , the swing angle and screw size tolerance) on the screws lubrication property was successfully explored. It can provide the prediction of the screw movement regular using the mechanical analysis method established in this study.

5:00 pm - 5:30 pm

Dynamic Modeling of Floating Valve Plate Motion in an Axial Piston Pump

David Richardson, Farshid Sadeghi, Purdue University, West Lafayette, IN

The purpose of this investigation was to model and predict the motion of the floating valve plate in an axial piston pump and compare results with experimentally measured motion. The balance pistons which support the valve plate were assumed to act as spring dashpot systems and their appropriate stiffness and damping coefficients were determined using impact tests. The dynamic equations were paired with a time dependent lubrication model to predict the valve plate motion. The floating valve plate motion was measured through the use of three proximity probes mounted in the pump housing. Comparing both the analytic and experimental results a large deviation was noticed. The stiffness and damping coefficients were then increased so that the analytic results matched closely with the experiments at most extreme operating condition. The adjusted values for the stiffness and damping coefficients resulted in a good correlation between analytics and experiments across all operating conditions.

5:30 pm - 6:00 pm

An Explicit Scheme for Large Models of Elastohydrodynamic Lubrication in Journal Bearings

Hiroki Fukagawa, Kazuyuki Yagi, Kyushu University, Fukuoka, Japan

The lubricant film in a journal bearing has to be thicker than the length of the asperities to protect the surfaces of the structural elements. The high pressure in the lubricant film causes deformation of the structural elements. This deformation, in turn, changes the boundary conditions of the lubricant film. Dynamic analysis of large-scale models is essential to lead to a better understanding of the system behavior, and to develop reliable bearings. In this study, we develop a parallel numerical methodology by employing explicit method. We solve the Navier-Stokes equations for the lubricant film and viscoelastic equations like the equations for the structural elements. Our approach has advantages in large-scale analysis, because the explicit method is a high degree of parallelism and effectively exploits the many-core architectures, such as Xeon Phis and GPUs.

6:00 pm - 6:30 pm - Fluid Film Bearings Business Meeting

4G Regency V

Lubrication Fundamentals II - Additives and Additive Degradation

Session Chair: P. Shiller, The University of Akron, Akron, OH
Session Vice Chair: M. Patel, Vanderbilt Chemicals, LLC, Norwalk, CT

2:00 pm - 2:30 pm
Wear From Biodiesel Oil-Dilution on IC-Engine Materials: A Preliminary Tribometer Study on the Effects of Biodiesel Components
Gustavo Molina, Valentin Soloiu, Emeka Onyejizu, Md Alam, Georgia Southern University, Statesboro, GA

Use of biodiesels in internal combustion engines leads to oil dilution because unburned biodiesel is being scrapped to the engine oil pan, and its lower volatility and early aging (as compared to those of mineral diesel fuel) can enhance degradation of oil lubricity. The authors conducted research in a pin-on-disk tribometer showing that oil dilution (of SAE 15W40 mineral oil contaminated by known percentages of the biodiesels from canola-, peanut-, soybean-, chicken-fat-, and cotton-seed-oil) can significantly reduce wear-protection. But wear-outcomes substantially varied between different biodiesels under same testing conditions. Current research is presented on fatty-oil breakdown of the original oils (and corresponding composition of the biodiesel methyl-esters) as a likely factor for the observed differences between biodiesels, because of possible interactions of methyl-esters with mineral-oil components, and recommendations are made for future research.

2:30 pm - 3:00 pm
Impact of Renewable Group III+ Base Oil on the Energy Efficiency and Drain Interval of Industrial Gear Oil
Jeffrey Guevremont, American Refining Group, Bradford, PA, Paula Vettel, Hyeok Hahn, Novvi LLC, Emeryville, CA

Constant advancement of gear design imposes increased thermal and mechanical stresses on the lubricant. Renewable Group III+ base oils manufactured from naturally engineered farnesene provide pure synthetic hydrocarbons with well controlled molecular architecture, and these oils are well suited to handle these stresses. These tailored molecules have the potential to improve both energy efficiency and drain intervals. They can also be used where environmentally acceptable lubricants (EAL) are needed. A tribological examination and oxidative stability study of the base oils and fully formulated gear oils will be presented and discussed.

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

4:00 pm - 4:30 pm
Tackifiers for High Temperature Lubricants
Daniel Vargo, Erik Willett, Functional Products Inc., Macedonia, OH

Tackifiers are solutions of high molecular weight polymers in oil, typically polyisobutylene dissolved in petroleum oil. Molecular weights can range from 1 million to 6 million. A consequence of high molecular weight is poor shear stability either mechanically or thermally induced. Conventional tackifiers based on polyisobutylene are not thermally stable and tackiness and viscosity are lost at temperatures typically above 90°C. An increasingly important performance requirement for modern lubricants, however, is better thermal stability and lubricant formulators are turning to API Group III and IV base oils. A comparison of the high temperature performance of these polymers in Group I-II oils with the high temperature performance in Group III-IV oils (which are themselves much more thermally stable than Group I-II oils) show that degradation of the polymer can be slowed in a group III-IV oil.

4:30 pm - 5:00 pm
Thermal Oxidation Characteristic of Ester Oils Based on Raman Spectroscopy
Bingxue Cheng, Dan Jia, Haitao Duan, Yongliang Jin, Jian Li, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China

In this work, based on the continuous heating measure method by DXR laser microscopic Raman spectrometer, it studied that under online heating condition how to influence the Raman feature peaks of ester base oils, such as trimethylolpropane trioleate (TMPTO), tridecyl trimellitate (TDTM) and dioctyl adipate (DOA). The characteristics of ester oil molecular structure under different temperatures were discussed. The results show that some Raman shifts and Raman intensity of ester oils have obviously changed with the increase of heating temperature. The C-H stretching vibration peak of methyl and methylene and the shear vibration peak of methylene of ester oils are very sensitive to temperature. And the Raman intensity of =C-H and C=C of TMPTO ester oil cannot recover after cooling. Under the isothermal condition, the Raman intensity of TDTM and DOA have no obvious changes, and the Raman intensity of =C-H, C=C and -CH_2- of TMPTO decreases with the increase of oxidation time.

5:00 pm - 5:30 pm
Lubricant Additive Effects on Optically-Detected Particle Counts
Ashlie Martini, University of California Merced, Merced, CA, Scott Deskin, Chevron Lubricants, Richmond, CA, Jack Zakarian, JAZTech Consulting, Richmond, CA

Oil cleanliness is often measured using an optical particle counter, which provides information about the number and size distribution of particulates. However, some commonly-used lubricant additives can be detected by particle counters and so falsely indicate the presence of contaminants. Here, we study the effect of additives, including a detergent-inhibitor package, viscosity index improver and foam inhibitor on optically detected particle counts. A custom-built test rig enables circulation of the fluids, particle counts as well as filtration. Filtration can decrease particle counts, but may adversely affect the performance of some additives. The effects of filtration on both optically-detected particle counts and additive performance are quantified.

5:30 pm - 6:30 pm - Lubrication Fundamentals Business Meeting

4H — Regency VII

Grease I

Session Chair: W. Tuszynski, Unami Group, Quakertown, PA
Session Vice Chair: K. Mistry, Timken Co., Canton, OH

2:00 pm - 2:30 pm
A New Polyurea Thickener for Grease
Zhe Jia, John Cuthbert, Nathan Wilmot, Yifeng Liao, Dow Chemical, Freeport, TX

Polyurea grease consists of a three-dimensional network incorporating a lubricating base oil, a thickener formed *in situ* between isocyanates and amines, and a variety of additives to provide additional benefits. The featuring urea functional groups will generate sufficient hydrogen bonding to hold base stock for lubricating purpose. In this work, we proposed to develop a pre-formed hybrid polyurea thickener, with carefully designed chemical structure that allows the thickening agent to be compatible with the base oil at elevated temperatures and shearing conditions. The resulted product exhibits minimized handling complexity of toxic raw materials and inherent polyurea grease properties, including unique high temperature capabilities, enhanced shear stability and anti-oxidative characteristics. This hybrid thickener, offering improved lubrication properties and EH&S and handling benefits for grease manufacturers, would be a promising alternative for conventional polyurea grease.

2:30 pm - 3:00 pm
On the Impact of Water on Grease Lubrication in Rolling Bearings
Piet Lugt, SKF Engineering and Research Centre, Nieuwegein, Netherlands, Febin Cyriac, Rob Bosman, University of Twente, Enschede, Netherlands

Grease lubricated bearings are usually running in starved lubrication conditions. The supply of lubricant to the contacts happens from reservoirs of relatively stiff grease from where oil bleed takes place. Both the reservoir and oil bleed are affected by possible water contamination. This will be illustrated by means of yield stress measurements and film thickness measurements using different greases with various thickener and base oil types. It will be shown that most greases can take up much water and that the greases usually soften in the presence of water greases. The fully flooded film thickness is not affected by water. However, in the case of starvation water is shown to have clear impact on the film thickness. This will be shown both in single contact measurements and in full bearing film thickness measurements.

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

4:00 pm - 4:30 pm
Zero Leakage Grease for Speed Reduced Gear of Robots
Akihiro Shishikura, Idemitsu Kosan Co., Ltd., Ichihara, Chiba, Japan, Fumihiko Kusuyama, Idemitsu Kosan, Co., Ltd., Chiyoda-Ku, Tokyo, Japan

The most serious issue in industrial robots is a leakage of grease from reducers of robot arm. Therefore, “zero leakage grease” is strongly required from robot users. In order to develop “zero leakage grease”, the effects of grease structure (thickener shape) and shear stability were studied. In cases of planetary differential gear (RV gear) and strain wave generator (Harmonic Drive), grease was softened by high shear, and was pressed out from the reducer of robot by pumping action of rubber packing. The amount of grease leakage was depended on the fiber shape and the mixing ratio of Li complex grease which has high shear stability. New hybrid grease, which was optimized grease structure (thickener fiber shape) by mixing Li soap and Li complex grease, can be reduced leakage to 1/100 compared with conventional grease. Also torque transmission efficiency was increased over 5% compared with the conventional grease.

4:30 pm - 5:00 pm
The Effect of Water Ingress on Environmentally Adapted Greases.

Johanna Larsson, Roland Ardai, Johan Leckner, Axel Christiernsson International AB, Nol, Sweden

Environmentally adapted greases are coming into contact with water in most applications where they are used. Even when they are contaminated with water these greases are to provide lubrication, protect the lubricated surfaces, keep contaminants out while maintaining their rheological properties. In addition, at the end of life they need to decompose without any, or at least minimal, disturbance of the surrounding environment. In this paper we present a technical comparison of grease formulations suitable for example in marine, forestry, railway and agricultural applications. The main focus is on how different oil and thickener combinations respond to water ingress and how this affects their performance as lubricants at both normal operating conditions and at low temperatures.

5:00 pm - 5:30 pm
Assessment of Greases for Subsurface Rock Bit Bearing and Seal System with Improved Reliability
Mikey Benes, John Bomidi, Christopher Lane, Baker Hughes, The Woodlands, TX

Performance of bearing and seal assembly (BSA) directly impacts reliability of subsurface roller cone and hybrid drill bits. The cone motion is supported by a coupled radial/thrust fluid film bearing and is protected from the drilling environment by a mechanical seal; and this BSA operates in mixed or boundary lubrication regime. Lubricating grease, therefore, plays a pivotal role and is a candidate for potential enhancement in the tribological system. Greases with mineral and synthetic base oils were compared using industry standard and custom configured lab tests to understand their performance. Bit reliability in field tests was recorded, the bearing and seal surfaces were measured for wear and grease was analyzed for wear contaminants. Here, we present results of the tests and discuss the improvement in bit reliability with synthetic base oil grease.

4I The Learning Center (TLC)

Engine & Drivetrain Special Session I

Session Chair: K. Sinha, Chevron Oronite Co. LLC, Bellaire, TX
Session Vice Chair: M. Plumley, US Coast Guard Academy, New London, CT

2:00 pm - 3:00 pm
Growing Complexity and Globalization of Automotive Engine Oil Industry Standards/Specifications
Michael Plumley, US Coast Guard Academy, New London, CT

As we sit at the cross-roads of GF-6, dexos1, PC-11, ACEA developments in North America, Europe, growth of automotive engine oils in Asia the goal of this session is to provide a snapshot of the global trends in the automotive engine lubricants and associated complexity. This forum will provide key learnings from the advancements during the last couple of decades, a peek into the future challenges and the ability to get a perspective from industry leaders instrumental in shaping the future.This session will consist of 20 minute presentations from our invited speakers.

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

4:00 pm - 5:00 pm
Growing Complexity and Globalization of Automotive Engine Oil Industry Standards/Specifications (Continued)

5:00 pm - 5:30 pm - Engine & Drive Train Business Meeting

4J Dunwoody

Tribotesting IV

Session Chair: J. Xiao, Rtec-Instruments Inc., San Jose, CA
Session Vice Chair:

2:00 pm - 2:30 pm
Investigation of Hard Coating Roughness Modification And Impact on Coating Abrasiveness Sliding Against 52100 Steel
Gordon Krauss, Harvey Mudd College, Claremont, CA, Gary Doll, University of Akron, Akron, OH, Matthew Siniawski, Loyola Marymount University, Los Angeles, CA, Joseph Sinopoli, Andrea Vasquez, Harvey Mudd College, Claremont, CA

This work examines an inexpensive method of modifying the surface roughness of hard coatings such as Diamond Like Carbon and Boron Carbide. Previous research shows a linear decrease in coating abrasiveness is observed on a log scale plot as a function of the number of cycles tested. The decrease in abrasiveness is not solely due to the increasing nominal contact area between the polished ball and coating. The roughness of the coating changes as a function of the number of cycles as its abrasiveness decreases. Similarly, the roughness of the counter-surface (ball) changes with increasing cycles. The ability to control initial abrasiveness is explored through the use of laser ablation. This inexpensive method is shown in this work to change the initial abrasiveness of the coatings, indicating a potentially useful tool for controlling material removal and counter-surface polishing when using hard coatings.

2:30 pm - 3:00 pm
Thermal Behavior and Cooling Conditions of Wet Multi-plate Clutches in Modern Applications
Katharina Voelkel, Hermann Pflaum, Karsten Stahl, Technical University of Munich, Munich, Bavaria, Germany

Wet multi-plate clutches are important components in many applications, e.g. power shift transmissions, and industrial use. Functional behavior and durability mainly depend on the thermal conditions of the clutch.Thermal behavior and especially cooling conditions of wet multi-plate clutches depend on many and often very complex influencing parameters: not only design and lubrication but also the operating condition and the groove design with typical oil flow capacity and heat transfer show effects on the thermal conditions in the clutch. These data is important input parameters of the thermal simulation of wet multi-plate clutches. Lecture and paper will give an overview of influence parameters on thermal behavior and cooling conditions of wet multi-plate clutches. These parameters have been investigated in experiments and validated in comparison of temperature measurement and simulation. Descriptions will be linked to practice-relevant examples.

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

4:00 pm - 4:30 pm
The Tribological Characterization of Kerosene for Flight Applications
Greg Hansen, Peter Lee, Southwest Research Institute, San Antonio, TX, Matthew Billingsley, USAF, Edwards AFB, CA

The research drivers were lifecycle requirements for flight applications coupled with more highly refined fluids low in recognized lubricity-enhancing compounds. The aim was to measure fluid friction at relevant

interfacial conditions and the ability of the fluids to prevent wear. Lubricity was measured using two HFRR designs: the PCS Instruments and a custom rig developed at SwRI for high pressure testing of volatile fluids, allowing both ball-on-flat and line-on-flat contacts. Wear measurements were taken of both the pin/ball and the plate using 3D white light interferometry. For the frictional characterization custom test parts were machined for compatibility. In order to achieve the entrainment velocities required, two test rigs were required: the PCS Instruments MTM for lower speed and slide roll ratio, and the Bruker UMT-3 with pin-on-disk module for the higher speeds.

4:30 pm - 5:00 pm
Investigation Comparing Gas-phase Synthesized Graphene to Graphene Platelets for Effectiveness as a Lubricant Additive
Gordon Krauss, Albert Dato, Harvey Mudd College, Claremont, CA, Matthew Siniawski, Loyola Marymount University, Los Angeles, CA, Andrea Vasquez, Joseph Sinopoli, Harvey Mudd College, Claremont, CA

Low concentrations of suspended graphene additives (.01 and .1 % by mass) are investigated as friction and wear modifiers in this study. This work investigates and compares gas-phase synthesized graphene to commercially available graphene platelets suspended in rapeseed oil during pin-on-disk testing. Previous studies have found a benefit to processing of flat graphene such that it is morphologically changed into a “crumpled” shape. Gas-phase synthesized graphene is crumpled as a result of the gas synthesis process. As a result, GSG consists of folded and randomly oriented graphene structures. The wear and sliding friction of a 52100 steel ball counter-surface is measured during testing in neat rapeseed oil, in low concentrations (.01% wt.) and higher concentrations (.1% wt.). While significant difference is noted with respect to wear at even the low concentrations, friction differences are not apparent over the conditions tested.

5:00 pm - 5:30 pm
Enhanced Analysis of Benchtop Friction and Wear Measurements
Robert Erck, Nicholaos Demas, George Fenske, Argonne National Laboratory, Argonne, IL

Benchtop tests are widely used for tribological investigations. However, often the testing and characterization regimens do not take advantage of all of the information that is present. Much information can be obtained from data which assist in understanding tribological phenomena. This presentation will touch upon such topics as correct material loss measurement using white-light interferometry, freeze-frame video motion to understand scuffing and wear tests, observation of tribochemical films using conventional microscopy, methods to process friction data to extract detailed friction coefficient, potentiostatic measurements, and a look at summit parameters for use in Greenwood-Tripp contact friction models.

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

4K Courtland

Condition Monitoring I

Session Chair: K. Rogers, Pilot Thomas Logistics, N. Las Vegas, NV
Session Vice Chair: J. Mehta, Fluitec International, Jersey City, NJ

2:00 pm - 2:30 pm
Basic Oil Analysis
Michael Holloway, ALS Tribology, Highland Village, TX

Every piece of equipment has a heartbeat, blood stream, temperature and so on. Understanding the overall health and well-being of your equipment can improve your profitability and provide a competitive edge. There are various diagnostic tools and techniques that can be used that will provide a better understanding of the health state of your equipment and also provide insight into the longevity. Oil analysis is one method being used by forward thinking companies that are focused on getting the most out of their equipment. This seminar explains the latest tools and techniques used for oil analysis. Weather you looking to extend oil change intervals or to use oil analysis for diagnostics, the practice will help to drive down costs. Those considering professional certification in lubrication and reliability will want to use this course as a starting point.

2:30 pm - 3:00 pm
Business Case for Routine Fresh Oil Analysis
Nnamdi Achebe, Petrosave Integrated Services Ltd., Amuwo-Odofin, Lagos, Nigeria

Most operators think fresh oil testing is needless.Underlisted Nigeria case-studies show otherwise: #1Paper Mills operators observed sluggish Hydraulic Press plunger and ram movement after lube service. Fresh oil analysis detected wrong oil in use and saved the >$250K Hydraulic Unit from catastrophic failure. #2 Metal Can manufacturer contracted by major brewery companies escaped costly engine repairs, downtime & contract penalties. Gas Engines trend analysis, showed rapidly degrading oil. Fresh oil analysis investigation revealed properties appreciably different from OEM approved. #3 Leading Cement Plant, powered by 4 aero derivative Gas Turbines was saved from being short-changed in fresh oil stock replenishment. Spike increases in measured Copper levels after make-up with new oil, triggered controversies with Operators. Re-establishing fresh oil analysis baseline revealed new oil as source of abnormal Copper, thus prevented forced shutdown due to accelerated bearing wears concerns.

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

4:00 pm - 4:30 pm
Dealing With Sampling Errors
Mohamad Sabzi, Ravan Net Pars, Tehran, Tehran, Iran (the Islamic Republic of)

Taking samples is an important task in each oil analysis program. Samples provide the required feed for laboratory and CBM analysts to explore what is running inside the equipment. In recent years automated sampling methods have been introduced for different applications to improve sample quality. Sampling whether by hand or automated always is exposed to errors. For example, when two persons take samples from the same point, how can the sufficient accuracy be assured. To address the mentioned and similar issues, some help from statistical tools are needed. One of best tools in this way is DoE (Design of Experiments). DoE is a systematic method to determine the relationship between factors affecting a process and the output of that process in a quantative way. This article primarily discuss about sampling process and types of errors and variations may included, then DoE method is addressed and finally practical application is dealt aiding a structured procedure and some examples.

4:30 pm - 5:00 pm
Friction and wear properties of WJ2 sliding bearing material in artificial degradated oil
Tomomi Honda, Yusuke Mochida, Eiki Kitahara, University of Fukui, Fukui, Fukui, Japan, Yumiko Nakamura, Chikako Takatoh, EBARA Corporation, Fujisawa, Kanagawa, Japan

In tribology field, the main subject is systematizing the wear theory. To solve this subject, it is necessary to know how the wear modes occur in various conditions. Therefore, we focused on lubricating oil degradation, and investigated the relationship between degradation progress and lubricated wear mode. In this study, we prepared sample oils which were degraded by solid particles or oil oxidation products or both, and investigated about the lubricated wear mode for WJ2 which is general bearing material in power plant. We performed the sliding friction tests by using a block-on-ring type friction tester. As a result, in the

case of only existing wear particles in the oil, WJ2 was worn, but lubricated condition became gradually better. In contrast, in the case of existing hard particles in oil, lubricated condition became gradually bad. In the case of mixing oxidation products in oil, wear of WJ2 decreased as WJ2 was protected by oxidation products.

5:00 pm - 5:30 pm
Getting the Most from Oil Analysis
Michael Holloway, ALS Tribology, Highland Village, TX

This presentation will look at what we can ask from oil analysis laboratories to drive reliability and how the data is expected to match our maintenance goals and initiatives. Many organizations will use oil analysis, but not to the fullest extent. A structured in-service lubricant testing program has become an integral part in many best-in-class maintenance organizations. These teams take full advantage of the value oil analysis brings by partnering with their oil analysis provider and lubricant supplier to establish goals and targets that testing will support, as well as KPIs through the test data to monitor progress towards these goals. The discussion will focus on ways to set goals to help companies achieve success.

5:30 pm - 6:00 pm
Real Time Data Analytics and IIoT to Monitor Oil Consumption and Drive In-Depth Wear Debris Analysis
Matt Spurlock, LogiLube, Laramie, WY

Oil consumption is one of the most neglected values in oil analysis, yet it is one of the most valuable pieces of data in determining true machine condition. A dangerous level of wear debris generation can easily be masked by an unusually high level of oil consumption. When combining real-time oil consumption data with contaminant data derived from physical oil sample analysis, end users can increase the value received through condition monitoring. Integrating industrial internet of things (IIoT) precision oil flow meters, real-time particle classification sensors, edge-processed algorithms and detailed oil analysis results provides the end user with an opportunity to apply data analytics to develop a more relevant trigger for in-depth wear debris analysis. Learn how real-time oil consumption and fluid health monitoring coupled with data analytics tying lab data to real-time data helped identify an early stage of failure that would have been missed through traditional oil sample testing.

4L — Baker

Rolling Element Bearings Roundtable Discussion

2:00 pm - 3:00 pm - REB Round Table Topics Discussion

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

4:00 pm - 5:00 pm - REB Round Table Topics Discussion

Nanotribology IV

Session Chair: Z. Ye, Miami University, Oxford, OH
Session Vice Chair: J. Leong, SIM University, Singapore, Singapore

8:00 am - 8:30 am
Effect of Roughness on Atomic Friction of Few-Layer Graphene
Zhijiang Ye, Miami University, Oxford, OH, Arda Balkanci, McGill University, Montreal, Quebec, Canada, Mehmet Baykara, Bilkent University, Ankara, Turkey, Ashlie Martini, University of California, Merced, Merced, CA

Friction on graphene is known to exhibit unique layer dependence at the atomic scale where friction decreases with increasing number of layers. However this trend is not always observed for atomic force microscope (AFM) tips of different sizes and on different substrates. The precise roles of tip size and substrate topography (roughness, especially) are not yet completely understood. Here, we probe the origins of the roughness dependence of atomic friction on few-layer graphene using AFM measurements and molecular dynamics simulations. The layer-dependence of friction was shown to be affected by tip size in both experiments and simulations. Further, two opposite layer-dependence trends were observed on substrates with different roughness in simulations. The underlying mechanisms were investigated using atomistic details obtained from simulations, where the different friction trends were correlated to the surface roughness, contact size, and deformation of the surface during sliding.

8:30 am - 9:00 am
Effect of Surface Roughness of Colloid Probes on the Mechanical Properties of Hydrogels
Prathima Nalam, University of Illinois Urbana Champaign, Champaign, IL, Qiujie Zhao, University of Illinois, Ubrana-Champaign, Urbana-Champaign, IL, Luke Villermin, Louisiana Tech University, Ruston, IL, Rosa Espinosa-Marzal, University of Illinois Urbana Champaign, Champaign, IL, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Viscoelastic properties of biological materials such as cells, tissues *etc.* are known to change when infected. Thus, the altered elastic modulus of diseased material is an important diagnostic parameter for determining cell health. The localized mechanical properties of such soft and highly deformable materials are measured using colloid-probe atomic force microscopy. However, commercially available colloids probes are never smooth and possess some degree of roughness influencing quantitative measurements. In this paper, we examine the effect of surface roughness of silica colloids on the mechanical properties of a model system *i.e.* polyacrylamide hydrogel. Force-indentation curves are acquired using colloid probes with varying surface roughness to determine mechanical properties of hydrogels. While no effect is observed for interaction energies, a significant decrease in the elastic modulus (~50%) of the hydrogel is observed when the RMS roughness of the colloid increased (~ 2-12nm).

9:00 am - 10:00 am – Invited LectureF
An Atomistic View on Dry Friction: From Sticking Atoms to Superlubric Sliding
Udo Schwarz, Yale University, New Haven, CT

How do we connect properties exhibited by atomic surface structures to real-life friction? In this talk, we review the related fundamental principles of atomic-scale dry friction based on experiments using atomic force microscopy and in the light of simple analytic theories. We will start our journey by looking at the

most fundamental key ingredient to friction, the interlocking of atoms at opposing surfaces (the “sticking”), which is released in a dramatic “slip” event during which energy is dissipated. Such events cannot only be directly observed, but the underlying interaction potentials and lateral forces can be quantified with meV, pN, and pm resolution. With this understanding, the question that arises next is how to bridge the gap from atoms to macroscopic contacts. At the center of many studies and debates, we explore approaches relaying on describing surface roughness, contact area, and interface rigidity, and address outstanding challenges and opportunities in the field.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Nanoscale Investigation of the Surface Reactivity of Ionic Liquids
Pourya Parsaeian, University of Leeds, Leeds, United Kingdom

This study established a protocol for the investigation of the surface reactivity of ILs under harsh tribological conditions (i.e., high loads, low sliding speeds) on the basis of in situ atomic force microscopy (AFM) measurements and ex situ X-ray photoemission electron microscopy (X-PEEM) analyses(Diamond Light Source synchrotron Facilities Uk). This experimental framework was applied to a class of ILs (i.e., imidazolium alkyl phosphate/sulphate), thus providing novel insights into the mechano-chemistry of these ILs.

11:00 am - 11:30 am
Contribution of Shear Rate and Asperity-Scale Surface Interactions on the Growth of ZDDP Tribofilms: An *In-situ* Atomic Force Microscopy Study
Harman Khare, Nitya Gosvami, Daniel Anderson, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA

Zinc dialkyldithiophosphates (ZDDPs) are ubiquitous anti-wear additives for use in automotive lubricants. ZDDPs undergo tribochemical reactions at the sliding interface, thereby forming mechanically robust, protective tribofilms. Despite decades of research, the fundamental mechanisms which drive nucleation and growth of ZDDP tribofilms, and which impart them their unique mechanical properties, remain poorly understood. Recently, *in-situ* atomic force microscopy (AFM) has enabled measurements of ZDDP tribofilm growth kinetics at a simulated single asperity contact. We review the stress-activated and thermally-accelerated kinetics of ZDDP tribofilm growth revealed by these measurements. We then report how variations in contact conditions at the single-asperity scale, namely substrate chemistry, roughness and shear rate contribute to the observed growth kinetics, morphology and properties of ZDDP tribofilms.

11:30 am - 12:00 pm
Atomic-Resolved Reaction Mechanisms for the ZDDP Thermal Film Formation on Steel, H-DLC and Si-DLC
Somayeh Akbari, Mitjan Kalin, Ljubljana University, Ljubljana, Slovenia

Zinc dialkyl dithiophosphate (ZDDP) is the most used automotive antiwear additive, and its performance and reaction mechanism(s) for the DLC coatings, which are becoming increasingly used in automotive applications, is thus getting strong attention. While individual components of the tribofilms formed from the ZDDP-additivated oil have been studied in some previous studies, we propose in this study a more comprehensive reaction mechanisms that is lacking today, namely the atomic-resolved models for the lubricant thermal film formation of ZDDP on steel, hydrogenated non-doped DLC and Si-doped DLC. We have focused on the ZDDP film formation under well-controlled static thermal tests by using attenuated total reflection-Fourier transform infrared spectroscopy, XPS and Raman at different temperatures. According to the proposed models, ZDDP reacts differently with each surface. Moreover, the nanostructure of topmost layer of the DLC surfaces plays a crucial role in the reaction with ZDDP.

5B Hanover C

Commercial Marketing Forum V

8:00 am - 8:30 am - Available Slot

8:30 am - 9:00 am - The Dow Chemical Company

9:00 am - 9:30 am - Available Slot

9:30 am - 10:00 am - Afton Chemical Corporation

10:00 am - 10:30 am - Break

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

11:00 am - 11:30 am - Nease Company

11:30 am - 12:00 pm - Houghton International, Inc.

5C Hanover D

Rolling Element Bearings I - Rolling Contact Fatigue I

Session Chair: M. Correns, Schaeffler Technologies AG & Co KG, Herzogenaurach , Germany
Session Vice Chair: C. DellaCorte, NASA, Cleveland, OH

8:00 am - 8:30 am
Propagation of Surface Initiated Rolling Contact Fatigue Cracks: Influencing Factors and Potential Mechanisms
Amir Kadiric, Pawel Rycerz, Imperial College London, London, United Kingdom, Guillermo Morales-Espejel, SKF Engineering and Research Centre, Nieuwegein, Netherlands

This work studies the propagation of surface initiated rolling contact fatigue (RCF) cracks prior to the onset of pitting in an attempt to better understand crack propagation mechanisms. A triple-contact disc machine was used to grow surface cracks in bearing steel samples under closely controlled contact conditions. Crack growth across the specimen surface is monitored and crack propagation rates extracted. Influence of magnitude and direction of slide-roll ratio, surface roughness, contact pressure and steel type are studied. The work builds on the previously presented results where it was shown that propagation of surface RCF cracks exhibits two distinct stages of growth, stage 1, within which cracks grow at a slow and relatively steady rate; and stage 2, reached at a critical crack length, within which the

propagation rate rapidly increases. An attempt is made to interpret the current results in view of mechanisms that may be responsible for the observed crack growth behaviour.

8:30 am - 9:00 am

Effect of Gradations in Elastic Modulus and Residual Stresses on Rolling Contact Fatigue Life of Case-Hardened Bearing Steels

Nagaraj Arakere, Nikhil Londhe, Ghatu Subhash, University of Florida, Gainesville, FL

Finite Element Models were developed to study the influence of elastic modulus variation and residual stresses due to case hardening on subsurface stress fields of elliptical contacts in ball bearings. Carburization induces an elastic modulus gradient with depth and residual stress profiles in the circumferential and axial directions of the raceway. Both effects are considered in FE models. It was observed that Hertzian stress profile is significantly altered in the subsurface region due to graded material properties and presence of residual compressive stresses. Lundberg-Palmgren, Ioannides-Harris and Zaretsky's approaches are used to correlate altered subsurface stresses to predicted fatigue lives of ball bearings. It is observed that case hardening results in significant improvement in L_{10} fatigue life of ball bearings. Higher improvement is observed for bearings with larger dimensions. Also, volume integrated stresses predicts higher improvement in life compared to point stresses.

9:00 am - 9:30 am

EHL Modeling of Polycrystalline Anisotropy Effects on Rolling Contact Fatigue Stresses

Neil Paulson, Farshid Sadeghi, Purdue University, Lafayette, IN

Bearing steel is composed of a polycrystalline aggregate of anisotropic crystals which affects the stress distribution and subsurface fatigue crack formation. In this work an approach is proposed to compute the contact pressure, film thickness, and subsurface stresses in a polycrystalline aggregate operating under elastohydrodynamic lubrication (EHL). The approach is based on a fully coupled finite element EHL model using 1D finite element to solve the Reynolds equation and 2D finite elements to resolve elastic deformation. The polycrystalline material is generated using a Voronoi polygon discretization with each Voronoi polygon receiving a unique crystallographic orientation. Results from the Voronoi EHL model show contact pressures vary due to crystallographic orientation over the contacting surfaces and subsurface stresses increases at Voronoi polygon boundaries. EHL film thickness profiles did not change significantly when anisotropic was included in the model.

9:30 am - 10:00 am

Modeling of Carbide Assisted Cyclic Hardening in Bearing Steels during Rolling Contact Fatigue

Anup Pandkar, Nagaraj Arakere, ghatu Subhash, University of Florida, Gainesville, FL

Rolling Contact Fatigue (RCF) is commonly observed failure mechanism in rolling element bearings. Under RCF loading, contact region in the vicinity of rolling elements experiences complex triaxial state of stress. RCF bench tests conducted on M50-NiL bearing steel have shown a significant increase in subsurface hardness within the localized RCF affected regions. Such increase in hardness is also a function of number of RCF cycles. In current study, cyclic hardening response of M50-NiL steel during RCF is investigated using FEA. Heterogeneous carbide particles in the microstructure of M50-NiL are largely responsible for material hardening. These carbide particles accumulate micro-plastic strain via ratcheting under RCF loading. The observed micro-scale ratcheting behavior is proposed to be responsible for the cyclic hardening observed in experiments. FE simulations conducted using combined non-linear isotropic/kinematic hardening models show good co-relation with experimental findings.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am

Effect of Differential Hardness on Static Load Capacity of AISI 52100 Bearing Steel
Iqbal Shareef, Bradley University, Peoria, IL, Erwin Zaretsky, NASA Glenn Research Center, Cleveland, OH, Shruti Gour, Josh Brandis, Bradley University, Peoria, IL

Rolling-element bearing loading can be static, dynamic, or process generated. A. Palmgren defined the static load capacity as that load (stress) applied to a bearing that results in an indentation (visible Brinell mark) that is greater than 0.0001 times the diameter of the rolling element. If vibration, noise, and torque are critical performance criteria, a lower load (stress) must be required. Most commercial bearings are made from AISI 52100 steel. Generally, bearing races and rolling elements (balls or rollers) are heat treated to a minimum Rockwell C hardness of 58-63. The work reported determined the effect of both component and variable hardnesses on the static load capacity of AISI 52100 steel that have been heat treated to 6 different hardnesses and compressed together at 13 different loads (stresses). Indentation diameter, depth, volume, and surface finish were measured by white light interferometer. Results indicate significant increases in static load capacity beyond 58 HRC.

11:00 am - 11:30 am
Rolling Contact Fatigue Life Prediction under Elastic-Plastic Loading Conditions
Nagaraj Arakere, Nikhil Londhe, ghatu Subhash, University of Florida, Gainesville, FL

Bearing materials are often evaluated under accelerated Rolling Contact Fatigue (RCF) conditions using three-ball-rod testing at high Hertzian peak contact pressure of 5.5 GPa. At this load, bearing steels can undergo cyclic micro-plastic yielding in the subsurface material. Finite Element Models were developed to study the Hertzian contact stresses under elastic-plastic loading conditions. For carburized steels, gradations in elastic modulus and yield strength were incorporated as a function of depth. Due to low strain hardening exponent of high strength case-carburized bearing steels, subsurface elastic-plastic stresses were found to be significantly lower in magnitude than elastic stresses. Corresponding changes in RCF life is analyzed using Lungberg-Palmgren, Ionnides-Harris and Zaretsky's life prediction approaches. It was observed that accounting for subsurface plasticity and gradient effects of the case layer improves fatigue life predictions by up to 300%.

11:30 am - 12:00 pm
Study on the Surface Crack Behaviors of Elastohydrodynamically Lubricated Contacts
Weiyi Wang, Purdue University, West Lafayette, IN

This research aims to numerically study the behaviors of the surface cracks under EHL pressure. The EHL pressure and stress in the solid domain were solved with a Fully-Coupled line contact EHL solver based on the Finite Element approach. Usually, the EHL problem is solved by calculating the vertical deformation of the contact surfaces only. It does not give the stress and strain information in the entire solid domain, and ignores the surface deformation in the horizontal direction. The Fully-Coupled FE solver allows to obtain the surface pressure, as well as the stress and strain in the entire domain including the contact and crack surfaces in both vertical and horizontal directions. This paper focuses on the crack geometry's influence on the EHL pressure distribution, stress and strain on the crack surfaces and crack tips, as well as the opening and closure of the cracks. Cracks with various depth, width, and angle of inclination were studies.

5D — Hanover E

Materials Tribology V

Session Chair: A. Dunn, University of Illinois at Urbana, Urbana, IL
Session Vice Chair: A. Pitenis, University of Florida, Gainesville, FL

8:00 am - 8:30 am

Mechanochemistry of Physisorbed Molecules at Tribological Interfaces: Molecular Structure Dependence of Tribochemical Polymerization
Xin He, Seong Kim, The Pennsylvania State Univeristy, University Park, PA

Physisorbed molecules at a sliding solid interface could be activated by mechanical shear and react each other forming polymeric products which are often called tribo-polymers. The dependence of tribo-polymerization yield on applied load and adsorbate molecular structure was studied to obtain mechanistic insights into mechanochemical reactions at a tribological interface. Three hydrocarbon precursors - α-pinene ($C_{10}H_{16}$), pinane($C_{10}H_{18}$) and n-decane ($C_{10}H_{22}$) were studied. By comparing the adsorption isotherm of these molecules and tribo-polymer products, the reaction yield was found to be proportional to the amount of adsorbed molecules. An Arrhenius-type analysis of the applied load dependence of the tribo-polymerization yield revealed how the critical activation volume (ΔV^*) varies with the structure of adsorbed molecules. The tribo-polymer film synthesized *in situ* at the sliding interface exhibited an excellent boundary lubrication effect even without any external lubricant supply.

8:30 am - 9:00 am
Evaluating Transfer Film Wear Rates of Polymeric Solid Lubricants
Diana Haidar, University of Delaware, Newark, DE, Jiaxin Ye, Hefei University of Technology, Hefei, Anhui, China, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

Polymeric solid lubricants are important in many applications that preclude the use of traditional lubricants. Typically, these materials are mated against hard metallic surfaces of higher surface energy and result in polymer debris deposited on the counterface as a protective layer barring direct material contact. This transfer film tenaciously adheres to the counterface, displaying even lower wear rates than the polymer itself, is essential for supporting ultralow wear. One study assessed the tenacity of a 5%wt. alumina in 95% PTFE nanocomposite transfer film by testing the film's wear rate using various probe materials and found that a critical probe surface energy existed, below which the film displayed ultralow wear and above which high wear occurred. In this study, we aim to determine whether that observation is consistent and predictable among transfer films of other polymeric solid lubricants, thereby gaining insight into the tribological mechanism driving interface behavior.

9:00 am - 9:30 am
Ultra Low Wear of Fluoropolymer Composites and the Potential Link to Microstructure
Morgan Jones, Juan Manuel Uruena, Samuel Hart, Andrew Cooper, Angela Pitenis, Gregory Sawyer, University of Florida, Gainesville, FL

A great deal of research has been dedicated to the study of polytetrafluoroethylene (PTFE) in its role as a solid lubricant. PTFE is an attractive option in design applications due to its chemical inertness and low friction coefficient. The major drawback to PTFE is its wear rate (~5x10^-4 mm^3/Nm). PTFE-polymer composite systems add load support and fracture toughening mechanisms to reduce the crack propagation during sliding. In turn, this can produce wear rates nearly an order of magnitude lower than unfilled PTFE. In certain cases, these composites achieve ultra low wear while still maintaining a low coefficient of friction. Tribological experiments were performed at varying weight percentages of PTFE and polyamide-imide (PAI) to characterize an optimum composite for achieving ultra low wear. Preliminary analysis suggests that this phenomenon occurs around 30 wt.% (~40 vol.%). In addition, the microstructure of the composite may play a role in its ultra low wear mechanisms.

9:30 am - 10:00 am
Fluoropolymer and Alumina Composites: Tribochemistry and Ultralow Wear
Mark Sidebottom, Lehigh University , Bethlehem, PA, Heidi Burch, Gregory Blackman, DuPont Corporation, Wilmington, DE, Christopher Junk, Brandon Krick, Lehigh University , Bethlehem, PA

PTFE (polytetrafluoroethylene) and PFA (perfluoroalkoxy polymer, a perfluorinated TFE-copolymer) have desirable physical properties as solid lubricants (high service temperatures, low friction coefficient,

chemical inertness, etc.), but their use is limited due to high wear rates (K~1x10^{-4} mm^3/Nm). Through the addition of certain Al_2O_3 filler particles, both PTFE and PFA have shown remarkable improvements in wear performance (K ~ 4-7 x 10^{-8} mm^3/Nm) attributed to the formation of tribofilms at the sliding interface. Unlike PTFE, PFA can be injection molded, due to its a higher melt flow rate. Scrupulous tribological experiments and material characterization techniques were performed to evaluate the effects of environment, alumina particle structure, and sliding conditions on the formation of tribofilms. Additional evidence of the harmonious combination of mechanically induced tribochemical reactions leading to the formation of robust tribofilms will be presented.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Sliding Induced Solute Transport Into Articular Cartilage
Axel Moore, Brian Graham, Christopher Price, David Burris, University of Delaware, Newark, DE

Cartilage achieves its unusual tribological properties through a unique mechanism known as interstitial lubrication. Unfortunately, periods of rest (static loading) cause fluid exudation and the loss of interstitial lubrication. It was recently shown that interstitial lubrication can be maintained and recovered via a novel mechanism known as tribological rehydration. Tribological rehydration is thought to be the flow of hydrodynamically pressurized bath fluid back into the articular cartilage. To visualize this process, a tribometer was mounted over a confocal microscope and a cocktail of fluorescent solutes was added to the bath solution. The uptake and penetration of the solutes was imaged *in situ* for various dynamic conditions. These findings demonstrate that (1) fluid is driven back into cartilage during tribological activity, (2) fluid uptake initiates at the contact edge and then migrates toward the center, and (3) tissue degradation greatly impairs tribological rehydration.

11:00 am - 11:30 am
Slip And Flow: Competition In A Hydrogel-Glass Interface
Alison Dunn, Erik Reale, University of Illinois at Urbana, Urbana, IL

It is accepted that hydrogel surfaces use water for low friction, but applied stresses simultaneously squeeze water from the interface. The relative local dehydration should change drive friction. To investigate this, we measured the energy of adhesion upon retraction of a glass probe (R=1.7 mm) from a 10% (w/w) polyacrylamide flat after dwell times t=0 to 900 s. Over the calculated contact area, the surface energy densities were 10 - 50 mJ-m^{-2}. A second phase of investigation used micro-friction measurements of identical interfaces to confirm that the work of friction by adhesion drives the measured friction coefficient. We show that adhesion can semi-quantitatively predict kinetic friction coefficient between polyacrylamide and glass in a migrating contact. This model explains how faster sliding speeds do not disrupt interfacial hydration; the prevailing water maintains low friction. At low speeds, interface drainage dehydration works against slip for higher friction.

11:30 am - 12:00 pm
Shear-Induced Fluorescence in Hydrogels
Angela Pitenis, Christopher Kabb, Juan Manuel Urueña, Wyatt Ebert, Sean Niemi, Brent Sumerlin, Thomas Angelini, Greg Sawyer, University of Florida, Gainesville, FL

Over the past decade, the field of tribology has advanced to considering macroscopic interfaces in molecular and atomic terms, and enabled ultralow force measurements sensitive to single chemical bond breakage and friction measurements spatially resolved to the atomic level. These capabilities present an opportunity to interrogate the role of tribological action within soft polymer systems and to characterize polymer interfaces and interactions on a molecular scale. Hydrogels serve as model systems for these studies due to their ease of synthesis and high repeatability; however, direct observations of damage are precluded by their closely matched index of refraction with water. Here, hydrogels were prepared with a

crosslinker that fluoresces when cleaved by mechanical stress. Damage due to high shear events rupturing labile linkages in the hydrogel was evaluated by fluorescence microscopy in an effort to determine a threshold scaling criteria to initiate polymer chain scission.

5E Hanover F

Surface Engineering III

Session Chair: Z. Khan, Faculty of Science & Technology, Bournemouth University, Bournemouth, United Kingdom
Session Vice Chair: A. Saeed, GCET, Muscat, Oman

8:00 am - 8:30 am
Tribological Characteristics of En-19 And 16mncr5 Steel under Varying Roughness and Lubrication
Vivek Chacko, Zulfiqar Khan, Bournemouth University, Poole, Dorset, United Kingdom

The interacting combination of EN-19 and 16MnCr5 steel is widely used in heavy industrial applications. EN-19 steel is ductile, shock and wear resistant. 16MnCr5 steel is a case hardening, forgeable steel. However, the analysis of the friction and wear characteristics for this material combination has not been reported before. This paper presents both experimental and analytical results of tribological performance of EN-19 and 16MnCr5. The experiment is conducted on a reciprocating tribometer. The coefficient of friction for grease lubricated contact is recorded within the range of 0.15-0.25. Later Nickel-Alumina nano composite coating was applied onto16MnCr5 steel. Interfacial surface roughness profiles of nano coated 16MnCr5 and EN-19 samples are presented in conjunction with a detailed study of wear failure modes and the wear volume at varying test conditions. Comparative results of tribological performance of nano coated versus non coated 16MnCr5 are also presented.

8:30 am - 9:00 am
Prediction and Prognostics of Surface Failures through Sensing Technologies within Large Mobile Assets
Adil Saeed, GCET College of Engineering and Technology, Muscat, Oman, Zulfiqar Khan, NanoCorr Energy and Modelling Research Group, Bournemouth, Dorset, United Kingdom, Tasheen Rafik, GCET College of Engineering and Technology, Muscat, Oman

Large vehicles are usually subject to varying operational conditions during their service life. These operating conditions include highly saline and humid conditions, hot and dry atmospheres containing sand & soil particulates and extreme operating temperatures. These mobile assets endure structural degradation during post-operational storage. Large vehicles, which have been exposed to extreme operating conditions, exhibit various modes of structural degradation. Erosive wear in combination with corrosion leads to complex failure mechanisms. This research reports the failures of engineered surfaces during storage while these failures were essentially incubated during operation. To sustain structural integrity of large vehicles in storage, a framework based on sensing technology has been developed and implemented for monitoring, prediction and prognostics. This framework is condition-based that enables cost savings to relevant industries and replaces schedule-based maintenance approaches.

9:00 am - 9:30 am
Characterizing Nanoscale Surface Roughness Using Transmission Electron Microscope
Subarna Khanal, Abhijeet Gujrati, University of Pittsburgh, Pittsburgh, PA, Tevis Jacobs, University of Pittsburgh , Pittsburgh, PA

Conventional techniques for measuring surface topography are not able to accurately measure features with nanometer- or Angstrom-scale lateral dimensions. Even scanning probe microscopy, which can

achieve atomic-lattice resolution on very flat surfaces, is fundamentally limited in its measurement of rough surfaces by the geometry of the tip. Yet analytical models predict that smallest scales of roughness are most critical for adhesion and contact properties. Here, we demonstrate the use of transmission electron microscopy to characterize surface roughness down to the Angstrom-scale. Specifically, a surface-preserving cross-section technique has been developed and applied to silicon and nanodiamond materials. Two-dimensional surface profiles were obtained through direct side-view imaging and quantitative image analysis and also analyze three-dimensional surface profiles. Overall, the technique significantly expands the range over which rough-surface topography can be determined.

9:30 am - 10:00 am

An Experimental Study and Modelling of Tribo-corrosion Behaviour of Ni-graphene Nano Composite Coatings for Industrial Applications

Mian Hammad Nazir, Zulfiqar Khan, Bournemouth University, Bournemouth, Dorset, United Kingdom

This paper presents an experimental study of both wear and corrosion performance of Ni-Graphene nano composite coatings at simulated industrial conditions. It is essential to understand the performance of electrodeposited Ni-Graphene nano composite coating when subject to tribo-corrosion environments to predict service life and enhance durability of industrial equipment. During this research Tribo-corrosion performance of Ni-Graphene coating is evaluated and the main mechanisms associated with their degradation under combined wear and corrosion are highlighted. The effects of various critical parameters: coating composition, microstructure, defect level, adhesion, cohesion and substrate properties are discussed. Interactions between wear and corrosion mechanisms are significant in terms of their influences on the durability of these coatings. These mechanisms are studied in detailed through advanced experimental methods along with state-of-the-art predictive modelling techniques

10:00 am - 10:30 am - Break

10:30 am - 11:00 am

High Corrosion Resistance of Aisi 304 Bearings by Ultrasonic
Nanocrystalline Surface Modification Technique

Young-Sik Pyun, Auezhan Amanov, Bakhtiyor Urmanov, Jun-Hyong Kim, Sun Moon University, Asan, Korea (the Republic of)

AISI 304 stainless steel is one of most widely used nickel-chrome stainless steels. It has good corrosion and heat resistance, low temperature strength, and good mechanical properties. However, AISI 304 stainless steel bearings require regular cleaning maintenance in order to avoid corrosion which can extend the service life of them. In this study, the bearings made of AISI 304 stainless steel were subjected to an ultrasonic nanocrystalline surface modification (UNSM) technique. The corrosion resistance of AISI 304 stainless steel bearings with steel and ceramic balls was investigated using a rolling contact fatigue (RCF) corrosion tester under low loads and speeds. The results revealed that the UNSM-treated bearings with both steel and ceramic balls exhibited a higher resistance to corrosion compared to conventional untreated bearings. The UNSM-treated bearings are ideal for applications such as nuclear, medical, etc. where good corrosion resistance is highly important.

11:00 am - 11:30 am

An Analysis of Generated Fractal and Measured Rough Surfaces in Regards to Their Multi-scale Structure and Fractal Dimension

Xiaohan Zhang, Yang Xu, Robert Jackson, Mechanical Engineering, Auburn, AL

This work studies the methods used to extract fractal dimensions from surface profiles and the applicability of fractals to measured surfaces. The work used generated surfaces to first evaluate these methods, and later applies the methods to measured surfaces. Two methods for generating surface profiles are used. The fractal dimension values of all generated profiles are calculated by four methods,

then the results are compared. It is also found that self-similarity occurs at different fractal dimensions for the power spectrum and the Weierstrass-Mandelbrot generation methods. The analysis indicates that real measured rough surfaces are not easily represented as perfect fractals as researchers and engineers often assume.

11:30 am - 12:00 pm
Slurry Erosive Wear Behaviour Of Al6061 Plasma Sprayed with Titania
Ramesh Chinnakurli, Alliance University, Bangalore, Karnataka, India, Suresh Kumar R, Arun P, Pradyot Satyappanavar, BMSCE, Bangalore, India, Zulfiqar Khan, Bournemouth, Bournemouth, United Kingdom

Various surface modifications technologies are now available. Among them, thermal spraying, which refers to a family of material deposition techniques has emerged as an important tool for achieving tailor made engineering surfaces. In the light of the above, present investigation is aimed at developing plasma sprayed Titania coatings on Al6061 substrate and to evaluate its slurry erosive wear resistance. Titania powders were thermally sprayed on Al6061 substrate by Atmospheric Plasma Spray process. The developed coatings were subjected to slurry erosive wear tests in 3.5% NaCl solution with sand as erodent. The slurry erosive wear resistance of developed coatings are higher than that of uncoated substrate under identical test conditions owing to the increased hardness on coating.

5F Hanover G

Fluid Film Bearings V

Session Chair: L. Moraru, Aerospace Sciences, University Politehnica of Bucharest, Bucharest, Bucharest, Romania
Session Vice Chair: A. Cristea, Tecnitas SAS, Levallois-Perret, France

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

8:30 am - 9:00 am
Experimental Study of the Influence of the Misalignment Induced by Scratches on the Performance of a Two-Lobe Journal Bearing
Jean Bouyer, Michel Fillon, Pprime Institute, Futuroscope Chasseneuil Cedex, France

The damage of the supporting and guiding components of the rotating shafts, i.e the appearance of scratches, is often discovered during maintenance operations. Experimental tests have been carried out on the Pprime Institute test bench equipped with a two-lobe journal bearing (diameter: 100 mm, length: 68.4 mm, preload: 0.5) with ISO VG 46 oil. Scratches were created on the shaft at several locations, varying their depth (1/2, 1 and 2 times the radial clearance) and their width (0.5, 1 mm and 2mm). Local hydrodynamic pressure and temperature were measured during steady-state operation. It is shown how severe scratches can induce a bearing misalignment through pressure field measurements. The modification of the pressure and temperature fields due to the presence of one or more scratches is presented.

9:00 am - 9:30 am
Experimental Analysis of the Hydrodynamic Effect During Start-up of Fixed Geometry Thrust Bearings
Yann Henry, Jean Bouyer, Michel Fillon, Pprime Institute, Futuroscope Chasseneuil Cedex, France

The current work investigates the performance of thrust bearings during start-up focusing on the fluid film formation during this step. Most of the studies in the literature were focused on the steady state

conditions while start-up conditions – among other things – are a key parameter in determining the life time of bearings . For this analysis, a constant load is applied to the thrust bearings and the acceleration remains constant during the speeding up, for all the tests. Experimental investigations were carried out with four kinds of thrust bearings: the pad surfaces are either parallel, tapered, pocketed or partially textured. Original results prove that only certain specific texture geometry can improve the lift-up while a wrong configuration can be detrimental. Contrary to what it is generally admitted, flat land surfaces with a proper roughness have relatively good abilities to generate lift-up during start-up.

9:30 am - 10:00 am
Coupling Analysis on Dynamics and Tribology of Crankshaft-bearing Statically Indeterminate System Considering Misalignment
Liang Zhang, Xiqun Lu, Jianglong Luo, Fuzhan Huang, Harbin Engineering University, Harbin, China

The shaft journal is usually misaligned because of the changing cylinder pressure and other factors as firing sequence. What's more, the misalignment varies periodically with the rotation of shaft. In this research, focusing on the crankshaft of a two-stroke low-speed marine diesel, a coupled simulating model of crankshaft-bearing statically indeterminate system with tribo-dynamics was established. The effects of the load of crank and the oil film pressure due to the misalignment of shaft journal were considered, together with the coupling relationship between the misalignment and the oil film pressure. Furthermore, the deformation of crankshaft was calculated, and the minimum oil film thickness and pressure distribution were obtained. Finally, based on all the results, the axis trace was investigated.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
TEHD Performance of Fluid Film Bearings Supporting Highly Loaded Gears in Epicyclic Transmission Systems – Influence of Gear Tooth Geometry
Bálint Pap, Michel Fillon, Université De Poitiers - Intitut Pprime, Levallois-Perret, France

In transmission systems, to achieve a high transmission ratio, in a relatively small volume epicyclic gearboxes may be used. In epicyclic gearboxes a sun gear transmits its power to a sun carrier through (usually 3-5) satellite gears mounted on a carrier. A fluid film bearing is often used to support the satellite gears on the shafts of the carrier. The satellite gears can be spur or double helical gears, with different tooth profiles. The well-chosen gear tooth geometry can significantly improve the behavior of the bearing. In the present work, a thermoelastohydrodynamic (TEHD) model of a fluid film bearing is presented. Then, a case study is regarding the effects of different gear tooth profiles on the main characteristics of a fluid film bearing.

11:00 am - 11:30 am
Performance Characteristics of Non-Circular Floating Ring Bearing
Sandeep Soni, D. P. Vakharia, Svnit, Surat, Gujarat, India

In the present work, steady-state characteristics of non-circular floating ring bearing operating in laminar regime using Newtonian lubricant have been studied. The classical N-S equations along with the continuity equation in cylindrical co-ordinates, are solved by FEM.The finite bearing approximation and values of the clearance ratio of 0.7 and 1.3 is used. The non-circular floating ring bearing consists two fluid films, one around the journal and floating ring and other between the floating ring and the fixed bush.Steady-state characteristics of non-circular floating ring journal bearing in terms of load carrying capacity, attitude angle, axial oil flow, friction coefficient and temperature rise parameter are calculated for various eccentricity ratios. An analytical result exhibits good performance of proposed bearing in laminar rgime.

11:30 am - 12:00 pm
Thrust Bearing Enabled with Water Cooling Within the Pad: An Experimental Study
Farooq Najar, G. Harmain, National Institute of Technology , Srinagar, J&K, India

In the present work, the temperature profile has been monitored in the tilting pad thrust bearing which is subjected to a water cooling within the pad. An experimental test rig has been designed and developed indigenously. Test inputs are defined as the combination of speed and load of 1100 rpm and 6.5 kN respectively. The lubricating oil was used SAE-30. Cooling water temperature at pipe inlet is 20 ^{o}C. Firstly, conventional pad and then the water cooling enabled pad were tested under a predetermined set of operating conditions. The results show that there is a significant drop in temperature on the surface of the pad during 0.25 litre/min and 0.50 litre/min mass flow rate of water flowing along the cooling duct.

5G Regency V

Lubrication Fundamentals III - EHL Modelling and Evaluation

Session Chair: X. He, Mechanical Engineering, Northwestern University, Evanston, IL
Session Vice Chair: P. Shiller, The University of Akron, Akron, OH

8:00 am - 8:30 am
Analysis of the Elasto-hydrodynamic Lubrication in Coated Finite Length Line Contacts
Shivam Alakhramsing, Matthijn De Rooij, Dik Schipper, Faculty Of Engineering Technology, University Of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, Enschede, Overijssel, Netherlands, mark van Drogen, DAF Trucks N.V., P.O. Box 90065, 5600 PT Eindhoven, The Netherlands, Eindhoven, Noord-Brabant, Netherlands

A FEM-based model, enabling simulation of EHL in coated finite line contacts, has been developed. The pressure and film thickness distribution between a straight roller with rounded corners, was studied using this model. Furthermore, parameter studies were conducted in order to study the influence of varying operating conditions, coating mechanical properties and axial surface parameters on the overall EHL behavior of the contact. Unlike typical EHL behavior it was found that the maximum pressure and minimum film thickness, which are located at the rear of the contact, are highly affected by variations in contact load. From the results it is also evident that axial surface parameters and coating mechanical properties act as amplifiers to the effect of contact load on film thickness and pressure distribution. The lubrication performance of the finite line contact can thus significantly be enhanced if axial profiling parameters and coating mechanical properties are smartly chosen.

8:30 am - 9:00 am
EHL Analysis with Presence of Shear Band
Coda Pan, Illinois Institute of Technology\, Millbury, MA, Michael KHONSARI, Louisiana State Univeresity, Baton Rouge, LA

Observation of shear bands in rheological studies suggests the existence of a threshold limit in the use of Barus viscosity law in EHL studies. Revision of Reynolds' lubrication theory is required to observe the yield criterion of von Mises. When shear stress in the fluid film reaches the shear yield strength, fluid flow is diverted from adding to the film flux but enters directly into the shear band flow that bridges the incomplete film flux across the remaining film thickness. The popular Grubin-Ertel analysis can be modified to include the presence of shear band flow in EHL studies.

9:00 am - 9:30 am
Exploring Elasto-Hydrodynamic Lubrication Using a Finite Volume CFD Based Method

Damon Lee, Daniele Dini, Amir Kadiric, Imperial College London, London, United Kingdom

This paper uses a finite volume approach implemented using the OpenFOAM package to study elasto-hydrodynamic lubrication (EHL). The adopted methodology provides multiple benefits over standard Reynolds approaches including improved fluid-solid interaction (FSI) modelling, phase change, full thermal effects, resolving fluid flow gradients in all directions and influence of inlet conditions owing to a larger domain of study. Results are presented to firstly, provide a comparison of model predictions with experimental measurements and Reynolds based solutions, and subsequently, to explore significant effects in EHL lubrication such as influence of side-roll ratio, inlet and in-contact temperatures, EHL traction and film thickness profile.

9:30 am - 10:00 am
Advantages and disadvantages of Variational approach to Hyrdodynamic Lubrication Therory
Alexey Kornaev, Elena Kornaeva, Leonid Savin, Oryol State University named after I.S. Turgenev, Oryol, Russian Federation

Solution of new problems and obtainment of original results often require modification of theoretical approaches. The classic theoretical approach to problems of hydrodynamic lubrication theory is based on the Reynolds equation, which allows graceful solution of the majority of problems. However, the equation in question is hardly applicable when it comes to the problems with non-Newtonian fluids. In such cases a more general approach to solving fluid motion's equations itself faces the problem of nonlinearity. It then appears more convenient to use variational approach. The approach is based on finding the minimum of the power functional with an integral limit. Its analysis allows determination of strong and weak sides of the variational approach and conclusion regarding the perspectives of its development.

10:00 am - 10:30 am - Break

5Ga Regency V

Session Chair: P. Shiller, The University of Akron, Akron, OH
Session Vice Chair: X. He, Mechanical Engineering, Northwestern University, Evanston, IL

10:30 am - 11:00 am
Spreading Kinetics of Ultra-thin Polymer-based Lubricant Films Using Molecular Dynamics
Brooklyn Noble, Bart Raeymaekers, University of Utah, Salt Lake City, UT

Ultra-thin polymer-based lubricant films are essential in nanoscale engineering applications because surface forces become increasingly important with decreasing scale. While critical to the design of complex nanoscale lubricant systems, the physical mechanisms that govern spreading kinetics of these films are not well understood. We use molecular dynamics simulations to quantify the speed at which a lubricant droplet advances on a flat substrate as a function of polymer chain length, lubricant thickness, and functional end groups of the lubricant and substrate. The results show that lubricant advances as a power law with two regimes, which we attribute to competing physical mechanisms: pressure in the droplet and entanglement of molecules. This research unifies many years of lubricant kinetics research and has implications for the design of complex, ultra-thin lubricant systems, including micro and nanoelectromechanical devices, anti-biofouling coatings, and hard disk drives.

11:00 am - 11:30 pm
Study on the Lubricant Transfer at the Head-Disk Interface in Hard Disk Drive Using Molecular Dynamics Simulations

Jingan Song, Chang-Dong Yeo, Texas Tech University, Lubbock, TX

In order to achieve higher areal recording density of hard disk drive (HDD), it is required to reduce the physical spacing, i.e. flying height between the read/write elements in head and the magnetic material in disk. With the extremely small flying height, intermittent contact occurs at the head-disk interface (HDI) and possibly damages the head and disk. Therefore, diamond-like carbon (DLC) coating and perfluoropolyther (PFPE) lubricant are applied at the HDI to protect it from damages caused by the contact. However, it is observed that lubricant is transferred from the disk to the head air-bearing surface (ABS) during HDD operation. The transferred lubricant forms droplets on ABS, which act as a contaminant and affect the performance of HDD. In this research, the lubricant transfer mechanism is studied using molecular dynamics (MD) simulations. The effect of molecular weight on lubricant transfer is studied, and the air shear effect on droplet formation and movement is investigated.

11:30 pm - 12:00 pm
Md Simulation of the Adsorption of a Novel Friction Modifier in Pao4 on Hydrated Silica Surfaces
Jie Lu, Xingliang He, Michael Desanker, Tracy Lohr, Tobin Marks, Yip-Wah Chung, Qian Wang, Northwestern University, Evanston, IL

A new friction modifier (FM) with a four-nitrogen heterocyclic ring structure was designed and synthesized for enhanced boundary friction performance. Pin-on-disk tests show a 70% reduction in friction compared to a commercial product, especially in the high temperature region. Molecular dynamics (MD) simulations were pursued to compare the adsorption/desorption of the novel FM and a primary amine FM. Mass-density profiles, number-density profiles, layer thickness, and surface coverage under the influence of temperature changes were calculated. The simulated results provide insight to the nano-layer structures of the adsorbed FMs and further explain the friction reduction mechanisms of the new FM. It also reveals that the novel FM additive is more thermally stable and can provide a higher percentage of surface coverage than does the primary amine.

5H Regency VI

Wear I

Session Chair: M. Villavicencio, Mechanical Engineering, INSA Lyon, Montpellier, Languedoc-Roussillon, France
Session Vice Chair: J. Bomidi, BakerHughes, The Woodlands, TX

8:00 am - 8:30 am
Wear Effects Assessment of Alumina Nanofluids in a Through-flow Test-rig
Gustavo Molina, Kenshantis Martin, Fnu Aktaruzzaman, Valentin Soloiu, Mosfequr Rahman, Georgia Southern University, Statesboro, GA

Nanofluids are nano-size-powder suspensions studied as enhanced alternatives to ordinary cooling fluids. But the wear and erosion effects from their interactions with heat-exchanger materials are largely unknown. Experimental research is presented on typical nanofluids (2%-volume alumina-nanopowder in water, as compared to distilled water as base fluid) which are flowing parallel to the surfaces of typical heat-exchanger materials in a new through-flow test-rig. The substantially different surface modifications when same tests are conducted with the base fluids and with its alumina-nanofluid were assessed by roughness measurements, by weighing of removed-material, and by optical-microscopy. The obtained results with these through-flow tests are compared to the author’s previous investigations using a jet-impingement test-rig.

8:30 am - 9:00 am

Hot Nano-indentation Modeling of High Temperature Ni Alloys
Sepehr Salari, Ali Beheshti, Lamar University, Beaumont, TX

Understanding and optimizing tribological response of high temperature materials used in very high temperature gas cooled reactors is crucial to increase their durability, and operational reliability. Mechanical properties like hardness and elastic modulus can be determined by nano-indentation experiments. Nonetheless, numerical simulations are indispensable to estimate all other basic properties such as yield strength and shear strength as well as their variations with temperature. Although finite element modeling has been widely employed to understand nano-indentation behaviors of various materials, it is only very recently that hot nano-indentation modeling attracted researchers. In the current study, the nano-indentation simulations is performed for different tribological and material properties for near surface film and bulk material. The results are compared and validated against experiments at hot temperature, further are utilized to extract sought materials properties.

9:00 am - 9:30 am
Wear Based Frictional Law for Simulation of Ballast Tracks
Mathieu Renouf, CNRS - University of Montpellier, Montpellier, France, Yves Berthier, CNRS - Univeristy of Lyon, Villeurbanne, France

The ballast track is the granular medium upon which railway sleepers are laid. It is packed between, below, and around the ties. It is typically made of crushed stone. Its main roles is used to facilitate drainage of water, to bear the load and to hold the track in place as the trains roll by. For safety reasons, it is important to preserve and control the track quality. When numerical approaches are used to simulated its behaviour, a parameter such as grain wear remains to consider. Between the start up of a new ballast and withdrawal during maintenance process, the shape of the grain could strongly evolved in time. These changes are due mainly due to high pressures exerted under the sleepers and local cyclic displacement induced by vibration. To improve the modeling of ballast behavior, the present work proposes to account for grain wear by the way of a friction law based on statistic of experimental results of friction measure. Model is presented and results discussed.

9:30 am - 10:00 am
Experimental Investigation of Material Removal Mechanism of Single Crystal Sapphire in Single Diamond Grit Scratching
Hui Huang, Qingxu Lin, Feng Jiang, Xipeng Xu, Huaqiao University, Xiamen, China

This paper presents an important investigation of brittle fracture and the associated material removal behavior of single crystal sapphire during single diamond grit scratching. Conical diamond grits with different vertex angle were used to perform indentation testing and scratching testing on A-plane and C-plane sapphire. Scratching forces were measured and scratched surface morphologies were observed under different scratching speed and scratching depth. The results indicate that vertex angle and scratching depth have important influence on the scratching forces. Scratching force for C-plane is bigger than that for A-plane under same scratching condition. The influence of scratching speed on the scratching force is a less obvious. Typical pulverization and crack were observed on scratched surface, which is located below the diamond indenter. River-shaped crack and step-shaped crack were observed for A-plane and C-plane on the surface beyond the diamond indenter respectively.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Ultrasmooth Submicrometer Carbon Spheres as Lubricant Additives for Friction and Wear Reduction
Abdullah Alazemi, Farshid Sadeghi, Purdue University, West Lafayette, IN

Ultrasmooth submicrometer carbon spheres are demonstrated as an efficient additive for improving the tribological performance of lubricating oils. The tribological behavior of the new lubricant mixture is investigated in the boundary and mixed lubrication regimes using a pin-on-disk apparatus and cylinder-on-disk tribometer, respectively. The new lubricant composition containing 3 wt % carbon spheres suspended in a reference SAE 5W30 engine oil exhibited a substantial reduction in friction and wear (10−25%) compared to the reference oil, without change in the viscosity. Microscopic and spectroscopic investigation of the carbon spheres after the tribological experiments illustrated their excellent mechanical and chemical stability. The significantly better tribological performance of the hybrid lubricant is attributed to the perfectly spherical shape and ultrasmooth surface of carbon sphere additive filling the gap between surfaces and acting as a nanoscale ball bearing.

11:00 am - 11:30 am
Friction and Wear Mechanism of Metallic Glasses with Ionic Liquids as a Lubricant
Jaeho Lee, Chang-Dong Yeo, Texas Tech University, Lubbock, TX

The Ionic liquids (1-alkyl-3-methylimidazolium bis{(trifluoromethane)sulfonyl}amid and 1-alkyl-3-methylimidazolium bromide) were applied onto the surface of the metallic samples (pure Palladium/Platinum and Palladium/Platinum based metallic glasses) and their performance as a lubricant were investigated during the reciprocating sliding contact test against a steel ball in ambient temperature. Friction and wear behaviors were analyzed after the sliding contact test. The metallic glasses showed excellent reduction of friction force and wear resistance with better material strength than the pure metal samples during the sliding contact and the ionic liquids showed high lubrication performance. In addition, the formation of the tribofilm and material transfer behaviors on the sliding contact area were investigated by X-ray photoelectron spectroscopy (XPS) with ion gun sputtering which enables to examine the scratched area layer by layer.

11:30 am - 12:00 pm
A New Insight into the Interfacial Mechanisms of the Tribofilm Formed by Zinc Dialkyl Dithiophosphate
Pourya Parsaeian, University of Leeds, Leeds, United Kingdom

Understanding the true interfacial mechanisms of the growth of the tribofilms generated by Zinc Dialkyl Dithiophosphate (ZDDP) is important because it is the most widely used anti-wear additive and there is legislative pressure to find efficient environmentally friendly replacements. The main focus of this study is to investigate the durability of the ZDDP tribofilm and correlate it to the chemical properties of the glassy polyphosphates. The effect of parameters such as temperature and load on tribofilm formation and its durability has been studied experimentally by using a Mini Traction Machine (MTM) with the Spacer Layer Interferometry Method (SLIM) attachment. The role of additive depletion on the pre-formed tribofilm thickness under mechanical stress has also been studied. XPS analyses were carried out before suspending the test and after changing the oil to assess the difference in chemical structure of the tribofilm before and after stopping the test.

5I Regency VII

Grease II

Session Chair: M. Benes, Baker-Hughes, The Woodlands, TX
Session Vice Chair: P. Shiller, The University of Akron, Akron, OH

8:00 am - 8:30 am
On the Relationship Between Grease Formulation and Friction in Rolling-Sliding Concentrated Contacts
Nicola De Laurentis, Philippa Cann, Imperial College London, London , United Kingdom, Piet Lugt, SKF

Engineering and Research Centre, Nieuwegein, Netherlands, Amir Kadiric, Imperial College London, London , United Kingdom

Given that the majority of rolling bearings are lubricated with grease, one of the most effective ways to improve bearing efficiency is through a suitable grease formulation. However, the current knowledge and understanding of the relationship between grease formulation and its behaviour in lubricated bearing contacts are still rather limited. This study attempts to address some aspects of grease lubrication in bearing-like contacts, with the ultimate aim of improving the efficiency of rolling bearings through better grease formulation. A large set of commercial and custom greases, covering a wide range of bearing grease compositions, were tested in ball-on-disc tribometers. The friction and film thickness results are interpreted as a function of grease formulation, with specific focus on the influence of base oil type, viscosity, thickener type and presence of additives on friction.

8:30 am - 9:00 am
The Effect of Polymeric Additives on Grease Performance
Gaston Aguilar, Afton Chemical Corporation, Richmond, VA

The purpose of the paper to show the influence of polymers on the physical, mechanical and functional properties of grease. Specifically, three polymer types were selected for the study. The types are olefin copolymer (OCP), dispersant olefin copolymer (DOCP) and hydrogenated styrene butadiene polymer (HSB) of similar molecular weight and shear stability. For this study, baseline lithium grease was produced followed by the production of three greases by the same process to which the polymers were added at beginning of the manufacturing process. For this study, properties of interest are soap thickening efficiency, mechanical stability, water resistance, fretting wear and grease bearing life. Microstructure and rheological analyses were also performed and correlated to performance.

9:00 am - 9:30 am
Additive Technology to Improve the Grease Making Process
Gareth Fish, The Lubrizol Corporation, Wickliffe, OH

The process to manufacture grease is as important to grease properties as are the base oil, thickener, and the additives used to enhance performance. Grease producers manufacture greases using a wide variety of processes. This can be attributed to the availability of the raw materials for grease making and differences in the equipment. Provided that the response of each variable is known, grease making is a controlled acid / base chemical reaction process. Grease makers strive to optimize their process for each thickener type based upon an understanding of the process variables.
This paper will discuss additive technologies that can enable grease producers to improve their grease making process. The additive technologies discussed are for: improving the grease yield without compromising the general properties of the grease; reducing oil bleed at both storage and elevated temperatures; and enhancing the dropping points of lithium and calcium 12-hydroxystearate soap thickened greases.

9:30 am - 10:00 am
Effects of Li Grease Components on Radial Ball Bearing Torque and Their Properties
Kazumi Sakai, David Kostal, Brno University of Technology, Brno, Czech Republic, Yuji Shitara, JX Nippon Oil & Energy Corporation, Yokohama, Japan, Motohiro Kaneta, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

The friction torque of radial ball bearing with lithium type greases were evaluated in order to investigate the dependence of thickener and base oil types. The greases providing lower bearing torques were not identical depending on the bearing rotation speed. For the discussion of the influence of grease components on the bearing torque behaviors, the rheological properties, such as viscoelasticity and viscosity, and the film thickness of greases were evaluated. The results suggest that the film thickness under low speed condition correlate to the bearing torque under lower bearing speed range and

rheological parameters correlate to the torque under higher bearing speed range. It seems that the importance of grease properties for reduction of bearing torque depends on bearing operating conditions because grease behaviors differed by the bearing rotation speeds. Based on the results, the lubrication mechanism for this study will be proposed.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Polypropylene – A Thickener Technology With Many Surprises.
Johan Leckner, René Westbroek, Axel Christiernsson International AB, Nol, Sweden

In recent conference presentations we have shown that the lubricating mechanism of polypropylene thickened greases in rolling element bearings differ significantly from that of soap based greases. These differences give rise to lower self-induced running temperatures, seven times longer grease life and a very effective replenishment mechanism. In this paper we dive deeper into the mechanistic differences that we have already presented. Furthermore, we expand the study into showing differences in additive response, low temperature lubricity and behavior when subjected to high temperature and oxidation promoting conditions.

11:00 am - 11:30 am
Rust for the Record: Significant Factors Affecting Corrosion Protection in Grease
Joseph Kaperick, Gaston Aguilar, Afton Chemical Corporation, Richmond, VA

All corrosion inhibitors are not equal and none of them work in a vacuum. There are several significant factors that can affect the ability of rust inhibitors to protect the metal surfaces with which they are entrusted. Case studies are presented exploring the impact of differences in grease thickener chemistry on the effectiveness of various rust inhibitors, as well as the effect of competition with other performance additives. Both positive and negative synergies are seen and explored.

11:30 am - 12:00 pm - OPEN

5J — The Learning Center (TLC)

Tribochemistry I

Session Chair: J. Harrison, Chemistry, US Naval Academy, Annapolis, MD
Session Vice Chair:

8:00 am - 8:30 am
Mechanochemical Behaviour of ZDDP
Hugh Spikes, jie zhang, Imperial College London, London, United Kingdom

It has recently been shown that tribofilm formation by the widely-used antiwear additive zinc dialkyldithiophosphate (ZDDP) is driven by the applied shear stress present in rubbing contacts rather than by the energy dissipated in these contacts. This means that ZDDP reaction results from the stretching and breaking of molecular bonds under stress, *i.e*. mechanochemistry; an insight that enables relationships between molecular structure and reactivity to be developed. This presentation described a study of the impact of applied stress on ZDDP film formation under both full film and boundary lubrication conditions to support the principle that ZDDP reaction is controlled by mechanochemistry .

8:30 am - 9:00 am

Sliding Evolution of the Chemical And Mechanical Properties of the Tribofilms Formed From Low- and High-saps Oils And Zddp on Steel, H-dlc and Si-dlc

Somayeh Akbari, Mitjan Kalin, Eva Oblak, Ljubljana University, Ljubljana, Slovenia

Different studies have been performed to understand the chemical structure and the mechanical characteristics of tribofilms on steel and coatings surfaces, but the interactions between these properties are still lacked of deep understanding. In this work, the evolution of the chemical structure and mechanical characteristics of tribofilms formed in the boundary-lubricated steel/steel, steel/Si-DLC and steel/H-DLC contacts were examined at two different times. Three oils have been used: two fully formulated oils with various quantities of SAPS additive and a base oil with ZDDP additive. AFM has been used in different modes to analyse topography, stiffness and thickness of tribofilms. Moreover, ATR-FTIR has been used for the chemical characterization of tribofilms. The results have indicated that the chemical structure strongly support understanding of the tribofilm mechanical properties, growth and tribofilm's evolution, which are clearly dependent of the oil additives and surface type.

9:00 am - 9:30 am

In-situ Raman Investigation of Tribofilm Formation and Degradation During Boundary Friction

Jean-Louis Mansot, Jean-Wilner Petit, Audrey Molza, yves Bercion, Université des antilles, Pointe a Pitre, Guadeloupe, France

The present work is concerned with the in situ investigation, using Raman microspectrometry in the dynamic lubricated boundary contact, of the tribofilm built up and degradation during friction tests. Experiments are carried out on reciprocating sphere (monocrystalline sapphire) on plane (52100 AISI steel) tribometer coupled to a Raman microspectrometer. The lubricant is a 5% dispersion of graphitized carbon nanoparticles into pentane. Raman point spectra acquired in the sliding contact during the tribofilm building up to its damaging period allowed us, by specific treatments of the Raman spectra, to measure quantitatively and simultaneously the pressure, the lubricant film thickness, the chemical and structural evolution of the tribofilm in the sliding interface.

9:30 am - 10:00 am

The Effect of Lubricant Environments on Hydrogen Embrittlement

Joshua Seetanah, Monica Ratoi, University of Southampton, Southampton, Hampshire, United Kingdom

The presence of Hydrogen (H) in rolling-contact-fatigue (RCF) tests is one of the factors influencing the formation of white etching cracks (WEC) in the sub-surface [1]. High pressure, high temperature RCF tests were conducted on bearing steel (JIS SUJ2) to failure, in controlled atmospheres (Air, inert Argon and Hydrogen), lubricated with a synthetic Polyalphaolefin (PAO32) oil. Ball/disc specimens were investigated using thermal desorption spectrometry for H content evaluation. Wear was investigated using optical microscopy and profilometry. Serial sectioning methods and high energy micro-computed-tomography were used for sub-surface analysis and WEC characterisation. It was found that H permeation is primarily due to the physical decomposition of the PAO32 under heat and pressure. The atmosphere controls the formation of oxidative films, which reduces asperity contact and helps prevent further hydrogen decomposition. Inert atmospheres promote surface distress, friction and fatigue.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am

Surface Passivation and Boundary Lubrication of Self-mated Tetrahedral Amorphous Carbon Asperities Under Extreme Tribological Conditions

Michael Moseler, Pedro Romero, Lars Pastewka, Fraunhofer Institute for Mechanics of Materials, Freiburg, Germany

Tetrahedral amorphous carbon coatings have the potential to significantly reduce friction and wear between sliding components. Here, we provide atomistic insights into the evolution of the sliding interface between naked and hydrogen-passivated ta-C sliding partners under dry and lubricated conditions. Using reactive classical atomistic simulations we show that sliding induces a sp3 to sp2 rehybridization and that the shear resistance is reduced by hydrogen-passivation and hexadecane-lubrication. As asperities deform, carbon atoms within the hexadecane lubricant bind to the ta-C sliding partners resulting in degradation of the hexadecane molecules and in increased material intermixing at the sliding interface. Hydrogen atoms from the passivation layer and from the hexadecane chains continue to be mixed within a sp2 rich sliding interface eventually generating a tribo-layer that resembles an a-C:H type of material.

11:00 am - 11:30 am
Contacts Between Nanoparticles Investigation by In Situ Nano-tribologic Experiments in Environmental Stem
Jean-Louis Mansot, andi Mikosch Cuka, université des antilles, Pointe a Pitre, Guadeloupe, France, Philippe Bilas, GTSI université des Antilles, Pointe a Pitre, Guadeloupe, France, yves Bercion, université des antilles, Pointe a Pitre, Guadeloupe, France

Numerous works clearly pointed out that tribologic properties of tribofilm are strongly related to their nanostructure. In many cases, when the tribofilms are obtained from nanoparticles in dispersion in lubricant bases for examples, the contact between individual particles in the tribofilm appear to play an important role in the global tribological behaviour. A nano-tribometer developed at C^3MAG allows us to carry out nano-tribologic experiment in environmental STEM and to investigate at micro and nanoscale the tribologic behaviour of static and dynamic boundary contacts between individual nanoparticles or aggregates under vacuum and in the presence of various environmental conditions (inert gaz, oxygen, hydrocarbons). Friction coefficient and particles deformations and damages are quantitatively measured. Correlation of results acquired at nanoscale to the macroscale properties is attempted.

11:30 am - 12:00 pm
Linking Microstructure to Wear-induced Pitting Corrosion in Aged 2507 Super Duplex Stainless Steel
J. Michael Shockley, US Naval Research Lab, Washington, DC, Derek Horton, Chemistry Division, Center for Corrosion Science and Engineering Branch, US Naval Research Lab, Washington, DC, Kathryn Wahl, US Naval Research Lab, Washington, DC

Grade 2507 super duplex stainless steel ordinarily achieves a balance of corrosion resistance and mechanical properties through its dual phase ferrite-austenite microstructure. However, heat treatment in the 600-900°C temperature range causes phase transformations to occur, developing complex microstructures with secondary phases including sigma phase, secondary austenite, chi phase, and chromium nitrides. It has been shown that in tribocorrosion experiments in 0.6 M NaCl in anodic conditions, the passivity of aged 2507 can be eliminated due to mechanical wear, causing pitting to occur in and near the wear track. However, the precise mechanism of this loss of passivity is not yet understood. In the present study, we explore the tribocorrosion behavior at selected phases and grain boundaries. Correlating the microstructural features to local surface topography changes and the current transient response promises to reveal precise details of the wear-induced corrosion behavior.

5K Dunwoody

Non-Ferrous Metals I (Working)

Session Chair: P. Deneuville, Constellium CRV, Voreppe, France
Session Vice Chair: R. Pruhs, Quaker Chemical, Conshohocken, PA

8:00 am - 8:30 am
Evaluation of Lubricants for Forming Al Alloys
Taylan Altan, The Ohio State University, Columbus, OH, David Diaz, GRA, Center for Precision Forming, The Ohio State University

To reduce vehicle weight and CO_2 emissions, lightweighting using Al alloys are very important. Forming of Al alloys offer various challenges, in terms of material formability properties and also in the development of new lubricants to form the new Al alloys. In sheet metal forming lubricants are necessary to avoid adhesion, galling and scratching during the forming or stamping operations. This presentation will review the classical methods used for evaluating lubricants such as strip draw test, draw bead simulations, twist compression and the Cup Draw Test. Examples of CDT to evaluate the lubricity and performance of various lubricants is discussed. The effect of forming or sliding speed and temperature, at the sheet/die interface is presented. Recommendations will be presented on how best to evaluate lubricants for use under production conditions

8:30 am - 9:00 am
The Effect of Temperature on the Tribological Behavior of Tungsten Disulphide and Graphene Oxide in Aluminum-on-Steel Contact
Olufisayo Gali, Afsaneh Edrisy, Reza Riahi, University of Windsor, Windsor, Ontario, Canada

Aluminums' high tendency to adhere to steel has led to extensive research into the application of lubricants to reduce adhesion and friction during forming processes. The behavior of lubricants like tungsten disulfide (WS_2) and graphene oxide (GO) are sensitive to their deposition method. WS_2 applied through aerosol spray was found to increase its useful temperature range. Previous work with commercial aerosols and a novel carbon-based WS_2 sprays revealed low COF and effective aluminum adhesion mitigation but low durability at 450°C. The aerosol spray, though released nauseating gases. Research on GO has been limited. This research compares the anti-friction, adhesion mitigation and durability properties at elevated temperatures of GO and WS_2, deposited through similar novel spray deposition. These tribological properties were determined using ball-on-disc sliding tests and surface characterization / analysis. The application of GO to extend the durability of WS_2 was also investigated.

9:00 am - 9:30 am
Testing Criteria in the Additive Selection for MWF Involving Aluminum Alloys
John Nussbaumer, Dover Chemical Corporation, Dover, OH

In this presentation we will discuss the various testing methodologies that can be employed in evaluating additives to be used in metalworking fluids. Alloys to be evaluated will be 356T6 and 6061. Testing methods will include Microtap Tap and Torque, Falex Pin and Vee Block and CNC (Computer Numerical Control) evaluations. These methods will show what the effects of various additives have on torque, load and wear on the tool. The surface finish of the workpiece will also be evaluated. Additives for evaluation will include phosphate esters and amides, esters, polymeric esters, chlorinated alkanes and phosphites.

9:30 am - 10:00 am
Investigation of Lubricity Additives for Chlorinated Paraffin Replacement on Aluminum in Boundary and Mixed/EHL Regimes
Yixing (Philip) Zhao, Alexandra Goode, houghton international, Norristown, PA

Due to more and more regulatory restriction on chlorinated paraffins in metalworking fluid applications, many manufacturers are urgently working on the possible replacement with other alternative lubricity additives such as phosphate esters, sulfurized additives and esters. Obviously it is very helpful to have good understanding of the tribological properties of these additives, such as lubricity and lubricant film strength. This presentation will report the investigation of tribological properties of lubricity additives on aluminum by a multi-purpose tribology tester and white light optical profilometer. Each pure additive was tested under boundary lubrication and mixed/EHL conditions, respectively. We have found that some

lubricity additives can have lower COF values than CPs, but CPs normally have much stronger lubricant film strength which makes CPs unique. These tribological properties will provide guidance in our formulation work of CP replacement for different applications.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
A New Generation of Phosphate-esters for Non-ferrous Metals Machining: Balancing Performance, Labeling and Economics
Claude Hedoire, Solvay, Aubervilliers, France

Phosphate-esters are well known multi-functional additives for non-ferrous metals machining.
The most currently used phosphate-esters are based on long carbon chains, like cetyl oleyl chain. While providing excellent emulsion stability, good anti-wear performance and good staining inhibition, they tend to foam too much and to generate soap in hard water, creating deposits on tools, work-pieces or filters. Besides, their eco-toxicity has been reviewed in 2015 and they are now classified as very toxic to aquatic life. Solvay researchers took a number of steps to optimize the performance and classification of phosphate-esters..The result is the development of a new generation of non-ecotoxic phosphate-esters with enhanced foam control.

11:00 am - 11:30 am
Nanotribology of a Catechol-Functionalized Alkane with Terminal Chain Branching
Marina Ruths, University of Massachusetts Lowell, Lowell, MA, Karin Persson, SP Technical Research Institute of Sweden, Stockholm, Sweden

A bio-inspired system was studied where the terminal chain branching found in fatty acids naturally present on hair and wool was combined with a catechol group as the hydrophilic moiety to mimic the adhesion strategies found in mussel proteins. Atomic force microscopy (AFM) was used to study the adhesion and nanoscopic friction of monolayers of a catechol-functionalized branched alkane, 4-[(18S)-18-methyleicosyl]benzene-1,2-diol, formed by Langmuir-Blodgett deposition on silicon oxide, mica, and polydimethylsiloxane (PDMS) substrates. Measurements were done in ambient air and in dry N_2 gas. In dry N_2, the friction of these monolayers was low and the adhesion was well described by van der Waals interactions. In ambient air, the adhesion and friction showed a stronger hysteresis and different friction responses at low and high loads. The results will be discussed in view of possible bonding to the substrate and lateral cross-linking in the monolayer.

5L Courtland

Gears I

Session Chair: S. Li, Wright State University, Dayton, OH
Session Vice Chair:

8:00 am - 8:30 am
Experimental Evaluation and Microscopic Analysis of Surface Coatings for Scuffing Resistance in Rotorcraft Gear Steels
Mark Riggs, Stephen Berkebile, Nikhil Murthy, Army Research Lab, Aberdeen Proving Ground, MD, Andras Korenyi-Both, Tribologix Inc., Golden, CO

During a loss-of-lubrication condition in rotorcraft transmissions, liquid lubricant supply to the contact zone diminishes. The eventual breakdown of the lubricating film leads to the initiation of scuffing, which eventually results in catastrophic failure. A nanocomposite coating and a nanocomposite coating with a

sublayer of a hard coating have been applied to 9310 gear steel. These coatings have been evaluated for their ability to delay scuffing initiation during a loss of lubrication event with a ball-on-disc tribometer at high speed (16 m/s) and load (1.3 GPa). The time to scuffing initiation for the coated samples and a baseline gear steel have been compared along with friction coefficient data to characterize the behavior of the mechanical contact under various operating conditions relevant to aerospace spur gears. Analysis of the surfaces are also provided using electron and optical microscopes for profile measurements and chemical analysis to demonstrate the failure mode.

8:30 am - 9:00 am
Influence of a DLC Coating on the Temperature and Friction in a Helical Tooth Flank Contact
Ronny Beilicke, Lars Bobach, Dirk Bartel, Otto von Guericke University Magdeburg, Magdeburg, Germany

In the presentation a transient 3D thermal elastohydrodynamic simulation model will be introduced. In this model the real gear geometry including arbitrary modifications, rough surfaces and mixed friction conditions, realistic load distribution and shear thinning behavior of the lubricant as well as friction-induced temperature development of the lubricant and the tooth flanks are considered. From the DLC coating and the substrate the thermo-physical properties are taken into account depending upon the depth to allow for temperature computation in the DLC coating and the substrate. The lubricant data is taken from high-pressure viscometry and traction measurements performed on a twin-disk machine. Using the example of a helical gear pair, it will be shown, what influence selected parameters and a DLC coating have on the lubricating conditions, temperature, friction and power loss. Therefore, the computation results are presented in a well understandable way using diagrams and animations.

9:00 am - 9:30 am
Preliminary Investigations on the Influence of Micropitting on Friction
Thomas Touret, Lamcos - Ecam, Villeurbanne, Rhone, France, Fabrice Ville, Lamcos, Villeurbanne, Rhone, France, Christophe Changenet, Ecam, Lyon, Rhone, France

Micropitting is a common damage in gears. It modifies surface aspect and thus roughness of contacting surfaces. The link between friction and roughness has been studied but correlation between friction and micropitting still needs to be quantified. Twin-disk apparatus allows simulating lubricated contacts for specific contact conditions: rolling speed, slide-to-roll ratio, load, surface geometry. The present study aims to generate micropitting on a twin-disk machine and to measure friction generated by this specimen. Micropitting evolution and induced friction are then analyzed

9:30 am - 10:00 am
Investigation of Solid Lubricants for Use in Aviation Gearboxes
Jeffrey Ewin, Joseph Ullmann, Angelo Viray, NAVAIR, Patuxent River, MD

Gearboxes have historically required oil lubrication to provide wear resistance and heat dissipation for the internal gears and bearings; however smaller Unmanned Aerial Vehicles (UAVs) that are becoming prevalent for military and commercial use may not require oil lubrication for their small gearboxes. Bench tests were performed on diamond like carbon (DLC) and other solid lubricant coatings applied to superfinished AISI 9310 steel. The coatings were evaluated using a Wedeven Associates Machine (WAM) and the U.S. NAVY Ryder rig at various speeds and loads to quantify the time to failure. The objective was to quantify the operating envelope of these technologies in an oil free gearbox system.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Onset and Progression of Micropitting Damage in Gear Teeth Contacts

Amir Kadiric, Pawel Rycerz, Imperial College London, London, United Kingdom, Guillermo Morales-Espejel, SKF Engineering and Research Centre, Nieuwegein, Netherlands

This paper describes the results of a numerical and experimental study into the factors influencing the onset and progression of micropitting damage in gear teeth contacts. A previously developed micropitting model based on contact damage criterion and accounting for competing effects of wear and micropitting in lubricated, rough rolling-sliding contacts, which was successfully used in the past to study micropitting in rolling bearings, is utilized here to model micropitting in spur gears. Experiments carried out on a triple-contact micropitting test rig are first used to validate the model predictions under gear teeth contact conditions. The model is then used to study the influence of several parameters on the extent and distribution of micropitting along gear teeth with particular focus on the role of sliding. The results show that the observed increase in micropitting at higher slide-roll-ratios is primarily due to the increase in the number of load micro-cycles on asperity level.

11:00 am - 11:30 am
Influences on the Wear Behavior of Grease Lubricated Gears Operated with Dip and Spray Lubrication.
Andreas Dobler, Thomas Tobie, Karsten Stahl, Technical University of Munich, Garching b. München, Germany

ISO 14635-3 offers a method to investigate the wear behavior of grease lubricated gears in the FZG back-to-back test rig. This standardized test is run with dip lubrication. Grease thickener, base oil viscosity and lubricant additives are known to have significant influence on the wear behavior. Some studies have also identified the lubrication supply mechanisms ‘channeling’ and ‘circulating’ to affect the wear intensity considerably. Large open gear drives, however, are often spray lubricated. It is uncertain, to what extent the test results with dip lubrication apply to spray lubricated gear drives. Within a research project, comparative tests have been performed, showing the effects of different lubrication types on the wear behavior of gears. A test rig was modified and the bulk temperature was measured via an infrared sensor. Under nominally equivalent tribological test conditions, spray lubrication has been found to reduce gear wear significantly compared to dip lubrication.

11:30 am - 12:00 pm
Analysis of Twin-Disk Machine Experiments by Using Thermal Network Method
Gregoire Isaac, Jerome Cavoret, Fabrice Ville, INSA Lyon, Villeurbanne, France, Christophe Changenet, ECAM Lyon, Lyon, France, Guillaume Beck, Samuel Becquerelle, SAFRAN Transmission Systems, Colombes, France

Two kinds of studies can be found in the literature concerning elastohydrodynamic lubrication. On one hand, some are based on experiments that are fairly representative of contact conditions observed in real applications (gears, REB) and hence deduce empirical friction laws with classical models. On the other hand, some focus on rheological experiments on a lubricant and aim at better understanding its behavior. The latter are generally performed with operating conditions that are not representative of the severe conditions encountered in real applications. Correlations are thus difficult to establish between both approaches. In this study, a numerical model of the test-rig used to perform traction curves is proposed. The aim is to extend the focus beyond the very limited contact area and to represent the whole system in order to obtain a better understanding of its global behavior, for example in case of scuffing analyses.

5M — Baker

Condition Monitoring II

Session Chair: J. Mehta, Fluitec International, Jersey City, NJ

Session Vice Chair: C. Henrique, Grupo Oil Check, Contagem, Brazil

8:00 am - 8:30 am
Using Oil Analysis to Trigger Wear Debris Analysis
Michael Holloway, ALS Tribology, Highland Village, TX

Oil analysis has become a common practice for maintenance and reliability teams looking to improve equipment reliability and reduce operating costs. There are some companies now that are using oil analysis to direct when to sample for wear debris analysis. Using data points in oil analysis allows a trigger to when to run direct and analytical Ferrography. This advanced form for condition monitoring helps identify where debris its being generated and what contaminates are contributing to early failure modes. This class examines case studies of such examples and the benefits achieved.

8:30 am - 9:00 am
Operating Conditions That Shorten Gas Engine Oil Life
Nnamdi Achebe, Petrosave Integrated Services Ltd., Amuwo-Odofin, Lagos, Nigeria

In-service oil life may span 500 to > 8,000 Hrs depending on conditions. 1)Food company averaged 3,500 oil Hrs now experiencing <1,000 Hrs for same running conditions. 50Hrs sampling interval showed oxidation, TBN & TAN crossed Limits; Viscosity at Warning. Total make-up oil since oil change was lesser than calculated using OEM's 0.3g of oil per KwH. 2)Oil sample taken <50Hrs Oil Change revealed 50% remaining life. Oil analysis showed insufficient oil changeout as reason for rapid degradation. 3) 850kW from new Production Line shared across running Gas Engines raised load from previously 60% to 90%; resulted in emergence of "sacrificial metals" – Tin, Chrome, Molly occurring during peak and shock loads consequentially shortened oil life from prior 2,500 Hrs ODI to barely 1,500 Hrs. 4)Operators' self-help initiative to replace GEO with multi-grade DEO shortened oil life; thinned down oil viscosity, raised Nitration, TAN & TBN; thus forcing oil change reversal to proper OEM approved GEO.

9:00 am - 9:30 am
Building a Championship Organization
Brett Minges, POLARIS Laboratories, Indianapolis, IN

A program champion is the catalyst for change within an organization, and their influence can guide an oil analysis program from reactive maintenance to predictive maintenance. Adopting oil analysis into a maintenance program and integrating it into the company culture is never easy, but it can have a profound effect on maintenance costs and equipment reliability. From triaging equipment breakdowns to adjusting sump capacity based off of data trends, this presentation covers the challenges, setbacks and successes associated over the first few years of integrating fluid analysis into a company. One size never fits all, but there are common techniques to organize the people, processes, and technology in order to generate longer equipment life and maintenance savings.

9:30 am - 10:00 am
Observance and Identification of an Unusual Contaminant in a Press Hydraulic System
John Duchowski, Timo Lang, Valerie Diehl-Klein, HYDAC FluidCareCenter, Sulzbach, Saar, Germany

The appearance of a highly unusual contaminant was noted in a hydraulic system of a large press located in Columbia. The quantities of the contaminant were sufficiently large to completely occlude the entire surface of the filter elements employed in the system leading to their extremely and unacceptably short service interval. For reasons of their own, neither the press OEM nor the operator chose to divulge the nature of the application for which the press was being employed leaving the detective work of contaminant identification to our laboratories. In the course of the investigative work that utilized several sophisticated and highly specialized analytical techniques, we have successfully identified the nature of the contaminant, pinpointed its source and identified the process for which the press was employed. The results of the investigative work carried out will be described herein.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Lubricant Volatility Analysis by Thermogravimetric Analysis (TGA) using ASTM D6375
Keith Schomburg, PerkinElmer, Shelton, CT

Many of the formulated lubricants made today are designed to meet the stringent specifications and demand of newer high performance engines and machines. These newer lubricants are found to be lower in viscosity for improved fuel economy but this also leads to higher evaporation rates in service due to higher temperatures and stress. One of the tests used to determine lubricant volatility is the NOACK test by ASTM D6375. The TGA NOACK test has many positive attributes leading to its use, such as high volume testing, speed of analysis, repeatability of testing, low volume of sample and ease of use. In this ASTM test a sample is heated to the NOACK temperature in a TGA instrument and held isothermal for a period of time. During this time the NOACK volatility is determined based on the value of a NOACK reference standard. In this presentation several method improvements and considerations are discussed that are used to improve the repeatability and reproducibility of NOACK results.

11:00 am - 11:30 am
Move Beyond the Individual Oil Analysis Result
Henry Neicamp, POLARIS Laboratories, Indianapolis, IN

Examining aggregate fluid sampling data will help maintenance programs discover the root cause for high-severity reports and help maintenance staff address issues before damage occurs on other units. Examining the aggregate testing data can reveal valuable data about: Common causes of wear and failures, Fluid mixing, Contamination sources, Optimal drain intervals, Equipment make/models that support operations best management reports, scattergrams, and program reviews are used to discover trends and systemic problems. In most instances, programs already have enough data today to drive changes, increase uptime, and reduce maintenance costs, but program champions need to uncover the data trends and adjust their maintenance strategies in order to minimize wear and maximize savings.

11:30 am - 12:00 pm
Foam-DDI_ Fast, Reliable and Unbiased Determination of Foaming Tendencies of Lubricants by Digital Detection Imaging.
Aaron Mendez, Ayalytical Instruments, Houston, TX

Oil industry operations are negatively impacted by loss of efficiency of lubricants. They degrade overtime due to: loss of viscosity, oxidation, polar and water contamination and foaming tendency. These characteristics are assessed by ASTM D892 that empirically rates the lubricants. D892 determines lubricants ability to resist foam formation and dissipate foam creation, however D892 is operator-biased, lengthy and render low repeatable and reproducible results. Foam inhibitors eliminate or retard the formation of stable foam, however, it is a challenge that demands precise selection of the defoamant and careful control of optimum concentration. The effect of antifoams and the lubricant properties require continuous, fast response tests, that Foam-DDI can provide. Foam-DDI accurately controls the air flow, temperature and sequence, using a precise VISION algorithm to determine static and dynamic foam heights, fast and accurately. Repeatability and reproducibility are excellent.

Session Chair: M. Holloway, ALS Tribology, Highland Village, TX
Session Vice Chair: K. Rogers, Pilot Thomas Logistics, N. Las Vegas, NV

1:30 pm - 2:00 pm
Using Lubrication Failure for Spend Analysis and Specification Development
Michael Holloway, ALS Tribology, Highland Village, TX

When we consider that the biggest machines that do the most work are made up of smaller machines that are made up of components, it becomes obvious that when a large machine breaks it is normally due to a small component or components failing. This seminar presents a method by which you can lower your operational costs and increase productivity by establishing a performance based procurement specification on the very components that are a cancer to your facility, plant, mill or mine. In order to develop the specification it is vital that you understand what you are spending the most money on also known as a spend analysis. This is covered in the seminar. It will also require a basic understanding of influential components and materials physical properties which are also covered. Finally, by uncovering the various contributors that adversely affect the profitability, a sound procurement specification can be drafted.

2:00 pm - 2:30 pm
Predicting Asset Failures Using Data Analytics of Lubricating Oil
Brian Byrne, T.E. Laboratories, Tullow, Carlow, Ireland

Oil analysis programs depend massively on the accuracy of the data they are monitoring as well as the interpretation and presentation of that data to operations and maintenance. To do this effectively involves emphasising quality throughout the process, from sample taking and analysis, through to diagnosis and reporting. Once quality is assured, the service provider can then concentrate on reviewing and trending data to try achieve these proactive and predictive goals outlined earlier. Statistical analysis of historical data can establish precise oil change intervals, establish effective alarm and alert limits, as well as predict remaining life of machinery based off historical tendencies. This allows a systematic approach towards condition-based maintenance. Taking this approach in a retrospective manner, and collaborating alongside maintenance intervention data, this paper intends to establish predictive indicators in a proactive capacity.

2:30 pm - 3:00 pm - Condition Monitoring Meeting

3:00 pm - 3:30 pm - Break

6P — The Learning Center (TLC)

Engine & Drivetrain II

Session Chair: D. Uy, Ford Motor Co., Dearborn, MI
Session Vice Chair: W. Anderson, Afton Chemical Corp., Richmond, VA

1:30 pm - 2:00 pm
TheTribological Response Under Slip-Rolling of Bismuth Compounds Versus Molybdenum Dithiocarbamate
Mathias Woydt, BAM, Berlin, Germany, John-Theodore Burbank, FUCHS Europe Schmierstoffe GmbH, Mannheim, Germany

The frictional response of molybdenum bis(C11-14 branched and linear alkyl) carbamodithioate oxo thioxo complex (Mo-dttc) versus bismuth dimethyldithiocarbamate (Bi-dtc) and bismuth dodecylbenzene sulfonate (Bi-ddbsa) slip-rolling under mixed/boundary lubrication (T= 120°C, n= 10 millions of cycles, P_{0max}= 2.25 GPa) in PAO-based formulation against three different steel alloys were compared. Bismuth compounds have so far a favorable eco-toxocological profile. Bismuth compounds showed a pronounced frictional response in PAO-based formulations and clearly formstable and wear resistant tribofilms. The additive response and tribofilm formation is linked to the steel metallurgy. Bi-ddbsa showed the lowest coefficients of friction against 20MnCr5 (SAE 4820, or 5120, case-hardened) and 45SiCrMo6 (1.8062, non-case-hardened) over Mo-dtc. The wear protection of Bi-compounds is similar to Mo-dtc against 20MnCr5 and 45SiCrMo6 as well as more pronounced against 36NiCrMoV1-5-7 (non-case-hardened).

2:00 pm - 2:30 pm

Development and Characterization of a High Surface Porosity Thermally Sprayed Coating

Hamed Ghaednia, Arup Gangopadhyay, Cliff Maki, James Boileau, Timothy Beyer, Caroline Mueller, Michael Marku, Ford Motor Company, Dearborn, MI

Reducing surface roughness is one of the major methods of reducing friction force. A reduction in roughness results in reduced direct asperity contact and therefore a reduction in friction. However, a reduced surface roughness also reduces oil retention that could have an adverse effect on friction. To overcome this barrier a new generation of Plasma Transferred Wired Arc (PTWA) coating has been developed that offers a unique surface structure. The coating possesses pores on the final finished surface that boosts oil retention. The presence of surface porosity boosts oil retention regardless of the surface roughness. Therefore, the porous coating structure can enable the use of an even smoother surface finish while maintaining adequate oil retention. The new coating offers a substantial reduction in friction as demonstrated by ring on liner reciprocating bench top studies. The current work presents the development and tribological characterization of this novel PTWA coating.

2:30 pm - 3:00 pm

Effect of Steel Hardness on Soot Wear

Artemis Kontou, Hugh Spikes, Imperial College London, London, United Kingdom

Due to incomplete combustion, high levels of soot can accumulate in engine lubricants between drain intervals promoting wear in engine parts. One standard approach to reducing wear is to increase the hardness of the rubbing components used. To explore this approach for controlling soot wear, wear tests have been conducted in a High Frequency Reciprocating Rig using steel discs of various hardness against a hard steel ball. Tests have been conducted using carbon black (soot surrogate) dispersions in model lubricants based on solutions of ZDDP and dispersant in GTL base oil. Wear volumes have been measured and wear scars and tribofilms were analysed using scanning white light interferometry and SEM-EDS. It is found that, while most blends show wear that reduces with increasing hardness, for blends that contain both ZDDP and carbon black wear rate markedly increases with disc hardness as the latter approaches the hardness of the ball. The origins of this behaviour are discussed.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm

The Effectiveness of Lubricant Additives in Preventing Soot Induced Wear

Ian Hobday, Oliver Rough, Aitziber Viadas, John Eastwood, Croda, New Castle, DE

Soot generation is an expected phenomenon when carbon rich fuels are used in combustion engines. OEMs have looked to mitigate increased soot generation caused by exhaust treatment systems via further development of such systems, balancing NOx/soot production through controlled combustion, and the use of diesel particulate filters. Increased drain intervals and soot from turbocharged engines is constantly changing in terms of abundance and morphology. Numerous studies have demonstrated the

impact of dispersant technology on soot induced wear. Initial work conducted by Croda demonstrated that the use of organic film formers (OFFs) could significantly reduce wear in the presence of a soot surrogate by building a thick and durable film of the metal's surface. This paper will continue to evaluate the effect of OFFs in terms of wear and dispersancy characteristics using both a soot surrogate and real sooted engine oils.

4:00 pm - 4:30 pm
Use of Radioactive Tracer Technology to Investigation Wear in a 3.6L V6 Gasoline Engine
Peter Lee, Southwest Research Institute, San Antonio, TX, varun Gauba, Tushar Bera, Jannik Reitz, Edward Nelson, Shell, Houston, TX, Greg Hansen, craig Wileman, Southwest Research Institute, San Antonio, TX

Radioactive Tracer Technology was used to investigate wear of critical components in a 3.6L V6 Gasoline Engine. Areas of the engine liner were surface activated and the top ring was bulk activated giving three distinct isotopes that could be traced in the engine oil as the ring face and ring side were different materials. Prior to assembly and at the end of the test the engine was measured thoroughly using traditional surface profilometry. This data was compared with the real time wear measurements captured using the radioactive signals present in the engine oil. Additional white light interferometry measurements were undertaken at end of test to further understand the wear phenomena that had occurred during the engine run.

4:30 pm - 5:00 pm
Friction and Wear Performance of Low-viscosity Synthetic Mixed Fluids
M. Cinta Lorenzo Martin, Ali Erdemir, George Fenske, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL

Higher demands in fuel efficiency is the main driver for the use of lower-viscosity lubricants. This can result in increased friction and wear in lubricated components. This paper presents the results of experimental studies of friction and wear performance of based fluid mixture consisting of low viscosity PAO and polyol ester. Experiments were conducted using 52100 steel ball against 52100 flat under reciprocating and unidirectional lubricated sliding contact. Addition of polyol ester to PAO in the range of 30% to 70% resulted in significant reduction in wear (up to x6), and friction (50%) under both configurations. This improved performance when ester is present is attributed to the formation of a protective tribofilm. When lubricant additives were added to the fluids, similar friction and wear performance was observed in all mixtures.

5:00 pm - 5:30 pm
Effect of Organic Friction Modifiers on Properties of Antiwear Film
Joanna Dawczyk, Hugh Spikes, Imperial College London, London, London, United Kingdom, Joe Russo, Shell Projects and Technology (US), Houston, TX

Zinc dialkyl dithiophosphates (ZDDPs) are generally considered as the most versatile and cost-effective antiwear additives used in formulated engine oils and it appears likely that they will remain so for the foreseeable future. Although they are excellent antiwear additives, ZDDPs can have a detrimental effect of friction and thus on fuel economy. This may be alleviated to some extent by the use of appropriate friction modifier additives. The presentation describes a study of the effect of organic friction modifiers (OFMs) on ZDDP tribofilms; their thickness, their morphology and their frictional properties.

6A Hanover AB

Nanotribology V

Session Chair: J. Choo, Petronas Group Technical Solutions, Kuala Lumpur, Malaysia
Session Vice Chair:

1:30 pm - 2:00 pm
Detection of Interlayer Friction in Twisted Multilayer MoS_2 Based on Phonon Vibration
Ke Jin, Dameng Liu, The State Key Laboratory of Tribology,Tsinghua University, Beijing, China

Few-layer MoS_2 have recently gained great attention owing to its remarkable mechanical and photoelectric properties, which are strongly influenced by the interactions and relative orientations between layers. Here, we report on low-frequency Raman scattering measurements of twisted MoS_2 flakes prepared by exfoliation, nondestructive transfer and thermal annealing treatment. We have calculated the interlayer shear and adhesive force by a diatomic chain model (DCM) and found that the shear force of the friction interface between the twisted MoS_2 layers is ~70% weaker than the Bernal-stacked layers and it shows no dependence on the twisting angle. The density functional theory (DFT) calculations for MoS_2 structures with various thickness and twisting angle were performed to verify the results. This work developed a new approach for ultra-low friction detection based on phonon vibration and could promote the development of superlubricity materials.

2:00 pm - 2:30 pm
Tribological Research of Few-Layer MoS_2 Based on First-Principles Calculation
Dameng Liu, The State Key Laboratory of Tribology,Tsinghua University, Beijing, China, Liang Fang, Tsinghua University, Beijing, China, Ke Jin, The State Key Laboratory of Tribology,Tsinghua University, Beijing, China

With the in-depth research, friction mechanism at nanoscale, where interactions between atoms and molecules play an important role, has received wide attention in tribology. As quantum effect and the contribution of electrons, phonons cannot be neglected, density functional theory (DFT) calculation becomes a suitable method studying nanoscale friction mechanism. By calculating potential energy surface (PES), Raman spectra and binding energy, we researched the tribological properties of few-layer MoS_2 and other transition metal dichalcogenides (TMDs), and the results well correspond to our recent experiments. The higher PES on thicker layers indicates the monotonically increasing friction variation trend with thicknesses. Simulated low-frequency Raman spectra calculation reveals the phonon vibration and interlayer van der Waals interactions, which contributes to detecting the interlayer shear and adhesive force in twisted multilayer MoS_2.

2:30 pm - 3:00 pm
Effect of Surface-Coating Biomolecules on the Resistive Pulses of Nanoparticles Translocating Nanopores
Jing Shi, Ming Zhou, Tsinghua University, Beijing, China

The resistive pulses of nanoparticles functionalized with biomolecules transversing a conical-shaped nanopore were investigated by measuring their translocating signal and simulation. Aptamers and proteins were conjugated to polystyrene nanoparticles for analysis respectively. A model was also developed to calculate the electrostatic interaction between the nanopore and nanoparticles as well as the current signal. The results illustrated that the coating molecules enlarged the particles to some extent, thus resulting in distinct current peaks. The charges carried by the particles lead to the redistribution of ions during translocation process, and thus different waveshapes. Besides, the pulse waveshape is also affected by the electrical double layer and ion concentration. The work elucidates the mechanism of surface-coating molecules' effect on the resistive pulses of nanoparticles flowing through nanopores and the sensing method has great potential in detecting specific biomolecules.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Interfacial Slip During Nanoscale Sliding.
Jeffrey Streator, Georgia Tech, Atlanta, GA

A 2D simulation of nanoscale friction is developed via elastostatics. A smooth rigid indenter of specified geometry is brought into contact with an elastic slab, the surface of which is given a prescribed nanometer-scale roughness. The pin is translated laterally across the slab, qausi-statically, in sub-nanometer increments. One of two nodal boundary conditions is imposed: either an intrinsic friction coefficient or a shear stress limit. When a given contacting node reaches a critical point, the node is relaxed (slipped) and the stresses at all other nodes are re-computed, which may lead to subsequent nodal slips. For a given lateral step, the number of slipping nodes may range from zero to the total number of contacting nodes. That is, an incremental displacement may result in no slip, partial slip or full slip, depending upon the conditions. Implications of nanoscale slip behavior upon macroscopic coefficients of friction are discussed.

4:00 pm - 4:30 pm
Study of tribochemical reacting processes by Material Studio QMERA method
Chao Zhang, Shanghai University, Shanghai, China

The process behind ZDDP antiwear performance include the decomposition of the ZDDP, the decomposition product adsorption to the metal surface, further transformation in an oxidative reaction, and polymerization. Each of the preceding reactions can be approximated using classical chemical kinetics, with an Arrhenius-type dependence on temperature. A kinetic model for reaction film formation considers representing reactant molecules and constructing reaction networks by the structure oriented lumping (SOL) method. QMERA is a program that allows combined quantum mechanical (QM) and molecular mechanics (MM) forcefield calculations to be performed using the ChemShell environment. QMERA is used to simulate the preceding reactions and the results are compared with the experiment results by the XANES methodology.

4:30 pm - 5:00 pm - Nanotribology Business Meeting

6B Hanover C

Commercial Marketing Forum VI

1:30 pm - 2:00 pm - Available Slot

2:00 pm - 2:30 pm - The Lubrizol Corporation

2:30 pm - 3:00 pm - The Lubrizol Corporation

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm - The Lubrizol Corporation

4:00 pm - 4:30 pm - Available Slot

6C Hanover D

Rolling Element Bearings II - Rolling Element Bearing dynamics

Session Chair: M. Brouwer, Williams International, Waterford, MI
Session Vice Chair: L. Stacke, SKF Sverige RB, Goteborg, Sweden

1:30 pm - 2:00 pm
Simulation Based Design of a High-Speed Tapered Roller Bearing
Alexander Hassis, Christian Brecher, Marcel Fey, RWTH Aachen University, Laboratory for Machine

Tools and Production Engineering (WZL), Chair of Machine Tools, Aachen, Germany
Tapered roller bearings (TRB) feature a higher load rating and stiffness at a considerably lower speed rating than high-speed angular contact ball bearings (spindle bearings, SPB). Thus, SPBs are the most commonly used type of bearings for machine tool main spindles. However, there is a growing demand for spindles that operate at medium speeds and high loads or with a very compact design. Focusing on these applications a simulation based design process for a high-speed TRB is presented. Calculations show the influence of macro- and microgeometrical design parameters (e.g. roller geometry, location of rib, profiling, crowning) on spindle-relevant bearing properties (e.g. load and speed induced displacement, speed induced stiffness variations). As a result, the design of a newly developed high-speed TRB and simulations of its properties are shown. Finally, experimental results (i.e. displacements, friction, temperatures) from an earlier prototype show the potential of high-speed TRBs.

2:00 pm - 2:30 pm
Combined EFEM-DEM Rotor-Bearing System Modeling
Lijun Cao, Farshid Sadeghi, Purdue University, West Lafayette, IN, Lars-Erik Stacke, SKF, Goteborg, Sweden

A dynamic model was developed to study the effects of rotor and bearing and support flexibilities on the performance of rotor-bearing system. The system is composed of a flexible rotor and two supporting deep-groove ball bearings mounted in flexible bearing housings. The dynamics of the ball bearings were simulated using an existing dynamic bearing model, which was developed using the discrete element method (DEM). The explicit finite element method (EFEM) was used to model the flexibilities of the rotor and bearing support. New approaches were developed to improve the contact algorithms between the DEM bearing model and EFEM housing and rotor models. The previously developed flexible rotor model was updated using the Total Lagrangian formulation to improve the efficiency and stability of the model. The combined DEM-EFEM model was used to study the rotor-bearing system under various conditions.

2:30 pm - 3:00 pm
NVH Calculation of Rolling Element Bearings – Effects of Roller Diameter Sorting of a TRB
Hannes Grillenberger, Schaeffler Technologies AG & Co.KG, Herzogenaurach, Germany

Noise and vibration (NVH) characteristics of rolling element bearings see an increasing attention due to higher demands by customer needs not only limited to field of silent electrified cars. To meet these challenges, validated simulations of the NVH are necessary to understand and efficiently produce high quality and NVH optimized bearings. The presentation shows simulations of the effects of different roller diameters on the NVH of a tapered roller bearing. All simulations are investigated by multi body simulations, i.e. using the tool Caba3D developed by Schaeffler. Influences of the load case (force and speed) as well as different roller diameter distributions are discussed. Further, an overview on the cage dynamics affected by the direction of gravity and roller sorting is given and the links to the noise of the bearing are shown.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Experimental Study of Cage Imbalance and Wear in Deep Groove Ball Bearing Under Cryogenic Environments
Yongbok Lee, Bokseong Choe, korea institute of science and technology, Seoul, Korea (the Republic of), Jeon-Kook Lee, Korea Institute of Science and Technology, Seoul, Korea (the Republic of)

In cryogenic environments, Polytetrafluoroethylene (PTFE) is universally used in the ball bearing cages, since PTFE has a small coefficient of friction. Thus, PTFE cage is important to enhance stability of ball bearing functioned as solid lubricant. However, the PTFE cage is easy to appear the imbalance mass by friction and wear loss, since it has a large wear coefficient. In addition, accelerated wear loss generated by imbalance force can lead to damage of the cage. This study measured to evaluate the characteristics of cage dynamic as well as the bearing torque, cage whirling amplitude, probability density function of cage whirling frequency, and wear loss as functions of the inner race speed and cage imbalance mass under cryogenic conditions. The effects of the imbalance mass and rotating speed on cage dynamics and performance are discussed using the obtained results.

4:00 pm - 4:30 pm
Capacitances and Lubricant Film Thicknesses of Grease and Oil Lubricated Bearings
Alexander Furtmann, Norbert Bader, Leibniz Universitaet Hannover, Hannover, Germany, Hans Tischmacher, Siemens AG, Nuremberg, Germany, Gerhard Poll, Leibniz Universitaet Hannover, Hannover, Germany

This research deals with the electric capacitance of bearings as an important factor for the determination of possibly harmful parasitic currents in drive trains. With the theory of the elastohydrodynamic lubrication the film-thickness between the discs of a two-disc test-rig are calculated. In combination with the Hertzian contact area this film-thickness is transformed into an electric capacitance. The temperature and pressure behaviour of the lubricant is also considered. Measurements are used to validate the calculation method. In a second step the method is used to calculate the capacitance of rolling element bearings which consist of multiple EHL contacts. On a bearing test-rig a variation of oil and grease lubricants, axial and radial loads, speeds and temperatures is tested and used to optimize and validate the calculation method of the capacitance. This work delivers a better understanding of lubrication as well as the electrical behaviour of bearings and EHL-contacts.

4:30 pm - 5:00 pm
Self-lubricating Composite Bearings: Dem Modeling of the Self-lubricating Cage Material
Maria Villavicencio, Lamcos. Insa Lyon, Villeurbanne, Rhone-Alpes, France, Mathieu Renouf, CNRS - University Of Montpellier, Montpellier, France, Aurelien Saulot , LAMCOS. INSA Lyon, Villeurbanne, Rhone-Alpes, France, Yann Michel, CNES. French Space Agency, Toulouse, France, Yves Maheo, SKF Aerospace, Châteauneuf-sur-Isère, France, Guillaume Colas, Tobin Filleter, University of Toronto, Toronto, Ontario, Canada, Yves Berthier, LAMCOS. INSA Lyon, Villeurbanne, RHONE-ALPES, France

In space mechanisms, solid lubrication is often used, particularly when liquid lubrication is not reliable for long term missions. Such solid lubricant can be inside a composite material. This work is focused on the study of bearings in which the cage is made of a self-lubricating composite [1]: such as RT/Duroid 5813 [2][3] and PGM-HT [2][3]. In these bearings, the lubricant is transferred to the balls and races, by a mechanism called double-transfer [4]. As the confined nature of the contact does not allow in-situ observation, a numerical approach is selected to reproduce this mechanism. Discrete Element Methods (DEM) are chosen to construct the numerical composites, because they allow to represent wear. Such numerical materials are nourished by experimental data as the volume fraction and the adhesion mesurements, obtained from X-Ray tomography and AFM tests respectively. The motivation to our work

is the numerical representation, of the third body rheology of these materials.

5:00 pm - 5:30 pm - Rolling Element Bearing Business Meeting

6D Hanover E

Materials Tribology VI

Session Chair: M. Sidebottom, Mechanical Engineering, Lehigh University, Bethlehem, PA
Session Vice Chair: S. Niemi, Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL

1:30 pm - 2:00 pm
Wear in Polymer Composite With Solid Lubricants for Cage of Cryogenic Ball Bearing
Jeon-Kook Lee, Woo-Seok Seo, Bokseong Choe, Korea Institute of Science and Technology, Seoul, Korea (the Republic of), Yongbok Lee, korea institute of science and technology, Seoul, Korea (the Republic of)

We experimentally elucidate the mechanism of friction wear surface for the sliding and rolling contact movement in the cryogenic atmosphere, such as low temperature for the equipment and space for the machine element. To evaluate the properties of the solid lubricating cage, we should minimize the frictional wear of the contact surface at a low temperature condition. Investigations of wear resistance of polymers, using the cryogenic pin-on-disk apparatus has been carried out. Normal load, rotating speed and liquid nitrogen flow rate were considered variables in the cryogenic wear tests. The self-lubricating effect of polymer composite cage fabricated by PTFE(Teflon) with MoS_2, glass fibers, and bronze were verified. Disc of PTFE composite were tested against metal round pin. In all tests, debris and flakes of worn materials were verified to define the wear mechanism. Among the tested materials, the composites PTFE with additive MoS_2 have shown good friction coefficient.

2:00 pm - 2:30 pm
Effects of Blending Proportion on Tribological Properties of PI/UHMWPE Composites at High Working Environmental Temperature
Song Chen, Jian Li, Lei Wei, Bingxue Cheng, Haitao Duan, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China

Composites of polyimide (PI) and ultra-high molecular weight polyethylene (UHMWPE) were fabricated by hot press forming. Experiments of the tribological behavior of PI/UHMWPE on a reciprocating ball-on-flat contact tribometer show: (i) the decrease in friction coefficient and wear rate of composites with the increase in PI content when the mass fraction of PI is less than 50wt%; and (ii) the increase in both friction coefficient and wear rate with the increase in PI ratio beyond 50wt%. SEM images for the worn surfaces of composites with PI content between 30~50wt% are mirror-like smooth and clean, suggesting excellent wear resistance of these samples. Observing of the worn surfaces of composites with PI content less than 30wt% indicates the wear mode to be adhesive in nature. Appearance of fatigue micro-cracks on worn surfaces of composites with PI content more than 50wt% suggests their wear mechanisms to be mainly a fatigue mode.

2:30 pm - 3:00 pm
Wear and Friction Behaviour of a Lubricated Thermoset-Pairing on a Ball-on-Three-Disks-Test
Dominik Rocker, Thorsten Stoeberl, Yihao Zhu, Marco Vorbach, Mireia Gargallo, Robert Bosch GmbH, Stuttgart, Baden-Württemberg, Germany, Frank Mantwill, Helmut-Schmidt-University/University of German Federal Armed Forces, Hamburg, Germany

The wear and friction behaviour of a thermoset-pairing under the lubrication of an aqueous urea solution on a ball-on-three-disks-tester (BOTD) is presented in this work. The test specimen are thermosets based on reinforced Novolac-Resin. The effects of load, speed and temperature were investigated. The tests were executed for tempered and non-tempered parts to evaluate the influence of an additional processing stage. For the two conditions of the materials, two different wear and friction behaviours were observed. While the tempered parts had a fast running-in, the non-tempered parts showed heavy wear and a high coefficient of friction during the whole test duration. For the different test- parameters it was found that wear was more influenced by load than by speed or temperature. Friction was more sensitive to all factors. Also the differences in the behaviour of tempered and non-tempered parts were investigated.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Topology Optimization of a Composite Surface Using a Level Set Method
Tomas Grejtak, Mark Sidebottom, Xiu Jia, Lehigh University, Bethlehem, PA, Florian Feppon, Massachusetts Institute of Technology, Cambridge, MA, Natasha Vermaak, Brandon Krick, Lehigh University, Bethlehem, PA

Composite materials can combine or configure the constituent materials in such a way as to have attributes not offered by any one material alone. Predictions of the removal of a material from a solid surface are useful for estimating component or device service life and can be used as a component of mechanical design. Predicting the topographical evolution of a wearing surface involves applying physics-based models that relate geometry, pressure, and material wear properties for a given configuration of materials. However, to date, these models have never been integrated into optimization design protocols prescribing configurations or topologies for optimal wear surfaces. Topology optimization offers the ability to determine optimal configurations, connectivity, and architectures of material(s) and space. A level set method is a mathematical tool used to evaluate multi-phase models. Topology optimization via level set method has never been done before in the context of wear.

4:00 pm - 4:30 pm
Analysis the Influence of Asperities in Rough Surface of Optical Lens to its Subsurface Damage
Zhiying Ren, Fuzhou University, Fuzhou, China

For the current research about the sub-subsurface damage of optical lens mainly concentrated in terms of machining parameters, abrasive size and distribution, etc. Based on the theory of indentation fracture of brittle materials, in-depth analysis of the relationship between the sub-subsurface damage and the surface topography of optical lenses, and microscopic simulation of the dynamic contact process between grains and optical lenses, under the condition of certain pressure, different machining parameters : abrasive size and grinding speed. Simulation results show that the influence of stress superimposed effect of two adjacent asperity to the depth of subsurface damage increases with the increase of grinding speed no matter how abrasive size changes,. Therefore, the research of adjacent asperity topographical feature on the surface of the optical lens has a very important significance to the further control of its sub-subsurface damage .

4:30 pm - 5:00 pm
Rare Earth Silicate Phosphor and the Triboluminescence Properties in the Sliding Friction
Qiang Zhou, China Agricultural University , Beijing , Beijing, China

Silicate sample $Sr_2MgSi_2O_7$:Ce and $Sr_2MgSi_2O_7$:Ce,Dy with different Ce/Dy doping ratio were formulated using chemicals $SrCO_3$, MgO, SiO_2, CeO_2, Dy_2O_3, and were formed in press to diameter 70mm with thickness 6mm. They were calcined in the high temperature up to 1200 degree to obtain silicate

phosphors. The MCJ-01A friction tester was modified into line-surface pair to obtain a larger contact stress in the triboemission(TL) test. It has a reciprocating sliding velocity of 0.086m/s and applied load from 5 to 50N. AvaSpec-ULS fiber optical spectrometer was used to measure the TL. Phosphor $Sr_2MgSi_2O_7$:Ce with 0.010mol Ce doping concentration obtains a high TL emission with 230 counts in the peak wavelength 444nm and a narrow full width at half maximum; $Sr_2MgSi_2O_7$:Ce,Dy with 0.0100 mole Ce and 0.0025 mole Dy doped concentration obtains 310 counts TL peak in the rang of 353-531nm wavelength. In TL process of phosphors, applied load about 40N guarantees the high TL output, suitable wear ratio.

5:00 pm - 5:30 pm
High Temperature Tube Fretting Wear Performance Against Cellulosic Wire Bushes
Marcus Byron Huffman, GE Power Gas Power Systems, Greenville, SC, Kesavan Dhanasekaran, GE Global Research, Bangalore, India, Bangalore, India

The focus of this study is to understand the fretting wear behavior of structural tubing and a sliding tube support which will be used in GE Power Combustor in Gas Turbines running multi-year operation with cyclic on/off duty cycle. Component level fretting wear tests are carried out on a spray coated and uncoated tubes against three dissimilar cellulosic mesh components which are considered as potential candidates for fretting application. From the results, it is observed the mesh wear is reduced almost by half by minimizing the tube surface roughness from baseline R_a 125µin to 20µin. Coating on tube helps to minimize wear at mild test conditions tested for a long stroke & short runs, but not for severe test conditions tested for short stroke & long runs. The results are strongly attributed to operating regimes, wherein hard coating with high hardness which is brittle in nature exhibits least fretting resistance under shorter stroke and aggravating fretting due to subsurface cracking.

6F Hanover F

Surface Engineering IV

Session Chair: R. Chinnakurli, Mechanical Engineering, Alliance University, Bangalore, Karnataka, India
Session Vice Chair: S. Kosarieh, University of Leeds, Leeds, United Kingdom

1:30 pm - 2:00 pm
Sliding Wear Behaviour of Mild Steel Coated with Titania Using Taguchi Approach
Ramesh Chinnakurli, Alliance University, Bangalore, Karnataka, India, Suresh Kumar R, Nitish U, Prasidh N Kushavar, Anand Mani, BMSCE, Bangalore, India

Titania coatings have been developed by Air Plasma spray technique on the most popular engineering material namely mild steel whose wear and corrosion esistance are poor. Dry sliding wear tests using pin on disc configuration has been adopted to assess the tribological behaviour of the developed coatings. Further ,Taghuchi techniquehas been employed to study the effect of test parameters on the wear behaviour of the developed titania coatings on mild steel, Titania coatings exhibited excellent wear resistance when compared with uncoated mild steel under identical test conditions.

2:00 pm - 2:30 pm
MoDTC-induced Wear of Hydrogenated DLC
Shahriar Kosarieh, Ardian Morina, Anne Neville, University of Leeds, Leeds, United Kingdom

The application of non-ferrous Diamond-like Carbon (DLC) coatings have become an attractive Surface Engineering solution as they show unique tribological properties including low friction and excellent wear resistance resulting in improved fuel economy and durability of the engine components in contact. Commercially available oils are optimised to work on conventional ferrous surfaces and are not necessarily effective in lubricating non-ferrous surfaces. Molybdenum Dithiocarbamate (MoDTC) is a well-

known friction modifier which has been used for ferrous surfaces for quite long time. However, the adverse effect of MoDTC in increasing wear of a DLC coating in a DLC/steel contact has been reported recentlly.In this work, the friction and wear properties of a hydrogenated DLC coating when lubricated in oils containing MoDTC (under boundary lubrication conditions) have been investigated and the wear mechanisms by which MoDTC is giving high wear to DLC are proposed.

2:30 pm - 3:00 pm
Polymer Brush Lubrication of Silicon Nitride on Steel Contacts: a Colloidal Force Microscopy Study
Simon Watson, Ling Wang, Mengyan Nie, University of Southampton , Southampton, United Kingdom, Steven Hinder, University of Surrey, Guildford, United Kingdom, Keith Stokes, University of Southampton , Southampton, United Kingdom

A greener lubrication solution based on self-assembling methods for steel on silicon nitride hybrid contacts is investigated in this study. Surface initiated atom transfer radical polymerisation (ATRP) is employed to produce oleophilic polymer brushes based on methyl methacrylate (MMA). This paper presents the synthesis and characteristics of poly(MMA) brushes that have been designed to synergize with a PAO lubricant whilst forming a strong covalent bond with the silicon nitride surface. By utilising activators regenerated by electron transfer (ARGET) the amount of catalyst needed is reduced to ppm levels allowing polymerisations to take place in a limited amount of air. The initiators and the polymer brushes formed on silicon nitride surfaces are characterised using XPS, contact angle, gel permeation chromatography and atomic force microscopy. The lubricating effects of the polymer brushes under dry and swollen states are evaluated using lateral force microscopy with a steel colloid.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Surface Engineering of Ti6Al4V Firewater Valves for the World's Largest Spar Gas Platform
Vladimir Totolin, Vladimir Pejakovic, Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria

The innovation of unique titanium valves is part of the industry’s effort to ensure the highest safety levels for newly developed offshore floating platforms. Titanium reduces the installation weight by half, is immune to corrosion and, therefore, the extended service lifetime and reduced maintenance combined with enhanced safety provide crucial benefits for offshore platforms. However, it is known that under sliding conditions, titanium and its alloys exhibit poor tribological performance. Therefore, the aim of this study was to find suitable surface treatments for titanium valves to be used under saline environmental conditions. Application of various surface engineering technologies (DLC, HVOF and Ion implantation) showed a significant improvement of tribocorrosion performance in artificial seawater of titanium. The underlying reasons leading to this performance are discussed and the main mechanisms associated with surface degradation under combined wear and corrosion are revealed.

4:00 pm - 4:30 pm
Load Induced Hydrodynamic Lubrication of Porous Polymers: An Explanatory Study of Underlying Mechanisms
Shreyas Oak, Tushar Khosla, Noshir Pesika, Tulane University, New Orleans, LA

We present an exploratory study of the tribological properties and mechanisms of porous polymer surfaces under applied loads in aqueous media. We demonstrate that it is possible to change the lubrication regime from boundary lubrication to hydrodynamic lubrication even at relatively low shearing velocities by the addition of vertical pores to a compliant polymer. It is hypothesized that the compressed, pressurized liquid in the pores produces a repulsive hydrodynamic force as it extrudes from the pores. The presence of the fluid between two shearing surfaces results in low coefficient of friction.

4:30 pm - 5:00 pm
Solution of Three-dimensional Steady State Heat Conduction in Multilayered Materials
Wenzhong Wang, Beijing institution of technology, Beijing, Beijing, China

Multilayer coatings have been used widely in a wide range of applications, including industrial, biological and electrical areas, and the thermal distribution in a multilayered material are of great interest. In the paper the frequency response functions (FRFs) of temperature field under unit point heat source are derived through thermal diffusion equation. The unknown coefficients in the FRFs are assembled in a linear system of matrix equations according to the heat input and continuity condition of heat flux and temperature at each interface. Then the coefficients are solved and expressed recursively. There is no limits on the number or the thickness of layers. Based on the closed-form solution of FRFs, a fast semi-analytical method (SAM) is developed to solve the three-dimensional steady state heat conduction in any multilayered materials. The temperature fields under different kinds of heat source are studied. Moving heat source and convection on the surface are also considered.

5:00 pm - 5:00 pm
A Review of Elastic-Plastic Asperity Contact Mechanics
Robert Jackson, Hamid Ghaednia, Xianzhang Wang, Swarna Saha, Yang Xu, Aman Sharma, Auburn University, Auburn University, AL

In most typical metallic contacts, the stresses are very high and result in yielding of the material. Therefore the study of contacts which include elastic and plastic deformation is of critical importance. This work reviews the current work in this area and also provides a few new recent findings. Several different geometries are considered, including cylindrical, spherical, sinusoidal or wavy, and axisymmetric sinusoidal. Based on these different geometries it is clear that the pressure during heavily loaded elastic-plastic contact is not governed by the conventional hardness to yield strength ratio of three. For spherical contact, the differences between flattening and indentation have also been summarized. In addition, this work summarizes work on tangentially loaded contacts up to the initiation of sliding.

5:00 pm - 5:30 pm
Faster, Lighter, and More Durable Si_3N_4 Ceramic By Ultrasonic Nanocrystalline
Surface Modification Technique for Ceramic Bearing Applications
Auezhan Amanov, Young-Sik Pyun, Sun Moon University, Asan, Korea (the Republic of)

Silicon Nitride (Si_3N_4) ceramic bearings are 30% lighter and 40% stronger than steel, these properties reduce the load on the other components in the bearing, thereby increasing the maximum speed of the bearing by 30-50%. Hence, they exhibit a higher performance in comparison with steel or hybrid bearings. In this study, an ultrasonic nanocrystalline surface modification (UNSM) technique was applied to Si_3N_4 ceramic in order to further improve the tribological properties and to further increase the fatigue life of bearings. The friction and wear properties of samples were assessed using a ball-on-disk tribometer, while the fatigue life was investigated using a rolling contact fatigue (RCF) tester. The UNSM treated Si_3N_4 ceramic bearings have an extremely hard and smooth surface, and are better than steel, hybrid, and conventional ceramic bearings in all ways for machine tool spindles, special operating conditions including corrosive, high-temperature, non-lubricated applications.

6G Hanover G

Fluid Film Bearings VI

Session Chair: A. Fatu, Institut Pprime, Angoulême, France

Session Vice Chair: D. Gropper, Faculty of Engineering and the Environment, University of Southampton, Southampton, Hampshire, United Kingdom

1:30 pm - 2:00 pm - Available Slot

2:00 pm - 2:30 pm - Available Slot

2:30 pm - 3:00 pm
Hybrid Hydrostatic Bearing with Hydrodynamic Porous Media
Hui-An Hsieh, Dein Shaw, Yi-Yun Chen, Yang-Jun Wang, National Tsing Hua university, Hsinchu City, Taiwan

This work investigates a hybrid hydrostatic rotating bearing with hydrodynamic porous media which superimposed the hydrostatic and hydrodynamic effects to improve the stiffness of the typical hydrostatic bearing at high speed. Because of the property of porous media, the lubricant could flow through the porous media to the oil film that covered spindle, and it also could exert the effect of pressure difference in hydrostatic pads. The theoretical model of hybrid hydrostatic bearing was developed and was verified by experiments. The results of the experiment indicate that the hybrid hydrostatic bearing could provide greater stiffness than typical hydrostatic bearing effectively.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Design of a Hydrostatic Symmetric-Pad Linear Bearing With the Membrane-Type Restrictor
TaHua Lai, YaLu Yang, Shih-Chieh Lin, National Tsing Hua University, Hsinchu, Taiwan

It is well-known that when the membrane-type restrictor (a.k.a. diaphragm controlled restrictor) is used to regulate the recess pressure of a hydrostatic bearing, a very high stiffness of the bearing can be obtained. Generally, design of a membrane-type restrictor is much complicated than other frequently used restrictors such as capillary and orifice. It depends on many parameters, such as restrictor type, applied load, bearing dimensions, supply pressure, etc. In this paper, a design procedure of the membrane-type restrictor was introduced, and two design parameters were chosen analytically to obtained the infinite static stiffness of the bearing. At the end, a hydrostatic symmetric-pad bearing had been studied as a design example. The result shows that the membrane-type restrictor has greater bearing stiffness than traditional ones (i.e. capillary and orifice). The bearing clearance will be maintained in most application range without any negative stiffness phenomena.

4:00 pm - 4:30 pm
Development of a Design Environment for High-Speed Air-Bearing Spindles in Machine Tool Applications
Hua-Chih Huang, Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan, Farid Al-Bender, Hendrik Van Brussel, Katholieke Universiteit Leuven , Leuven (Heverlee), , Belgium

This paper describes the development of a design environment for high-speed spindles with air bearings particularly in machine tool applications. It proposes an overall optimisation scheme using two level approach with genetic algorithm for the design of air bearings and spindle shaft. Designs of air bearings are completed in first level optimization and then it starts the second level optimisation task on the spindle shaft by maximising the first resonance frequency using the shaft's rigid-body mode analysis to obtain the optimum dimensions. Finally it generates the preliminary dimensions of the air-bearing spindle set. The whole design processes have been integrated into an interactive design environment using the graphical user interface. The system is built on PC platform using Matlab software and has been developed into a self-contained "Design Optimisation Toolbox of Air-Bearing Spindles".

4:30 pm - 5:00 pm
Water-Lubricated Ceramic Hydrostatic Bearing for High-Performance Machine Tool Spindle
Shuai Yan, Bin Lin, Wenbin Hu, Xiaofeng Zhang, Shumin Wan, Tianjin University, Tianjin, China

The modern manufacturing industry brings forward higher demand for machine tool spindles. The speed and accuracy of conventional hydrostatic spindles are limited due to the frictional heat of lubricating oil, so water is paid more attention as a low viscosity lubricant. In water, self-mated ceramics show extremely low friction coefficient (< 0.01) and low wear rate. In this work, a novel machine tool spindle supported with water-lubricated ceramic hydrostatic bearings is presented. Special “whole-wrap” structure was used to enhance the reliability of the bearing. Silicon carbide was used to build the hydrostatic bearing; the aqueous solution of glycerol was used as the water-based lubricant. The spindle was tested in different speed (up to 10,000 rpm). The results show that the water-based lubricant could reduce the temperature rise significantly (up to 66%) compared to ISO VG 2 oil. And the ceramic bearings show excellent reliability and wear resistance in water-based lubricant.

5:00 pm - 5:30 pm
Design and Test of Hydrostatic Built-in Grinding Spindle with Orifice Restrictors
Chun Hsien Chang, Shih-Chieh Lin, National Tsing Hua University, Hsinchu, Taiwan

In order to achieve fine surface roughness, multi-recess hydrostatic bearings are extensively used in high precision grinding. Stiffness is the most important issue of bearing design. Previous studies have revealed that the stiffness of orifice-compensated bearing is higher than capillary-compensated counterpart. Concerning to the compact characteristic of orifice restrictor also, it is of interest to design a built-in grinding spindle with the use of orifice restrictor. In this paper, the simulation of orifice-compensated bearing lubricant was introduced by solving Reynolds equation with finite difference method to evaluate the recess pressure, load capacity, and the flow rate. By the results of the simulation, we designed a built-in grinding spindle, containing two hydrostatic thrust bearings and two hydrostatic journal bearings, which were all orifice-compensated. Experimental measurements will be carried out on the real grinding machine. Also the polishing tests will be conducted.

6H Regency V

Lubrication Fundamentals IV - Novel Base Fluids & Additives

Session Chair: J. Qu, Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: K. Mistry, Timken Co., Canton, OH

1:30 pm - 2:00 pm
The Effects of ZDDP and Ionic Liquid Concentrations on Friction and Wear Behavior
Yan Zhou, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

The effects of various concentrations of anti-wear additives on friction and wear of a steel-cast iron contact have been investigated. A secondary ZDDP, a phosphonium-phosphate ionic liquid (IL), and a ZDDP+IL combination were added into a base oil in a wide range of concentrations with the phosphorus content (P) from 100 to 6400 ppm. Increasing the ZDDP concentration resulted in a higher friction coefficient, which is attributed to a thicker and rougher tribofilm, but did not enhance the wear protection. For the IL, a transition to better wear protection occurred at 800–1200 ppm of P while little change in friction was observed over the entire concentration range. For the ZDDP+IL, 400 ppm or more of P was necessary to achieve a low friction and 400–1600 ppm of P was optimal for wear protection. The structural and compositional change in the tribofilms at different additive concentrations was revealed by

comprehensive surface characterization to allow an understanding in mechanisms.

2:00 pm - 2:30 pm
Ionic Liquids for the Lubrication of Steel-steel Contacts in Space Devices
Nicole Doerr, Nicholas Shore, AC2T research GmbH, Wiener Neustadt, Austria, Andreas Merstallinger, Roland Holzbauer, Aerospace & Advanced Composites GmbH, Wiener Neustadt, Austria

Liquid lubrication for space applications comes along with a number of challenges: vacuum, extreme temperature ranges and radiation in space, in conjunction with long storage periods on the ground before launch. Generally, space lubricants are composed of perfluorinated polyethers (PFPE), such as Fomblin Z25, or of multi-alkylated cyclopentanes (MAC). Ionic liquids have been proposed as alternative space and vacuum lubricants especially due to their low volatility and good lubricating properties. Selected ionic liquids were benchmarked against Fomblin Z25 comprising the most crucial requirements: corrosion protection on ground, thermal outgassing due to evaporation or decomposition in thermal vacuum, low-temperature viscosity, friction and wear performance in air and in vacuum as well as endurance tests. A ionic liquid outperformed the reference Fomblin Z25 in vacuum stability and tribological performance as well as significantly higher lifetime.

2:30 pm - 3:00 pm
Elastohydrodynamic Performance of a Non-Corrosive Non-Protonic Ioniq Liquid
Marcus Björling, Yijun Shi, Division of Machine Elements, Luleå, Sweden

Ioniq liquids have been defined as molten salts with melting points below 100 degrees C that are entirely ionic in nature, comprising both cationic and anionic species. The industrial use of ioniq liquids are mostly as solvents, electrolytes, extractants and catalysts. In tribological applications, Ioniq liquids are mainly studied in boundary lubrication and in pure sliding contacts. In this work, the elastohydrodynamic performance of a non-corrosive, non-protonic ioniq liqiud is studied to assess the feasibility to use this kind of ioniq liquid in machine components such as gears, rolling bearings and cam followers. This study includes ball on disc friction experiments in rolling sliding full film elastohydrodynamic lubrication at high slide to roll ratios, as well as film thickness measurements with optical interferometry. A commercially available paraffin oil has been used as a reference.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Processes in White Etching Crack formation
Walter Holweger, Schaeffler Technologies AG , Herzogenaurach, Germany

White Etching Crack formation is accompagnied by well defined changes in microstructure as a fact of dynamics, electricity and lubrication. The present paper will give an understanding about those processes and how to get an appropriate solution by combining real time analytical measurements on the base of new results in the root cause analysis.

4:00 pm - 4:30 pm
Wall-Wetting Effects on the Tribological Performance of Cylinder Liner-Piston Ring in Diesel Engines
Bifeng Yin, Bo Xu, Hekun Jia, Huiqin Zhou, School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, China

The application of novel injection strategies (high-pressure injection, early injection, and retarded injection etc.) in diesel engines has made the wall-wetting problem more severer. As the splashed fuel dilutes the

lubricating oil, the tribological performance of the cylinder liner-piston ring will be affected. Based on the experiment of the wall-wetting influence on the lubricant viscosity, a mixed lubrication model is built to explore the ring/liner frictional properties changing with the percentage of fuel mixed in lubricant. The results indicate that when the wall-wetting ratio increases, the lubricant viscosity drops rapidly, and it declines by 45.8% when the ratio rises from zero to 15%; also, the fluid lubrication region shrinks, while the mixed and boundary region extends, causing the asperity friction force to increase. When the ratio is over 15%, the friction force increases around TDC, and the frictional loss grows during the whole working cycle.

4:30 pm - 5:00 pm
A novel marine cylinder oil solution to the IMO's emission regulations
Zhang Jie, PetroChina Dalian lube R&D institute, Dalian, China

The International Maritime Organization (IMO) released regulation to reduce sulfur content to 0.1% or less in ECAs, but in open sea, the sulfur content is still keeping below 3.5%. Consequently, cylinder oils should provide 30TBN -100TBN to neutralize acids from engine combustion. In this paper, laboratory tests were carried out to evaluate performances of this novel additive package. This package shows higher capacity to control deposit and resist friction compared with a competitor's reference and will be helpful to prolong engine overhaul and keep cleanliness in crankcase. Using in BOB system, the package can blend cylinder oils with desired base number in the range of 30TBN -100TBN meeting the demands of IMO.

6I Regency VI

Wear II

Session Chair: Q. Zou, Oakland University, Rochester, MI
Session Vice Chair: C. Wang, Cummins, Greenwood, IN

1:30 pm - 2:00 pm
Modelling Electrochemical and Mechanical Wear in a Tribocorrosive Wear Environment
Ali Ghanbarzadeh, University of Leeds, Leeds, United Kingdom

In this paper, a computational contact mechanics model is used to capture the surface topography and the variation in the real area of contact in a tribocorrosive wear environment. An electrochemistry model was employed at the asperity scale which can capture current on the contacting asperities. The material degradation model considers both mechanical and electrochemical wear. The numerical model is adapted to ball-on-plate sliding reciprocating contact and the prediction results for the current density and its evolution during the time is validated against experiments. The model shows the importance of the real area of contact in the electrochemistry measurements. The effect of load on the electrochemistry and the real area of contact has been presented numerically and experimentally in this work. It is shown that if the topography of the surfaces change in a tribocorrosive system, the current density will vary due to the change in the real area of contact and the contact conformity.

2:00 pm - 2:30 pm
A Thermal Investigation of Transfer Film Development and Wear Behavior of Polyetheretherketone (PEEK) in Multi-directional Sliding
Cris Schwartz, Mark Placette, Iowa State University, Ames, IA

Transfer films are a common wear phenomenon in dry sliding of polymers. It is often assumed a uniform transfer film decreases wear by protecting the sub-surface polymer bulk from abrasion of the counterface. However, little is known about its development and adhesion. In this study, the transfer films deposited by PEEK on a steel counterface were examined to determine mechanisms of film formation and its

relationship to wear. The relationship between counterface temperature and transfer films were investigated using a thermal camera. Wear path geometry was varied since it has been observed wear paths and counterface orientation produce different transfer film coverage. The transfer film was further analyzed via infrared profilometry, and the volumetric wear was measured. It was found that thermal effects had a profound impact on the film deposition, creating a heterogeneity of film qualities indicative of substantial thermally-driven morphological transformations in the polymer.

2:30 pm - 3:00 pm
Physics Based Computational Model to Predict Wear in Metallic Contacts
Arnab Ghosh, Sentient Science, Indianapolis, IN

Computational analysis of wear is typically conducted using constants obtained from experiments. These experiments are highly influenced by environmental factors and prove to be expensive in terms of time and resources. Therefore, there is a necessity of models which can predict wear based on the physics of contact. An elastic-plastic computational model to predict wear is presented which is based on fundamental theories of friction and adhesion. The computational model is based on readily available material properties and does not include experimentally obtained wear coefficients. However, computationally obtained wear coefficients are compared to typical experimentally obtained coefficients to validate the model. A sensitivity study is conducted with parameters such as surface energy, hardness and surface roughness. In addition, a study on the effect of RPM and temperature dependence of viscosity on wind turbine main bearings is also presented.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Analysis of Tool Wear Mechanism in High-speed Milling of Carbon Fiber Reinforced Polymer
Youxi Lin, Fuzhou University, Fuzhou, Fujian, China

Carbon fiber reinforced polymer (CFRP) was tested by high-speed milling with YG6 carbide tool and TiAlN coated tool. By means of tool microscope, scanning electron microscope (SEM) and energy dispersive spectrum (EDS), the cutting tools wear form and wear mechanism were studied. The results show that in high-speed milling of CFRP there was no typical crater wear of metal cutting on rake face.The rake face appeared slight chip adhesion, but the adhesion of uncoated cemented carbide tool is unusually severe, and the phenomenon of collapse edge appears. Wear areas are showing wear and tear like polished band and there has slight groove on cutting direction. The coating flaking is obvious on flank face of coated tool. The wear mechanism of two different tools is mainly abrasive wear and adhesion wear.

4:00 pm - 4:30 pm
Wear of Brittle Material: Competition Between Mechanical, Electrical and Thermal Effects.
Mathieu Renouf, CNRS - University of Montpellier, Montpellier, France, Chaoqun Zeng, University of Montpellier, Montpellier, France, Yves Berthier, CNRS - Univeristy of Lyon, Villeurbanne, France

Even if the number of works dealing on the subject increases, understand wear process of brittle material is a hard task especially when they are subjected to different physical sollicitations. One of the best example is the brush of car starter, a copper-graphite composite submitted to tribological solicitations as well as electrical ones. Indeed, according to the current intensity, the wear process are really different and such a difference is not well understood. To investigate such a multi-physical behavior, a numerical model combining the local degradation of the brush under mechanical and electrical sollicitations is developped. Several results are presented and discussed and compared to experimental data.

4:30 pm - 5:00 pm

Evolution of Surface Topography for Running-in Process Under Mixed Lubrication Condition
Yazhao Zhang, Tsinghua University, Beijing, China, Yonggang Meng, Tsinghua university, Beijing, China

Surface topography of the contacting tribopairs changes due to elastic-plastic deformation, pitting and scoring or abrasive wear, and the change of topography, in turn, affects mixed lubrication condition. By supporting a certain size distribution of wear particles generated from friction surfaces under mixed lubrication condition, the evolution of surface topography is calculated. Combining the average flow model and statistical contact model, this research establishes a prediction model of wear to reveal the evolution of surface topography and the variation of wear rate and friction coefficient in running-in process under mixed lubrication.

5:00 pm - 5:30 pm - Wear and Biotribology Business Meeting

6J — Regency VII

Grease III

Session Chair: G. Fish, Industrial Additives, The Lubrizol Corporation, Wickliffe, OH
Session Vice Chair: W. Tuszynski, Unami Group, Quakertown, PA

1:30 pm - 2:00 pm
Approach to Evaluate Tribochemistry of Greases for Journal Bearings
Giovanni Ramirez, Argonne National Laboratory, Argonne, IL, John Bomidi, Mikey Benes, Christopher Lane, Baker-Hughes, The Woodlands, TX, Osman Eryilmaz, Ali Erdemir, Argonne National Laboratory, Argonne, IL

During its useful life, the constituents in grease (additives, oil, thickener, etc.) interact with surfaces to form tribofilms. To make significant improvements in performance of the entire system, the specific tribofilm chemistry needs to be understood. Here, we present our approach of evaluating greases formulated specifically to protect journal bearings and mechanical seals in rock drill-bits. Test pairs consisted of silver coated steel and a counter-face made of Stellite; the specimens were prepared in the shape of conformal and non-conformal Block-on-Ring to simulate the journal bearing geometry and loading. We further discuss the use of Pin-on-Disc and Block-on-Ring tests to produce tribofilms and how each technique represents a different regime for the rubbing surfaces. To understand the important role of grease additives in the tribological behavior, this paper also features sample preparation for chemical analysis by characterization techniques such as XPS and Raman.

2:00 pm - 2:30 pm
3D Study of Wear Scars Using Optical Profilometry
Nicole St Pierre, Nye Lubricants, Inc, Fairhaven, MA

For years, wear additives have been evaluated by testing samples via 4 Ball Wear and SRV Coefficient of Friction tests where the wear scars from the various tribological tests are measured two dimensionally using optical microscopes. This wear study will utilize optical profilometry to look at the wear scars in the third dimension to see if there are noticeable differences in total wear volume that would further distinguish differences between wear additive chemistries. We will look at traditionally used wear additives of different chemistries at two different treatment levels in multiple base oil chemistries.

2:30 pm - 3:00 pm
Grease Lubricated Fretting – Influence of Base Oil Viscosity and Material Combination
Elin Larsson, Uppsala University, Uppsala, Sweden, Johan Leckner, René Westbroek, Axel

Christiernsson International AB, Nol, Sweden, Åsa Rudolphi, Uppsala University, Uppsala, Sweden

In fretting (material in contact subjected to small relative vibrating motion), the lubrication ability of grease is dependent on the contact load and vibration amplitude. An earlier study has shown different behavior between lithium complex (LiX) and polypropylene (PP) thickened grease lubricated fretting contacts. The viscosity of the base oil has an effect on the prevailing fretting regime, wear and coefficient of friction. By varying the viscosity of the base oil in the greases, this study aims to obtain a better understanding of the lubrication mechanisms of these greases under fretting conditions. A cross cylinder set up is used and the friction force and contact resistance are measured during the tests. The influence of different material combinations for the sliding substrates is considered and in addition to fretting, larger amplitudes of the reciprocating motion is studied.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Modelling of Lubricating Grease Flow Using Computational Fluid Dynamics
Lars Westerberg, Luleå University of Technology, Luleå, Sweden

In this paper numerical simulations of lubricating grease flow using Computational Fluid Dynamics is presented. The grease is treated as a single-phase Herschel-Bulkley fluid, where three different rheolgical properties, corresponding to NLGI grade 00, 1 and 2 respectively, have been considered in two different configurations comprised by a restricted straight channel, and a double restriction seal with- and without ring. The numerical code and rheology model have been validated with analytical solutions and flow measurements using micro Particle Image Velocimetry. The grease velocity distribution in the geometries are obtained and the motion of contaminant particles inserted into the flow is investigated. The latter is of special interest in seal geometries which intend to protect the moving mechanical components from contamination.

4:00 pm - 4:30 pm
Direct Probing of Lubricant Additives
Yunyun Chen, Carlos Sanchez, Texas A&M University, College station, TX, Dilworth Parkinson, Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, Hong Liang, Texas A&M University, College station, TX

Additives in a lubricant play important roles but direct observation of their performance has not been possible. In this research, we investigate feasibility using tomography techniques to directly observe the fate of micro- and nano-particles as lubricate additives. A commercial grease was added with inorganic particles of Fe_3O_4. It was found that under a shear stress, those particles adhere to the calcium complex thickeners. During sliding, the grease forms a film with increased density. Mechanisms of such behavior will be discussed during presentation.

4:30 pm - 5:00 pm - Open

5:00 pm - 5:30 pm - Grease Business Meeting

6L Dunwoody

Non-Ferrous Metals II (Rolling)

Session Chair: M. Shafiei, Novelis Global Research and Technology Center, Kennesaw, GA
Session Vice Chair: D. Compton, Skana Aluminum Co., Manitowoc, WI

1:30 pm - 2:00 pm
Selection of Rolling Oils and Additives: Lab Versus Reality
Patrick Deneuville, Constellium C-Tec, Voreppe, France

The productivity and quality of rolling mills is strongly dependant on the oil or the emulsion used. One of the main problems for the lubricant engineer is to advise the best new molecules of the market while respecting the limitations and costs of the process and ensuring an improvement of the performances on the plant mills. By the time, numerous tribology bench tests are available and give some discrimination. But how to trust such simple procedures so far from reality, not taking into account all the conditions and specific features of the sheet rolling process. The use of laboratory mills may be of great help in the approach of great scales and the similarity of the deformation environment. This paper addresses the issue of the gap between lab trials and the switch to an industrial trial. Some examples are given of possible lab procedures and the main obstacles to consider.

2:00 pm - 2:30 pm
The Use of a Pilot Mill For Development Of Lubricants For Aluminum Rolling
Bas Smeulders, Peter Schellingerhout, Quaker Chemical, Uithoorn, Netherlands

In this presentation we will introduce Quaker's new pilot mill. The mill is specially designed for, among others, aluminum rolling. First the mill specifications will be briefly shown. Trial protocols for aluminum rolling will be discussed, as well as some results. The pilot mill can be utilized to develop new lubricant concepts, emulsion properties and new raw materials. The pilot mill is also used for validation of existing laboratory (tribology) test methods, examples will be given.

2:30 pm - 3:00 pm
Roll Cooling in Novelis Aluminum Hot and Cold Rolling Mills
Andrew Hobbis, Novelis Inc, Kennesaw, GA

The rolling process requires cooling as well as lubrication. Often these functions, and others, are served by a single fluid. Novelis' hot mills use emulsion coolants. Some cold mills use kerosene oil coolants while others use water for cooling and a separate oil for lubrication. Novelis has developed design principles and tools, based on lab-scale measurements. These are used to design systems with sufficient cooling effect to maintain suitable roll temperature with adequate uniformity. This paper gives an overview of Novelis' roll cooling design principles.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Rolling Aluminium Bright Products
Patrick Deneuville, Constellium C-Tec, Voreppe, France

The reflective bright products in aluminium are widely used in the industry: reflectors for lights in buildings and automotive industry, for tanks and containers, for decorative aspects, for lithography. It is generally admitted that a good light reflexion requires a low roughness and preferably a pure aluminium. But some harder alloy may also be rolled to obtain a bright surface. This paper deals with the general rules required for a bright surface, on the tribological side. It presents the different means to characterise it. The reflective measurements and the colour spectrum, and the differences between s the main alloys.
The influence of some important rolling parameters, such as the rolling oil and the oil film thickness, the grinding operation and eventually the polishing phase, the rolling schedule is also discussed.

4:00 pm - 4:30 pm
Analysis of Possible Separations Based on Product Distillation Ranges
Jason Bandy, PetrolinkUSA & BaronUSA, Spokane, WA

We are presenting a case study related to the selection of Vacuum Distillation process that would allow an increase in quality of the rolling oil while reducing expenditures. This plant applies three different rolling oils without mixing them together at any point in time. It is desirable to distill each rolling oil separately, leaving behind the 'tramp' hydraulic oil, while preserving the additives in the rolling oil as much as possible. Equipment selection process considered Initial Boiling Point (IBP) and Final Boiling Point (FBP) in a distillation curve of each liquid, volume and frequency of distillation and estimated the return on investment for the project. Based on the FBP of Rolling Oil 1 and Rolling Oil 2 being higher than the IBP of the AW hydraulic oil, under some condition 'some' hydraulic oil might distill together with these rolling oils. The IBP of the Rolling Oil 3 was too close to that of the hydraulic oil and did not offer prospects for successful separation.

6M Courtland

Gears II

Session Chair: J. Wagner, John Deere, Denver, IA
Session Vice Chair: W. Tian, Caterpillar Inc., Champaign, IL

1:30 pm - 2:00 pm
An Investigation on the Surface Texture Effect on Friction of a Point Contact
Sheng Li, Wright State University, Dayton, OH

This study investigates the effects of the micro-dimple texture on the friction of a ball-on-disk contact, operating under the speed and load ranges that cover typical gearing applications. Circular shaped micro-dimple arrays with different dimple center distances and dimple depths are implemented on the ball surface to quantify the impacts of these two parameters on friction. The contacts of three surface texture combinations, namely micro-dimpled and polished ball surface versus polished disk surface, polished ball surface versus polished disk surface and ground ball surface versus ground disk surface, are compared to demonstrate any beneficial or detrimental effect of micro-dimples in heavily loaded high speed applications. This study adopts a thermal mixed EHL point contact model to quantify the deterministic tribological behavior within the contact, allowing the exploration of the underlying mechanism that governs the role of micro-dimples in the elastohydrodynamic lubrication.

2:00 pm - 2:30 pm
Deriving Energy Efficiency from Coal Mill Gear Box Lubricant
Anil Jaiswal, Indian Oil Corporation Limited, R&D Centre,, Faridabad, Haryana, India

The coal mill gear boxes are energy intensive equipments and consume significant amount of electrical energy during coal pulverization in thermal power plants. The industrial gear oil is being used in such equipments to provide lubrication and cooling of moving parts. The combination of additives were tried to reduce coefficient of friction and achieving reduction in energy consumption. This paper provides the details of new industrial gear oil over reference oil, its physico-chemical, tribological properties and field evaluation. The new oil provided excellent thermal-oxidation stability, reduction in coefficient of friction and energy efficiency in the laboratory. The back to back run carried in coal-mill gearbox over a period of 2500 hours and power savings measured. The new oil provided power savings of around 6 percentages and analysis of two oils exhibited less than fifty percentage changes in kinematic viscosity at 40 ^{0}C and wear debris generation over reference oil.

2:30 pm - 3:00 pm
Application Benefits of Polyglykols in Industrial Gear Oils
Andy Michael, Clariant Corporation, Mt. Holly, NC

Meeting today's performance requirements is no easy task. As the need for continuous productivity increases, machines are getting faster, gearboxes smaller, and loads higher. Synthetic gear oils are becoming more important as they offer performance advantages over mineral oil based gear oils. Simultaneously the industry is looking to reduce maintenance costs through reduced downtime, reduced energy consumption, and extended oil change intervals. This paper explores the detailed study we have conducted benchmarking the different base fluids (mineral oils, PAOs, Esters, and Polyalkylene Glycols) for industrial gears oils. Criteria and the results of this benchmarking study include: Viscosity Index, Wear Protection (FZG), Anti-Corrosion, Ageing Behavior, Thermal Conductivity, Compatibility with Coatings, Compatibility with Seals, and Interaction with Water.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Some Approximate Analytical Solutions For Elasto-plastic Contacts
Laurentiu Moraru, University Politehnica of Bucharest, Bucharest, Bucharest, Romania, Theo Keith Jr., The University of Toledo, Toledo, OH

The contact mechanics models incorporate various integral expressions that involve the probability density functions of the asperity heights. These integrals can be calculated numerically with the desired accuracy, however, in the practical applications of the contact mechanics, the computations are already quite time consuming. The current paper presents approximate analytical solution for the non-isotropic elasto-plastic model proposed by Horng and for the model of Zhao, Maietta and Chang, which incorporates a transitional phase form elastic deformation to fully plastic flow. The probability density of the asperity heights is approximated, so the integrals that describe the elastic contact, as well as the integrals that describe the plastic contact, can be obtained as closed form expressions. Finally, the plastic supported load and the elastic supported load for the non-isotropic roughness are expressed using the gap, the spectral moments of the roughness and the plasticity index.

4:00 pm - 4:30 pm
New High Viscosity Basestock for Gear Applications
Nawid Kashani, BASF SE, Ludwigshafen am Rhein, Rhineland Pallatonia, Germany, Gene Zehler, BASF, Tarrytown, NY, Karolin Geyer, Frank Rittig, BASF SE, Ludwigshafen am Rhein, Rhineland Pallatonia, Germany, Philip Ma, BASF, Tarrytown, NY

Synthetic industrial gear lubricants are dominated by two basestock chemistries: PAOs and PAGs. Whereas PAOs are compatible with most other mineral oil based lubricants, PAGs are able to deliver best in class frictional performance. The combination of both benefits has not been successful in the past. The authors would like to present a new type of high viscosity basestock which is able to combine both benefits. This will be shown not only for the basestock itself but also for real life formulations.

6O Baker

Biotribology I

Session Chair: A. Dunn, University of Illinois at Urbana, Urbana, IL
Session Vice Chair: B. Raeymaekers, University of Utah, Salt Lake City, UT

3:30 pm - 4:00 pm

A Comparative Study on Enamel Microstructure and Mechanical Properties of Human Incisor and Molar

Jing Zheng, Liang Zheng, Jiapin Peng, Zhongrong Zhou, Southwest Jiaotong University, Chengdu, Sichuan, China

The shape and function of human incisor and molar are totally different, however, little has been known about the difference in their microstructures and mechanical properties. The microstructures and mechanical properties of human incisor enamel and molar enamel have been investigated and compared in this study. Enamel samples were prepared from freshly extracted human incisors and molars. The microstructure of samples were examined using various microscope examinations, while their mechanical and tribological properties were studied by nano-indentation/scratch tester and impact machine. Results showed that both the mean HAP crystal size and the area ratio of rods and inter-rod enamel of incisor enamel were larger than those of molar enamel. The hardness, Young's modulus, and fracture toughness of incisor enamel were higher than those of molar enamel. Compared with molar enamel, the impact wear-resistance of incisor enamel was better but its sliding wear-resistance was inferior.

4:00 pm - 4:30 pm

Investigation into the Tribology of Toothbrushing

Richard Baker, Grace Hully, PCS Instruments, London, Not Applicable, United Kingdom, Marc Masen, Imperial College, London, United Kingdom

A new biotrbiology tribometer has been developed that is capable of allowing different (cyclic) loading steps, motion and frequency cycles to be run on the same instrument. The instrument can accomodate a toothbrush head and run over realistic stroke lenghts and brushing motions. A variety of tests have been run on the equipment and results will be shown to investigate the effect of varying the following items/parameters: Toothbrush/Totthpaste type – showing the difference between head size, composition (texture and size) and toothpastes, Toothbrush motion – reciprocal motion versus reciprocal/lateral motion and change in frequency (speed), Interface - Water interaction effect, adding water at different stages and in different volumes. Effect of various counterfaces (using cocoa, gelatine, coffee, lipstick and others) have been developed to see the effectiveness of a particular toothbrush type against different toothpaste formulations.

4:30 pm - 5:00 pm

A Comparison Study on Lubricating Properties of Human and Bovine Saliva Absorption Films Forming on Different Enamels

Liang Zheng, Jing Zheng, Dongwen Liu, Zhongrong Zhou, Tribology Research Institute, Southwest Jiaotong University, Chengdu, Sichuan, China

Salivary proteins adsorbed on enamel surface play an important role in the lubrication function of mammal salivary. The purpose of this study is to compare the different lubrications of bovine and human salivas resulting from different adsorbed proteins. In this paper, the shear energy, abrasion loss and contact angle of four saliva absorption films, including bovine saliva (BS) adsorbed on bovine enamel (BE) or human enamel (HE) surfaces and human saliva (HS) adsorbed on human enamel (HE) or bovine enamel (BE) surfaces, were tested using two kinds of nano-scratch testers and a Drop Analysis System. The adsorbed proteins of BS and HS were analyzed by SDS-PAGE. The results showed that both adhesive property and anti-attrition of HS absorption films on BE or HE were better than BS absorption films on two enamel surfaces. It might contribute to more mucoprotein in the HS in comparison with that of BS. The results of this investigation would be helpful to develop better artificial saliva.

5:00 pm - 5:30 pm - Open

7B Hanover C

Metalworking V

Session Chair:
Session Vice Chair:

8:00 am - 8:30 am
Neat Oil Solution Stability and Maximum Additive Loading - A Metalworking Fluid Stability Study
Thomas Norrby, Linda Malm, Nynas AB, Nynashamn, Sweden

Metalworking Neat Oils have to be able to dissolve high amounts of additives, creating concentrated solutions that must be stable over time. In this study, we have prepared concentrated solutions of seven (7) different additives, and studied their solution stability over time. We are subjected samples to different conditions: ambient, low temperature and elevated temperature, and made observations over several months. Key observables are the formation of precipitates, insolubles, separation at low temperature etc. Results were obtained and analysed for Naphthenic, Group I and Group II base oils, that represent a spectrum of solvencies and have different base oil chemical composition, aromatic content and aniline points. The conclusions of this study will give additional insights into how base oil solvency and low temperature flow properties affect the formulation of neat oil metalworking fluids.

8:30 am - 9:00 am
Metalworking Fluid Microbiology Basics Revisited
Frederick Passman, Biodeterioration Control Associates, Inc., Princeton, NJ

Metalworking fluid microbiology (MWF) has existed as a discipline for nearly 70 years. Initial research focused on the possible risks associated with machinists exposed to potentially pathogenic microbes. Later, MWF biodeterioration control became the primary impetus for better understanding how microbes existed in MWF systems. In the early 1990's, thanks to several clusters of hypersensitivity pneumonitis, health risks garnered most of the stakeholder community's attention. Recent regulatory actions make this a watershed period in terms of MWF chemistry and its potential impact on microbial contamination control. The presentation will address how both MWF performance and its role as a reservoir for disease-causing organisms are likely to be affected.

9:00 am - 9:30 am
New Trends, Challenges and Innovation Solutions in Metal Cutting Fluids
Yixing (Philip) Zhao, Shilpa Beesabathuni , Houghton International, Norristown, PA

Metal cutting fluid industry and technologies are facing a lot of many new trends and prblems such as machining new materials, requirement of superior emulsion stability with low foam, chlorinated paraffin replacement, and maintenance of fluid biostability and longevity etc. We have been pursuing these challenges in innovative ways to provide various solutions and noval technologies and new products. In this presentation we will discuss some new and different ways to test and evaluate lubricity on hard steels and titanium etc.as well as chlorinated alternatives. We will show the DoE approaches to balance excellent emulsion stability and low foam which usually go against each other. We will also present some works to investigate and develop biostable cutting fluid products.

9:30 am - 9:30 am - Available Slot

9:30 am - 10:00 am - Break

10:00 am - 10:30 am
Base Oil and Emulsifier Selection Principles Part II - A Metalworking Fluid Emulsion Stability Study
Thomas Norrby, Linda Malm, Nynas AB, Nynashamn, Sweden, Par Wedin, Naphthenics Research, Nynas AB, Nynashamn, Sweden

Emulsion stability is arguably the most important fundamental property of a metalworking fluid emulsion system. To further investigate how the Hydrophile-Lipophile Balance (HLB) of the surfactant and other formulation parameters affect the emulsion stability, a series of emulsions have been formulated. In this study, key variables were the base oil type, the emulsifier package selection and the water hardness. The properties studied were the droplet size distribution (DSD) and its correlation to emulsion stability over time. Results were obtained and analysed for Naphthenic, Group I and Group II base oils. The conclusions of this study will give additional insights into base oil and component selection to metalworking fluid formulator across geographical regions, with varying water hardness, and different access to base oils suitable for metalworking emulsion formulations.

10:30 am - 11:00 am
Organo Silicates and Silanes as Corrosion/Stain Inhibitors in MWF
Hoon Kim, Anna Tomaszewska, Peter Konopi, Chemetall, New Providence, NJ

Anti-corrosion/staining performance of most metalworking fluids (MWFs) primarily relies on carboxylate, phosphate, and sulfonate chemistry. Our previous study indicated that complex ester with carboxylate functionality improved anti-staining performance on aluminum alloys. However, the efficiency was relatively low compared to phosphates, and also high dosage was required for visible effect. On the other hand, most of organophosphorus or organosulfur compounds initially could exhibit superior anti-staining performance, but they are known to cause microbial proliferation which ultimately degrades MWF sump life. In order to avoid this undesirable microbial growth while maintaining the high inhibition efficiency, the potential alternative could be organosilicate or organosilane compounds. Along this line, here we present our investigation on various organosilicate/silane chemistries as promising corrosion/stain inhibitor systems in MWFs, especially for aluminum alloy surface applications.

11:00 am - 11:30 am
Hot Rolling Oil for Steel Plants - A Case Study
Deepak Saxena, N Sivasurian, Simmi Datta, S Paul, R Mahapatra, R Suresh, Indian Oil Corporation Limited, Faridabad, Haryana, India

Hot rolling is used mainly to produce sheet metal or structure, such as rail tracks. In India, steel plants are traditionally using water for hot rolling of steel slabs to steel sheets. Water provides cooling of work rolls and maintain temperature around 100 ^{0}C. Water spraying also helps in maintaining the steel slab / sheet temperature around 950-1050 ^{0}C. Higher work roll wear and energy consumption during hot rolling is an unresolved concern of this industry for a very long time. To solve this problem, a new hot rolling oil composition comprised of lubricity, antiwear & extreme pressure ingredients developed in authors' laboratory. The developed hot rolling oil mixed with water just before spraying on the intersection of Backup & work rolls of steel mill. Significant benefits like reduction in roll force by 5-10%, power consumption by 6-8 %, work roll wear by 50% and retention of original surface of work roll surface after rolling and lower peel off obtained.

Rolling Element Bearings III - EHL and Friction

Session Chair: F. Sadeghi, Purdue University, West Lafayette, IN
Session Vice Chair: F. Ville, INSA de Lyon, Villeurbanne, France

8:00 am - 8:30 am
Numerical Investigations on Drag of Cylinders in Cylindrical Roller Bearings
Yann Marchesse, Christophe Changenet, ECAM LYON, Lyon, France, Fabrice Ville, LaMCoS INSA LYON, LYON, France

In high-speed rolling element bearings the mixture of air and lubricant as oil generates an aerodynamic drag force on the moving elements. The authors showed previously using a simplified computational fluid dynamics approach that this force cannot be ignored for rolling ball bearings. This simplified approach is applied this time to cylindrical roller bearings for which the flows would be different. The influence of gap between consecutive cylinders and the presence of walls like the cage and the rings on the cylinder drag coefficient are investigated. The results that are obtained from both ball and cylindrical roller bearings are compared. Furthermore the influence of the drag coefficient value that is reached for cylinders on the temperature distribution in the rolling element bearing is investigated.

8:30 am - 9:00 am
Traction in EHL Contacts based on Local Temperature Measurements
Norbert Bader, Gerhard Poll, Leibniz University Hannover, Hannover, Germany

To reduce losses in rolling element bearings the understanding of traction plays an important role. Whilst the film thickness has been extensively studied, traction calculations rely heavily on assumptions and rheological models. Whilst many rheological models have been proposed based on empirical data from traction tests, these models often miss a physical explanation of the fluid behaviour in the contact. This is due to the fact, that most of these models are based on integral results. In the following paper the authors present a model for the maximum shear stress and a method to calculate traction based on this model. The integral traction data is however, supported by local temperature measurements conducted with infrared thermographic camera. Thus the integral model of the maximum shear stress is supported by local temperature data leading to good agreements between experiment and simulation. Furthermore this may allow a better understanding of the physical fluid characteristics.

9:00 am - 9:30 am
Influence of Surface Micro-Geometry on RCF: a Numerical Approach with a Microstructure Representative Model
Fabrice Ville, Guillaume Vouaillat, LaMCoS - INSA Lyon, Villeurbanne, France, Jean-Philippe Noyel, LabECAM - ECAM Lyon, Lyon, France, Xavier KLEBER, MATEIS - INSA de Lyon, Lyon, France, Christophe Changenet, LabECAM - ECAM Lyon, Lyon, France, Sylvain RatherY, SAFRAN Transmission Systems - SAFRAN Group, Colombes, France

Surface micro-geometries are known to have a major effect on rolling contact fatigue of industrial components. Several models have already been proposed in the literature to estimate this influence and predict bearings or gears fatigue life. The present study focuses on a new approach that combines both a contact pressure computation resulting from smooth, rough or dented surfaces and a numerical approach based on a microstructural representation of steel. The model estimates the number of cycles before first micro-crack nucleation and their location at grain boundaries inside the material. The study investigates the influence of contact parameters and material characteristics on rolling contact fatigue life.

9:30 am - 10:00 am - REB Roundtable Wrap-Up

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Dynamic Simulation of the Interaction between Raceway and Rip Contact of Cylindrical Roller Bearings
Bernd Sauer, Timo Kiekbusch, University of Kaiserslautern, Kaiserslautern, Germany

The dynamic simulation of roller bearings gives a detailed insight into the behaviour of the different contacts in the bearing. It is the tool of choice when targeting cage instability, slip or vibrations. Current models of the MEGT include discretized contact calculations for raceway and rip contacts. The detailed pressure and asperity load ratio calculation is based on the contact solvers developed for the tribo-simulation at the MEGT within the Collaborative Research Centre SFB926. The contribution at hand focuses on the modelling of mixed friction in raceway and rip contact. A model of a combined loaded cylindrical roller bearing is introduced and used for the investigation of the interaction between raceway and rip contact which is responsible e.g. for the rolling element skew, the lubrication conditions in both contacts and additionally the overall losses in the bearing. The results are validated with measured friction torques for different operation conditions.

11:00 am - 11:30 am
Direct Observation of Lubricant Films in a Model Rolling Bearing
He Liang, Amir Kadiric, Imperial College London, London, United Kingdom

In a rolling bearing, the formation of EHL film in a ball-ring contact is strongly affected by the replenishment of oil in the rolling track following the passage of the preceding ball. This paper uses a custom-made,model ball bearing rig to directly observe and measure lubricant films in the rolling track as well as EHL films in the ball-ring contacts at contact pressures and rotational speeds commensurate with those present in a real rolling bearing. Glass/sapphire ring is used as the outer bearing race allowing full optical access to the EHL contact. Lubricant films in the rolling track and contact inlet are measured using fluorescence technique, while optical interferometry is utilised to measure thin EHL films in ball-ring contacts. The results are presented to illustrate the influence of multiple factors including entrainment speed, oil fill level, time between passage of adjacent balls, and oil viscosity on oil films in and around the contact.

11:30 am - 12:00 pm
Numerical Investigations on Drag Coefficient of Circular Cylinder in Roller Bearings
Wenjun Gao, INSA de Lyon, Villeurbanne, Rhone, France, Daniel Nelias, INSA-Lyon, Villeurbanne, France, zhenxia Liu, Northwestern Polytechnical University, Xi'an, China

In high speed roller bearings the drag force generated by roller elements translating through the air-oil mixture is frequently calculated using the results for a nominally two-dimensional circular cylinder in a disturbance-free stream. However this model is infinitely long hence it is definitely different with the three-dimensional circular cylinder in roller bearings, which has a finite length and two free ends. Except the Reynolds number, the height-to-diameter ratio becomes an influencing parameter. In this article, a numerical CFD model is applied to simulate the flow pass a three-dimensional circular cylinder in open space. Besides, a three-dimensional circular cylinder sandwiched by two walls is analyzed also, to reveal the influence of two rings in the bearing. Finally a new graphic of drag coefficient vs Reynolds number that is suitable for the three-dimensional circular cylinder in roller bearings is present.

Session Chair: T. Jacobs, University of Pittsburgh , Pittsburgh, PA
Session Vice Chair:

8:00 am - 9:00 am
Thermal and Shear Effects in Boundary Film Formation
Wilfred Tysoe, UW-Milwaukee, Milwaukee, WI

The formation of a boundary film are studied for interfaces that are at thermodynamic equilibrium. The first regime occurs when the interfacial temperatures are high, so-called extreme-pressure (EP) lubrication. Here, the film formation pathways are dominated by thermal reactions and is illustrated using the example of small chlorinated hydrocarbons reacting with iron. The second regime occurs when the temperature rise is small and is investigated in ultrahigh vacuum, by analyzing the elemental composition in the wear track using Auger spectroscopy and by detecting gas-phase products. The approach is illustrated for the gas-phase lubrication of copper by dialkyl disulfides. The elementary steps in the reaction pathway can be measured using a monolayer of adsorbed species on the surface and the kinetic data for the elementary steps are then used to model the gas-phase lubrication of copper by dimethyl disulfide where good agreement is obtained between the model and experiment.

9:00 am - 9:30 am
Tribology, Surface Chemistry and Morphology of Self-healing Solid Lubricant Tribofilms Generated by Mechanochemical Surface Finishing
Boris Zhmud, Applied Nano Surfaces Sweden AB, Uppsala, Sweden

Mechanochemical surface finishing is steadily gaining industrial acceptance as an efficient way to improve the tribological properties of mechanical components made of iron or steel. The basic concept of mechanochemical processes is nearly 90 years old - in fact, older than the word "tribology" - and has its origin in the pioneering studies by Rebinder in the 1920s. Mechanochemical processes lie behind the well-known phenomen of "running-in" which is universally present in the field of tribology.
Quite recently, a new industrial method has been developed building upon the legacy of mechanochemical processes. Known as Triboconditioning, this method involves in-manufacture running-in of various mechanical parts in order to improve their tribological performance. This study presents results of tribological, surface chemical and structural studies of tribofilms generated by the Triboconditioning process, describes their transient behavior and look into the mechanism of self-regeneration.

9:30 am - 10:00 am
Study of Mechanisms of Action of Amine-based Friction Modifiers Using Electronic Structure and Molecular Dynamics Simulations
Rafael Pereira de Matos, Toni Massoud, Clotilde Minfray, Franck Dahlem, Ecole Centrale de Lyon, Ecully Cedex, France, Manami Sato, Nozomu Hatakeyama, Tohoku University, Sendai, Japan, Sophie Loehlé, TOTAL Marketing & Services, Solaize, France, Akira Miyamoto, Tohoku University, Sendai, Japan, Manuel Cobian, Ecole Centrale de Lyon, Ecully Cedex, France

Since fuel economy is an important issue, friction-modifier (FM) additives in automotive lubricants have become a crucial solution to improve efficiency. In particular, organic FM are used to improve tribological performance by forming a protective film on metal surfaces and preventing them from direct contact [1]. Besides, nitrogen-containing compounds (amines, amides & imides) seem to be promising additives due to their sulfur- & phosphorus-free chemical composition. Therefore, they fulfill the environmental requirements of the recent automotive emission legislation. In this work, we have investigated the mechanisms of action of amine-based FM using electronic structure and Molecular Dynamics calculations. Important phenomena were studied, such as the *diffusion* of different fatty amines in base oil

and their *adsorption* on iron-based surfaces. The aim was to better understand the effect of FM chemical structure on the thermal film formation and on their tribological behavior.

10:00 am - 10:30 am - BREAK

10:30 am - 11:00 am
Measuring Electro-mechano-chemical Oxidation and Reduction Reactions on Graphene Using Afm: Probing The Relationship Between Stress, Strain, and Reactivity at the Nanometer Scale
Jonathan Felts, Shivaranjan Raghuraman, Texas A&M University, College Station, TX

We investigate how local stress applied to a graphene surface using an atomic force microscope tip modifies oxidation and reduction reactions. A water meniscus forms around the conductive tip in ambient air, where an applied moderate voltage splits the water, and greater voltages subsequently drive oxidation and reduction at the surface. Dynamically sweeping the tip voltage at a constant tip load and monitoring changes in surface height and friction provides a quantitative measure of the kinetics of graphene oxidation and reduction. We find that higher tip loads increases the graphene oxidation rate, and hypothesize that this increase is due to local strain at the tip-sample contact. We further demonstrate spatially resolved variations in oxidation reaction rates on the surface. Finally, we use cyclic voltage sweeps to show that both oxidation and reduction reactions are nearly completely reversible. These results pave the way for surface engineering via complex stress fields.

11:00 am - 11:30 am
Tribological Behavior of Graphene Grain Boundaries on Single Crystal Copper Films
Pavlo Antonov, Joost Frenken, ARCNL, Amsterdam, Netherlands

We report the first results of an experiment to understand frictional properties of grain boundaries (GB) of single-monolayer CVD-grown graphene on Cu single-crystal films. The low friction of graphene has been well studied in recent years, as well as its dependence on the number of graphene layers, roughness of the substrate, environmental conditions etc. In this study we employ Atomic Force Microscopy and other surface characterization techniques to reveal an influence of local oxidation of the metal substrate on frictional properties of graphene. We show that the oxidation-induced change in interaction with the copper film leads to a significant lowering of the friction coefficient around the GBs in the graphene layer.

11:30 am - 12:00 pm
Impacts of Nanoscale Roughness on the Tribochemical and Frictional Properties of Graphene and MoS_2
James Batteas, Texas A&M Univ, College Station, TX

Nanomaterials such as graphene and MoS_2 have been shown to exhibit ultralow friction, making their use as friction modifiers of interest across a number of platforms. From previous studies, the effective frictional response of these materials has been shown to depend on the nature of the relative chemical interactions between the nanomaterial and the contacting interfaces. As many realistic machined interfaces have nanoscopic roughness (ca. 10 nm RMS), surface architecture also plays a critical role, as the degree of conformity of these materials is a competition between the bonding energy and the bending stiffness of the material leading to domains of varying friction that can impact function. To explore this, AFM and Raman microspectroscopy studies of graphene and MoS_2 as a function of substrate architecture and chemical composition have been conducted to explore the dynamic frictional properties of these materials and how local strain alters their tribochemical properties.

Session Chair: I. Green, Mechanical, Georgia Tech, Atlanta, GA
Session Vice Chair: H. Zhao, The Lubrizol Corp, Wickliff, OH

8:00 am - 8:30 am
Hydraulically Controlled Mechanical Seal for Reactor Coolant Pump
Richard Salant, William Johnson, Georgia Institute of Technology, Atlanta, GA

A hydraulically controlled mechanical seal for a nuclear reactor coolant pump (RCP) is under development. Its purpose is to correct excessive or insufficient leakage through RCP seals, a current expensive, though occasional, problem. The non-rotating stainless steel seal face contains an annular cavity filled with pressurized fluid. By changing the pressure within the cavity, the coning of the face can be changed. Such coning determines the thickness of the lubricating film between the two seal faces and the leakage rate; the larger the coning, the higher the leakage rate. The cavity pressures can be controlled by a closed loop electro-hydraulic control system. Simulations show that the design should perform well, correcting leakage rates over a relatively large range.

8:30 am - 9:00 am
Influence of Coupled Rotordynamics on Mechanical Face Seal Performance
Itzhak Green, Phil Varney, Georgia Institute of Technology, Atlanta, GA

Mechanical face seals are constitutive components of a larger turbomachine, and successfully designing a face seal requires a thorough understanding of the complete system dynamics. The objective here is to provide a fundamental understanding of how rotor vibration is transmitted to the seal. This issue is important because these mechanisms establish the efficacy of using mechanical face seal vibration monitoring to assess the rotor performance. A mechanical face seal model is presented where both seal elements, rotating and stationary, are described using axial, eccentric, and angular degrees of freedom. Coupled rotordynamics are included in the seal equations of motion for the first time, where the rotordynamics are described using a four degree-of-freedom lumped parameter model. Simulation results at steady-state indicate that the rotordynamics are inextricable from the seal dynamics. Specific implications of using the seal as a surrogate rotor vibration monitor are discussed.

9:00 am - 9:30 am
Using Mechanical Face Seal Vibration to Detect a Breathing Rotor Crack
Itzhak Green, Phil Varney, Georgia Institute of Technology, Atlanta, GA

Though rare, shaft fatigue cracks in rotor systems are exceptionally dangerous and can result in catastrophic machine failure. Consequentially, machine operators should employ state-of-the-art online crack detection schemes such as vibration monitoring to mitigate the risk associated with propagating fatigue cracks. The objective here is to establish the effectiveness of using mechanical face seal vibration to detect a breathing shaft crack located on the rotor. A dynamic model coupling the rotor and seal vibration is summarized accounting for angular and eccentric dynamics. The breathing crack mechanism is imposed via a known periodic function (i.e., shaft weight dominates). Steady-state results show that crack-induced shaft-speed harmonics are transmitted between the rotor and seal. Likewise, the seal vibration indicates sub-synchronous resonances associated with these harmonics that are hallmark signatures of a rotor fatigue crack.

9:30 am - 10:00 am
A Numerical and Experimental Investigation of the Performance of a Compliant Finger Seal
Sara Kline, Minel Braun, The University of Akron, Solon, OH

A numerical and experimental study on the performance of the finger seal was conducted. Experimentally, pressures on both sides of the seal, temperatures of the foot pads, and mass leakage

were measured. The numerical models were the same dimensions of the experimental seals, and the cases run used the same parameters as the experimental setup in order to more closely compare to the experiment. This numerical model was found to have leakages values of one order of magnitude lower than the experimental results. As a result, modified versions of the geometry were created and the numerical study was repeated. The disparity between the 'as designed' numerical results and the experimental results illustrates important considerations for manufacturing and usage.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Analysis of the Lift-off Speed of Water Lubricated Spiral Groove Seal
Noel Brunetiere, Andel Djamai, Institut Pprime - CNRS, Futuroscope, France

The spiral groove technology has been developed for gas applications to help in hydrodynamic pressure generation between the seal faces and avoid direct contact and wear. This technology could also be used in high speed liquid applications to limit temperature rise. One interesting characteristic is the speed at which the floating seal ring will lift off and be fully separated of the other face. The speed depends on the fluid pressure, fluid viscosity but also on the seal design parameters. In the present work an experimental analysis of the lift-off speed is performed at different fluid pressure values using displacement probes and friction torque measurements during start-up. The results are successfully compared to those given by a theoretical model.

11:00 am - 11:30 am
Effect of Lip Asperity Spatial Distribution on Mixed EHL in Radial Shaft Seals
Joichi Sugimura, Hiromichi Yoshimizu, Kyushu University, Fukuoka, Fukuoka, Japan, Hirotaka Mizuta, NOK Corporation, Fujisawa, Kanagawa, Japan

The effect of lip surface microgeometry on mixed EHL of radial seals is studied numerically. The finite-difference method is used to analyze the flow of fluids between the lip and a shaft. Modified lip surface asperity models are made to represent variations in asperity height and position, and compared with the simple sinusoidal function. It is shown that the asperity spatial distribution affects the coefficient of friction and formation of cavity. Scattered asperities generally enhance pressure generation and reduce friction coefficient, and the sinusoidal model does not show the average behavior. Also, lower friction models do not necessarily give greater pumping flow.

11:30 am - 12:00 pm
New Method for Estimating the Sealing Quality of Rotating Seals
Veith Pelzer, IMKT - Institute of Machine Design and Tribology, Hannover, Germany

Besides the classical application of radial shaft seals with a stationary sealing ring and a rotating shaft, there are various applications where the sealing ring itself is rotating. The best known examples are hub units for vehicles or centrifuges. Especially at high speeds, the rubber-elastic sealing lips may deform because of the centrifugal force, resulting in sealing problems. To estimate the application limits of rotating standard radial shaft seals and to ensure reliable sealing, a method was developed that, on the basis of static radial force studies, determines the critical speeds of rotating radial shaft seals. This offers the possibility to reduce friction losses without impairing sealing performance.

7F Hanover G

Power Generation I

Session Chair: K. Malik, Ontario Power Company, Pickering, Ontario, Canada
Session Vice Chair: A. Wegner, Engineering, C.C.Jensen, Inc., Newnan, GA

8:00 am - 8:30 am
Mechanisms of Varnish Formation and Implications for the Use of Varnish Removal Technology
Matthew Hobbs, Peter Dufresne, EPT, Calgary, Alberta, Canada

Oil breakdown produces varnish. Due to the costly nature of varnish-related failures, many studies have sought to elucidate the mechanism by which it forms. In all cases, O_2 is presumed to initiate breakdown via radical processes. While previous studies focused on characterization of oxidation products, we employed EPR spectroscopy to measure radical intermediates, gaining mechanistic insight. Our observations suggest that O_2 plays a greater role in the termination of radical processes than it does in their initiation. Even under anaerobic conditions, oil breakdown produces radicals. Once exposed to O_2 or polar traps, these radicals form varnish precursors which aggregate to yield deposits. As a radical trap, stoichiometric O_2 quantities are required for varnish formation to occur. Strategies aimed at eliminating O_2 are, therefore, well-suited to minimize varnishing. Other soluble polar species which can act as radical traps should also be removed to mitigate the risk of oil varnishing.

8:30 am - 9:00 am
New Management Approach for Turbine Oils in High Efficiency Turbines
James Dimas, Yuuhei Shirakura, Idemitsu, Southfield, MI, Shinji Aoki, Idemitsu Kosan Co., Ltd., Chiba, Japan

Current high efficiency turbines like gas turbine combined cycle (GTCC) for LNG thermal power generation and advanced ultra-supercritical system for coal fired power generation are pushing their lubricants to temperatures and conditions that have never been seen in the market. Further, for large power plants generating megawatts of electricity, long-term stable operation is required, which means management of turbine oils is important. It is therefore the mission of oil manufacturers to develop management technologies that enable prompt assessments of the status of turbine oils.

9:00 am - 9:30 am
What Routine EHC Fluid Analysis Fails to Detect: Improved Phosphate Ester Maintenance Through Non-Routine Testing
Matthew Hobbs, Peter Dufresne, EPT, Calgary, Alberta, Canada

EHC systems are among the most critical hydraulic applications in power plants operating steam turbines. These systems generally employ fire-resistant phosphate ester-based EHC fluids. Despite their importance, current fluid condition monitoring fails to detect many of the contaminants responsible for costly downtime and failures. Alternative tests are, nevertheless, available to more accurately assess EHC fluid condition. A detailed examination of these non-routine analyses allows for the identification of “hidden” contaminants that are often responsible for EHC system problems. By furthering knowledge of phosphate ester contamination and breakdown, these tests allow for the development of more effective EHC fluid maintenance practices.

9:30 am - 10:00 am
New PAG Turbine Oil That Enable Easy Management
Shinji Aoki, Idemitsu Kosan Co., Ltd., Chiba, Japan

For large power plants generating megawatts of electricity, long-term stable operation is required, which means management of turbine oils is important. It is therefore the mission of oil manufacturers to develop management technologies that enable prompt assessments of the status of turbine oils. PAG turbine oil is difficult to make sludge and varnish due to high solubility. However, some PAG turbine oil causes sudden oxidative degradation resulting from decrease of antioxidant, because the thermal stability of PAG base

oil is poor. Thus the PAG turbine oil has difficult management. We optimized antioxidant systems and developed new PAG turbine oil that management is easy. In addition, new PAG turbine oil exhibited high oxidation stability in the hydraulic system.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Dirt – A Lethal Diesel Fuel Contaminant
Nnamdi Achebe, Petrosave Integrated Services Ltd., Amuwo-Odofin, Lagos, Nigeria

For factories generating their own power, diesel quality is critical and severe contamination can potentially shutdown production.Subjected to varying handling practices, diesel is exposed to dirt ingress thus compromising its cleanliness.Typical ISO Cleanliness of unfiltered diesel averages ISO 23/22/18 as against ISO 18/16/13 spec by major OEMs. With Mechanical Injectors 15 years ago, diesel cleanliness was not an issue and fuel filters were typically 15 µm size or more. With today's prevalent use of Electronic Injectors (EI), clean diesel is a mandatory requirement.Some consequences of running high performance gensets on unfiltered fuel ranges from frequent replacements of expensive injectors, fuel filters, and pumps to incurring avoidable repair costs plus huge losses in production downtime and factory rejects.This case-study shares how a Power Plant, successfully overcame this challenge and saved well over $75,000 simply by kidney-loop filtration connection to its Service Tanks.

11:00 am - 11:30 am
Keeping Lubricants and Wetted Parts in "As New" Condition
Axel Wegner, C.C.Jensen, Inc., Newnan, GA

This presentation will show how permanent & proper fluid conditioning will extend the life of oil, oil wetted parts and at the same time keeping additive packages at near new levels. We may be able to present these findings together with a customer and major turbine OEM and tour a large local combined cycle power plant in the Atlanta area.

7G — Regency V

Lubrication Fundamentals V - EHL Modelling and Evaluation

Session Chair: J. Guevremont, American Refining Group Inc, Bradford, PA
Session Vice Chair:

8:00 am - 8:30 am
Viscoelastic Response of Lubricant in an EHL Contact Under Transient Bi-Directional Shear Loading
Josef Fryza, Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

There is currently great interest in the understanding of physical origins of friction in elastohydrodynamically lubricated (EHL) contacts of machine components, especially those operating under severe conditions. In such contacts, elastohydrodynamic friction is determined almost entirely by a non-Newtonian response of highly pressurized lubricant in the central area of the contact. Moreover, all of the contacts are affected by vibrations and the lubricant film is subjected to transient shear stress. In the current experimental study, an EHL point contact was exposed to steady-state sliding motion in one direction simultaneously with harmonic sliding motion in a perpendicular direction. Friction forces were measured in the both directions of contact by precise load cells. Results of this study indicate the response of viscoelastic behavior of lubricant to transient bi-directional shear loading and they are

confronted with the limiting shear stress phenomenon.

8:30 am - 9:00 am
Study on the Onset of Lubricant Film Breakdown
Jonny Hansen, Marcus Björling, Division of Machine Elements, Luleå University of Technology, Luleå, Sweden, Erland Nordin, Hubert Herbst, Scania CV AB, Södertälje, Sweden, Braham Prakash, Division of Machine Elements, Luleå University of Technology, Luleå, Sweden, Bo Alfredsson, Royal Institute of Technology, Stocholm, Sweden, Roland Larsson, Division of Machine Elements, Luleå University of Technology, Luleå, Sweden

Machine elements operating under EHD (elastohydrodynamic) conditions will eventually fail due to high stresses and fatigue-related causes. In order to find optimum protective measures, it is important to understand how the stresses arise and what factors that influence their magnitude. At this point the role of surface roughness and how it affects the material degradation due to fatigue and adhesive wear is not yet fully understood. To obtain a better understanding of this, surface topographies with well-defined characteristic roughness patterns, similar to those of real gear surfaces, are designed for evaluation of the lubrication mechanism. In this study, the onset of lubricant film breakdown is investigated. Such results highlight the importance of properly designed surfaces for optimal EHD performance under rolling-sliding conditions.

9:00 am - 9:30 am
A Method for Lubricant Flow Measurement in an EHL Contact by Particle Tracking
Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

Lubricant flowing across elastohydrodynamic (EHL) contact is exposed to extreme conditions of a high pressure and shear stress. Under these conditions, lubricant substantially increases viscosity and exhibits non-Newtonian behavior - shear thinning. In some cases lubricant can undergo glass transition. The behavior of lubricant under such conditions remains a challenging problem, despite, it is connected with friction, temperature rises and micro-EHL effects. Therefore, it is important to study lubricant flow inside highly loaded zone of the contact. In this study, a method for particle tracking in an EHL contact is presented. Lubricant adopted by nanoparticles was used in a ball-on-disc apparatus. The movement of particles is recorded by a high-speed camera and evaluated by image analyses algorithm. Particle position evolution over time corresponds to local speed. By statistical analyses of large number of particles a histogram of speeds and through-film speed profile can be obtained.

9:30 am - 10:00 am
Pressure Dependence of Density for Some Typical Lubricants up to 1 GPa
Bo Zhang, Saga University, Saga-shi, Saga, Japan

A novel high pressure densitometer has been developed, which can be used under pressure up to 1.2 GPa. The newly developed densitometer is calibrated by comparing it with the measurement reported in the literature under pressure lower than 500 MPa. Measurements for some typical lubricants were conducted. The results showed that the pressure dependence of density changes with pressure in much different way for different lubricants when the pressure reaches a critical value of around 400 MPa. Discussions based on the molecular conformation of lubricants were also given.

10:00 am - 10:30 am - Break

7H Regency VI

Wear III

Session Chair: M. Renouf, LMGC, CNRS - University of Montpellier, Montpellier, France
Session Vice Chair: A. Ghosh, Sentient Science, Indianapolis, IN

8:00 am - 8:30 am
Numerical Modeling and Analysis of Sub-surface Damage in the Cutting Process of Carbon Fiber Reinforced Plastic Composites
Youxi Lin, Fuzhou University, Fuzhou, Fujian, China

In order to reveal the mechanism of sub-surface damage during the cutting process of carbon fiberreinforced plastic (CFRP) composites, the Hashin failure criterion was used to establish the macro finite element model of CFRP cutting in this paper. Through the orthogonal test and variance analysis, the influence of cutting parameters on the sub-surface damage was studied. The simulation results showed that the fiber angle had an important influence on the sub-surface damage. The depth of sub-surface damage increased with the increasing of fiber angle. When the fiber direction was 0°, the depth of sub-surface damage was minimum and the obvious rebound phenomenon could be seen. When the fiber direction was 0°, the depth of sub-surface damage was the maximum and it extended the fastest along the cutting direction. The sequence of influential factors to the depth of sub-surface damage was as follows: fiber orientation>tool edge radius>depth of cut>tool rake angle.

8:30 am - 9:00 am
Status of Niobium Carbide (NbC) as a Substitute for Tungsten Carbide (WC) as Cutting Tools and for Wear Protection
Mathias Woydt, Bam, Berlin, Germany, Shuigen Huang, Jozef Vleugels, Ku Leuven, Hervelee, Belgium, Hardy Mohrbacher, Niobelcon Bvba, Schilde, Belgium

This paper displays the metallurgical progress on NbC based hard-metals since its first time STLE-2013 presentation and are characterized by: a.) substitution of Co-binder by Ni, b.) change from SPS to conventional sintering and c.) by switching from lab to pilot scale. The toughness was increased in the frame of these developments without loosening the hardness level. Stoichiometric and sub-stoichiometric, submicron NbC powders were used. The hardness-toughness profile of NbC grades match those of WC and cermet grades. Apart from previous parameters, the properties depend on powder processing and sintering conditions. The functional profile of NbC and WC grades bonded by Co and Ni are benchmarked by 4-point bending strength, elastic moduli and hot hardness until 1000°C, dry sliding wear (T= 22/400C; v= 0,1-10 m/s), abrasive wear (G65) and cutting performances under emulsion and coolant-free turning and milling against different alloys (C45E, 100Cr6, 42CrMo4, X90CrMoV18, 300WA, GG35).

9:00 am - 9:30 am
Mechanical Model of Contact Stress Distribution between Cutting Tool and Chip
Hua Guo, Cong Zhang, Feng Jiang, Huaqiao University, Xiamen, China

The ball-disc friction experiments have been performed by UMT-2 friction tester. The ball material is cemented carbide (material of cutting tool) while the disc material is Fe-Cr-Ni strainless steel (material of workpiece). The 3D profile of groove on the disc after friction test and wear pattern on the ball have been measured to determine the contact stress in the 3D stress conditions. A model of average friction coefficient, which considers the effect of sliding speed and average contact stress, has been presented. Orthogonal cutting experiments have been performed and the cutting forces and thrust forces have been measured to calculate the mechanical model, which is presented to describe the contact between cutting tool and chip. The contact length between cutting tool and chip, length of sticking and sliding zone in the different cutting conditions has been calculated.

9:30 am - 10:00 am
A Novel Method for the Determination of Wear of Engine Cylinder Liner Parts

Nicholaos Demas, Robert Erck, George Fenske, ANL, Argonne, IL

Quantification of wear of cylinder liner materials becomes very important in the selection of candidate oil formulations and materials for engine applications. The precise measurement of wear of realistic components with surface roughness and honing marks, as in the case of cylinder liners tested against piston rings is difficult. In this work, we discuss a novel method that can be used to determine wear, based on optical profilometry of a surface before and after testing, provided that the amount of wear remains low enough that the deepest honing grooves are largely unaffected. In cases when the surface before testing is not available or cannot be measured, as in the case of a cylinder liner that was used in an actual engine, the same method can be applied in a statistical manner outside the area of contact.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Time-dependent Analyses of Wear in Oscillating Bearing Applications
Fabian Schwack, Norbert Bader, Gerhard Poll, Leibniz Universität Hannover, Hannover, Lower Saxony, Germany

The most common wear damage modes in oscillating bearings are false brinelling and fretting corrosion. Under the aspect of big enough oscillating amplitude to contact area ratio, false brinelling can be described as the incubation process of fretting corrosion. Incubation process means, that at the beginning of the oscillating motion a lubricant film is present. If so, mild wear will occur, called false brinelling. The lubricant will squeezed out with time. Thus, the oxid film will be destroyed. The oxide particles lead to abrasive wear. This paper will show experimental results of bearings which operate oscillating. The analyses are focused on the time-dependent spreading of wear and the occurrence of different wear modes. Furthermore, fatigue spalls are analysed. The experiments are accomplished on several bearings with a constant amplitude, frequency and load. The used lubricant is mineral oil. The experiments were conducted using different number of cycles between 100 and 5.000.000.

11:00 am - 11:30 am
Wear Prediction by Field Data
Mohamad Sabzi, Ravan Net Pars, Tehran, Tehran, Iran (the Islamic Republic of)

Nowadys CBM (Condition Based Maintenance) is a well-established maintenance policy around the globe. But in most enterprises the data gathered from CBM techniques just are used to warn about a potential failure and preparing for inspection at the next PM. At the other side, wear estimation is an important concept in prognostic and system health management. To estimate wear some data are neded that are explored in two ways: from laboratory tests or field data. For the first source numerous research works has been done throughout the years and is not the case of this paper. But there is a lack of reliable models to convert field data to predict wear. This is mostly because the people involved in maintenance organization spend most of their time to daily activities and pay little attention to long term goals. Actually CBM can act as a valuable tool to fill the gap between theory and practice in the field of wear prediction. In this presentation this idea is dicussed in detail.

7I Regency VII

Synthetics & Hydraulics II

Session Chair: D. Kohler, Evonik Oil Additives, Horsham, PA
Session Vice Chair: P. Cusatis, BASFCorporation, Tarrytown, NY

8:00 am - 8:30 am

Can We Predict Vane Pump Wear With a Short Lab Test?
Emmanuel Georgiou, Dirk Drees, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium

Hydraulic systems are widely used in industrial applications and there is an increasing need to evaluate hydraulic fluids. Until now, the anti-wear behavior of hydraulic fluids for vane pumps is mainly evaluated by Conestoga Vickers Vane Pump tests as described in ASTM D7043 - DIN 51389 - ISO 20763 standards. However, this technique has certain drawbacks : long test duratn of 100 hrs (ASTM D7043) up to 250 hrs (ISO 20763), large quantity of hydraulic fluids (60 L for ASTM D7043 and 120 L for ISO 20763). In addition, no data on the frictional behavior of the tribosystem are obtained and there is no information on the wear evolution. Therefore, we propose a lab test that can ideally reduce testing time to 24 hours and hydraulic fluid quantity to 5 L, without losing correlation with the in-field conditions. With this method similar lubrication regimes and wear mechanisms are observed and the wear rates match those encountered in the Conestoga Vane Pump tests.

8:30 am - 9:00 am
Fluid Aeration Testing of Different Hydraulic Chemistries Using an In-line Imaging Method
Ricardo Hein, Conexo, Acworth, GA, Salvatore Rea, Chemtura Corporation, East Hanover, NJ

Air entrainment, air release, and foaming properties can be measured using a bench-top test system that was previously reported at STLE 2016. The measurement method uses an in-line imaging device that reports fluid aeration and deaeration in real time for quickly scanning a large number of fluid samples. The test equipment can be used to compare base fluids (both mineral and synthetic), additives, defoamers, and other chemistries used in lubricant formulations. The authors share the results of comparative fresh fluid aeration and deaeration for different synthetic hydraulic fluids, including fire resistant ones such as phosphate esters and polyol esters. These test protocols provide deeper insights into the phenomena of air entrainment (dispersed bubbles) and foaming (non-bursting bubbles) than other tests such as ASTM D3427 and D892, respectively.

9:00 am - 9:30 am
Reverse Polarity Electrostatic Discharge Signal Recorded in Fork Lift Truck Hydraulic Circuit
John Duchowski, Timo Lang, HYDAC FluidCareCenter GmbH, Sulzbach, Saar, Germany, Bhavbhuti Pandya, HYDAC Technology Corporation, Bethlehem, PA

The phenomenon of electrostatic discharges (ESD) has often been described before within the context of its appearance in turbine lubricating systems. In those applications numerous evidence presented before indicated that in general the filter elements were charging in the direction of positive polarity whereas the oil towards the negative polarity. This behavior can be readily explained and is consistent with the materials order of the triboelectric series. In stark contrast to the previously described behavior, we have now identified and recorded a signal for a case where this polarity order has been reversed. Direct experimental evidence obtained from measurements carried out on a hydraulic circuit of a fork lift truck to that effect will be shown and the possible causes for the observed polarity reversal will be presented herein.

9:30 am - 10:00 am
Formulation and Application of Efficient Industrial Lubricants
Justin Langston, Evonik Oil Additives, Horsham, PA, Thorsten Bartels, Evonik Industries AG, Darmstadt, Germany, Thomas Schimmel, Evonik Oil Additives, Horsham, PA, Frank Olaf-Maehling, Michael Alibert, Evonik Industries AG, Darmstadt, Germany

Within the construction and off-highway equipment markets, the efficiency benefits of high Viscosity Index (VI) hydraulic fluids (HF) are common knowledge. In other heavy-duty and demanding HF applications fluid viscosity has not always been considered as a design parameter by the manufacturers. These applications include such diverse industries as plastics manufacturing, papermaking and mining, and equipment like hydraulic presses, hydraulic elevators, metal-forming machinery and plastics injection

molding machines. Recent research studies and performance demonstrations have shown that significant gains can be obtained from equipment that typically runs 24/7. A smart combination of efficient VII technology for HF and novel synthetic base oil for industrial gears can help end users exploit the full potential for energy savings.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Alkylated Naphthalenes
Maureen Hunter, King Industries, Inc., Norwalk, CT

Alkylated naphthalenes are multifunctional, high performance basestock-type additives available in a diverse ISO viscosity range from 22-193 cSt. Alkylated naphthalenes are classified by the American Petroleum Institute as Group V base oils; however, they are rarely use as the sole base fluid. They are typically incorporated into lubricant formulations replacing a portion of a Group II, Group III or PAO base oil. Most alkylated naphthalenes also have HX-1 and H1 approvals for incidental food contact. This paper will present new data showing how alkylated naphthalenes extend the lifetime of high temperature lubricants by improving their thermal and thermo-oxidative stability, decreasing their volatility, and providing excellent dispersancy and varnish control for system cleanliness.

11:00 am - 11:30 am
Performance of Lubricants Formulated With a New Group V Base Stock
Ian Hobday, Mandi McElwain, Gemma Stephenson, Croda, New Castle, DE

Croda has previously presented on a new base stock that demonstrates improved hydrolytic stability and additive solubility compared to synthetic esters, whilst maintaining and improving upon other key properties. A key parameter affecting additive solubility is the polarity of the base stock/co-base stock. Liquid amides have a greater dipole moment compared with esters that not only improves additive solubility, but has also demonstrated the ability to reduce sludge formation in turbine formulations. This paper will focus on how the new Group V base stock can be used to enhance the properties of automotive engine oil formulations.

11:30 am - 12:00 pm
Studies on the Relationships of Molecular Structure and Properties for Metallocene Poly-alphaolefin (mpao) Based on A-olefins Made from Coal
Jiusheng Li, Jian Xu, Yuefeng Ma, Shanghai Advanced Research Institute, Shanghai, China

In this paper, the branching degree of a metallocene polyalphaolefin (PAO) based on α-olefins made from coal were characterized by both 1H NMR and GPC, and their physical-chemical properties, including kinematic viscosity (KV), viscosity index (VI), pour point (PP), flash point (FP), Noack evaporation loss and shear viscosity were investigated respectively. In addition, pressure differential scanning calorimetry (PDSC) and thermogravimetric analyzer (TGA) were used to study the thermal stability of the samples. Based on the results, it can be concluded that the branching degree, the branch chain length of PAO both have great effect on the thermal stability, pour point, flash point, viscosity index of the selected base oils.

Session Chair: W. Anderson, Afton Chemical Corp., Richmond, VA
Session Vice Chair: D. Uy, Ford Motor Co., Dearborn, MI

8:00 am - 8:30 am
Wear Performance of Used Heavy Duty Engine Oils
Mark Fowell, Lars Mattsson, Ahmed Zainelabdin, Volvo AB, Gothenburg, Sweden

Demand for increased oil drain intervals in heavy duty vehicles puts increasing stress on the lubricant. Understanding the factors which affect the performance of current generation heavy duty lubricants near the end of their prescribed life can assist in understanding the parts of the the engine which must be strengthened or areas where oil performance should be improved. In this study a series of lubricants extracted from field test vehicles and engine bench tests were compared with model fluids. The lubricants were tested using a custom reciprocating tribometer and the wear rate and scuffing resistance quantified. Standard oil analysis parameters were investigated to understand any correlation with observed lubricant performance.

8:30 am - 9:00 am
ROBO: A Method to Generate Aged Oil for Low Temperature Viscosity Assessment for Current and Future Engine Oil Categories
Alan Flamberg, Justin Mills, Joan Souchik, Evonik Oil Additives, Horsham, PA

Engine oils specifications require extensive testing to assure good performance and extended engine life. A difficult challenge is the replacement of expensive and lengthy engine tests with more cost-effective bench tests. The ASTM D7582 ROBO test is such a bench test, allowed as an alternate for the Sequence IIIGA engine test in the ILSAC GF-5 specification as the ROBO procedure has been shown to generate oil with similar rheology to that from the engine. In the upcoming ILSAC GF-6 specification, the Sequence IIIH test will replace the Sequence IIIG test. In this presentation, data comparing the rheology of oils aged in the new Sequence IIIH engine test with the ROBO bench procedure will be presented showing the continued suitability of ROBO as an alternative to the Sequence IIIH engine test. Insights on the importance of oxidation and volatilization in understanding aged oil rheology also will be shared.

9:00 am - 9:30 am
An Experimental Study of the Effects of Lubricants on Piston Ring Friction
Zach Westerfield, Dallwoo Kim, Tian Tian, Massachusetts Institute of Technology, Destin, FL

The Floating Liner Engine is a specialized internal combustion engine that allows detailed measurement of friction from components in the piston power system. The unique testing capabilities of this engine were used to explore the effects lubricants can play in the friction of the piston assembly. This study started by detailing the outcome on friction of changing lubricant viscosity through both temperature and formulation. Next, lubricants with and without anti-wear additives were tested. Formation of a tribo-layer and its effect on boundary lubrication could not be implicated from the friction measurement results. However, testing efforts led to new observations about the changing nature of the liner surface during firing conditions, and it is not clear if/what material is filling the valleys of the liner surface and influencing friction.

9:30 am - 10:00 am
Weight-Optimized Bushingless Connecting Rods: Improving the Tribological Performance of a Gudgeon Pin / Connecting Rod System by Using the Triboconditioning® Process
Boris Zhmud, Applied Nano Surfaces Sweden AB, Uppsala, Sweden

Ever increasing power density and torque output of modern TSI and TDI engines, in combination with the introduction of low-viscosity low-SAPS lubricants and general engine downsizing resulting in fewer

cylinders to bear the load, tends to stress the gudgeon pin/connecting rod tribosystem beyond the limits foreseen in the classical engine design. This leads to wear problems, especially if there's no forced pin oiling. This forces OEMs to look for innovative cost-efficient solutions. The present communication describes one such solution: the Triboconditioning® process. Triboconditioning is an industrial surface finishing process which attempts to carry out running-in of components during their manufacture. By applying the Triboconditioning® treatment on the bearing surface of the small connecting rod eye, the tribological performance of the pin/conrod tribocouple can be significantly improved leading the way to cost savings and component lightweighting due to bushingless design.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Lube Oil Consumption (LOC) Measurement on Internal Combustion Engines
Bernhard Rossegger, Large Engines Competence Center GmbH, Graz, Styria, Austria

LOC exerts a major influence on LCC and emissions of internal combustion engines. As reduction of LOC of combustion engines is necessary to meet future emission standards and forward economic operation, accurate LOC measurement is required. State of the art methods to perform LOC measurement are by different reasons not fully satisfying, thus motivation to develop new measurement systems is high. Deficiencies of currently available measurement techniques are shown by a comprehensive literature research and tests on large engines using the SO_2 method respectively. Considering tracer methods as most promising due to their potential in detecting minimal levels of oil consumption, research is focused on development of new tracer substances and/or detection methods. Main challenges when developing marker compounds are exemplified by test bench experiments using barium as tracer. In conclusion new potential approaches to measuring lube oil consumption by tracer methods are being discussed.

11:00 am - 11:30 am
Modeling Research of Piston Ring Pack on Blowby and Lubrication in Marine Low-speed Diesel Engine
Naikun Wang, Xiqun Lu, Yanning Wang, Xiuyi Lv, Ping Ren, Harbin Engineering University, Harbin, Heilongjiang, China

Under the low-speed and heavy-duty conditions, the cylinder liner will likely be scuffed or even damaged. Piston ring plays an important role in generating the oil film, which can make the cylinder better lubricated and reduce the scuffing. In terms of marine low-speed two-stroke diesel engine, this research focuses on the effect of piston ring structure on blowby and oil film, as well as the coupling relationship between them. Considering the piston ring lines, geometry of incision and groove on the ring surface, a model of large-scale low-speed two-stroke diesel was established to analyze the lubrication and blowby. In this study, the minimum film thickness, pressure distribution, coefficient of friction and the gas leakage were calculated under different structures of piston ring, and optimization procedure of ring was discussed.

11:30 am - 12:00 pm
THe Study of the Friction Properties of Railroad Engine Oils
Yue-Rong Li, Brendan Miller, Chevron Oronite, Richmond, CA

The friction properties of Railroad Engine oils, LMOA (Locomotive Maintenance Offi*cers Association) Generation 6 and Generation 7, have been investigated by Mini-Traction Machine (MTM). LMOA GEN 7 oil shows the reduction of the friction in the mixed and boundary regime comparing to LMOA GEN 6 oil. It is believed that the friction reduction over these regimes will improve the fuel economy of internal combustion engines. Further studies show that one additive (Component A), only present in LMOA Generation 7 oil, has dramatically reduced mixed and boundary friction. In addition, the reduction of friction is proportional to the dosage of Componnet A.

Non-Ferrous Metals III - (Biobased)

Session Chair: G. Biresaw, BOR, USDA-ARS-NCAUR, Peoria, IL
Session Vice Chair: A. King, Houghton International, Valley Forge, PA

8:00 am - 8:30 am
Recent Advances in the Development of the Isostearic Acid Process Using Environmentally Friendly and Cost Effective Approaches
Helen Ngo Lew, Majher Sarker, Renee Latona, Robert Moreau, Agricultural Research Service, Wyndmoor, PA

Isostearic acids (IA) are important bio-based ingredients for many commercial products such as lubricants, detergents and cosmetics. They are typically derived from linear-chain unsaturated fatty acids via catalytic dimerization and skeletal isomerization processes. This paper will focus on a number of factors we have modified to improve the skeletal isomerization process using the zeolite-Lewis base catalytic approach to produce IA. For instance, the molar ratio of the acidic zeolites, calcination temperatures, amount of water co-catalyst, and additive selection are all important factors for achieving up to 80% yield of IA and >99% conversion of fatty acids. The full scale characterization of fresh and spent zeolite results confirmed the sustainability of the catalysts for at least ten uses. Finally, the variation in the isomeric composition of IA product observed was found to be due to different zeolitic methods and interaction with the external acidic surface of zeolites.

8:30 am - 9:00 am
Polymercaptanized Soybean Oil – Properties and Tribological Characterization
Girma Biresaw, James Lansing, Grigor Bantchev, Rex Murray, USDA-ARS-NCAUR, Peoria, IL

Polymercaptanized vegetable oils are produced in industrial scale by the addition of hydrogen sulfide across double bonds or epoxides of vegetable oils, in the presence of UV-light. To date, soybean oil, epoxidized soybean oil and castor oil has been mercaptanized using such a procedure. Depending on the structure of the starting vegetable oil, the polymercaptanized product may contain multiple thiol groups only, or a mixture of multiple thiol and hydroxyl groups. This presentation deals with polymercaptanized soybean oil (PMSO), which contains up to 2.9 thiol groups per triglyceride and no hydroxyl groups. PMSO has been used as a co-monomer for numerous applications including for the synthesis of coatings, sealants and foam. This paper discusses our investigation into the chemical, physical and tribological properties of PMSO.

9:00 am - 9:30 am
Thermo-Oxidatively Improved Environmental Friendly Base Oils
Joseph P V, Indian Oil Corporation, Faridabad, Haryana, India, Deepak Saxena, Indian Oil Corporation Limited, Faridabad, Haryana, India

Vegetable oils have been used in lubricant industry as base oil because of its unique characteristics viz., high viscosity index, higher flash points, low coefficient of friction and environmental friendliness. However, since individual vegetable oil does not meet lubricant requirements like thermo-oxidative stability, blends of differently stable oils and blends with other base oils are preferred. This presentation will focus on studies on mixtures of differently stable vegetable oils and blends of vegetable oils with an ester oil and a diluent for obtaining bio base oils with improved thermo-oxidation characteristics. Details will be presented on studies on thermo-oxidative stability, low temperature fluidity, tribological performance and biodegradability of these blends. The study has demonstrated that there was a significant increase in oxidation stability with appropriate combination of vegetable oils and vegetable oil's combination with ester base oil and other diluent.

9:30 am - 10:00 am
17-Hydroxy Oleic Acid as Precursor for Unsaturated and Epoxy Fatty Acid Estolides: Application as Plasticizers in Poly(3-Hydroxybutyrate) Films
Richard Ashby, Daniel Solaiman, USDA/ARS/ERRC, Wyndmoor, PA

While estolides are commonly associated with lubricant applications, they can be beneficial as plasticizing agents. Our research group has produced unique estolide molecules from 17-hydroxy oleic acid derived from sophorolipids and applied them as plasticizers for poly(3-hydroxybutyrate) (PHB) polymer films. Estolides reduced the melting temperatures and glass transition temperatures of the PHB films while crystallinity remained constant (±2.0%). Estolides also influenced the tensile properties of the films by decreasing their strength and moduli while increasing elongation. A 3-month curing enhanced tensile strength and modulus at the same estolide concentration. Irradiation was used in an attempt to crosslink the estolides however, the result was a reduction in molecular weights. While the strength of the PHB films declined in the presence of both estolides, the plasticity and elongation improved validating that these unique estolides can serve as plasticizers in PHB films.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am
Comparison of the Lubricity Performance of Micro and Macro Emulsions of Vegetable Oils and their Derivatives on Aluminum and Steel Surfaces.
Selim Erhan, Dan Cahill, Michelle Peitz, Rachel Smith, ADM, Decatur, IL

Vegetable oils and their derivatives are excellent lubricity additives in water based metalworking fluids. They can be emulsified to give micro or macro emulsions by changing the emulsion particle size. In this study we have compared the lubricity performance of micro and macro emulsions of high oleic canola, high oleic soybean oil, and soybean oil based specialty esters and polymeric esters using a forming tap on a Microtap Instrument.

7M Baker

Biotribology II

Session Chair: J. Manuel Uruena, University of Florida, Gainesville, FL
Session Vice Chair: C. O'Bryan, Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL

8:00 am - 8:30 am
Diamond-like Carbon Coatings with Zirconium Inter-layers for Biotribological Applications
Dipankar Choudhury, University Of Arkansas, Fayetteville, Ar, Juergen Lackner, Joanneum Research Forschungsgesellschaft Mbh, Leobner Strasse , Austria, Robert Fleming, Josh Goss, Jingyi Chen, Min Zou, University of Arkansas, Fayetteville, AR

In this study, six types of N-doped DLC having multiple inter-layers (32 sub-layers of Zr:ZrN and a gradient layer of Zr-DLC) were fabricated on Ti-6Al-4V substrates for decreasing the coefficient of friction, squeaking noise, and wear of orthopedic implants. Surface and mechanical characterizations were performed before conducting biotribological studies. A ball-on-disc (Si_3N_4 on DLC coated Ti-6Al-4V) contact and a rotational oscillating motion were employed in the biotribological experiments in a simulated body fluid to mimic a hip joint motion in terms of gait angle, dynamic contact pressure, speed, and body temperature. The results showed that the gradient layer had a substantial influence on eliminating delamination of the DLC on substrates. The DLC/Si_3N_4 pairs significantly reduced friction coefficient,

squeaking noise and wear of both the balls and discs compared to those of the Ti-6Al-4V/Si_3N_4 pair after testing for a duration that is equivalent to one year of hip joint motion.

8:30 am - 9:00 am
Novel Friction Measurements of Intact Equine Articular Cartilage In Vitro
Lyndsey Hayden, Auburn University College of Veterinary Medicine, Auburn, AL, Robert Jackson, Auburn University, Auburn, AL, Sarah Escaro, R Reid Hanson, Auburn University College of Veterinary Medicine, Auburn, AL

This study's goal was to develop a novel method of intact cartilage on cartilage friction testing. In this technique the articular cartilage surface (ACS) is undamaged or manipulated.The coefficient of friction (COF) was measured between the proximal ACS of the second carpal bone sliding against ACS of the distal radial facet (DRF); and between the lateral femoral condyle (LFC) and medial femoral condyle. The COF of the DRF and LFC are also obtained when the opposing surface is medical grade glass and a steel sphere. Method allows for a more accurate determination of the COF, as it more closely resembles physiological conditions. COF was obtained with normal forces of 5 and 10N applied for 5 minutes. Cartilage on cartilage friction testing obtained the lowest COF in comparison to cartilage against glass and steel. No significant difference was seen when comparing left and right limbs. Results show that this testing method is precise in determining the COF of a migrating contact area.

9:00 am - 9:30 am
Characterizing Membrane Dynamics at a Biological Interface
Tristan Hormel, Tapomoy Bhattacharjee, Angela Pitenis, Juan Manuel Urueña, Greg Sawyer, Thomas Angelini, University of Florida, Gainesville, FL

Mucous membranes are important structures that form at the apical surface of many epithelial cell layers, protecting tissues from pathogens and environmental wear and damage. Although these membranes contain many materials they are primarily composed of mucin glycoproteins, the concentration of which must be tuned to maintain specific rheological properties in order to obtain proper lubrication. Nowhere is this truer than at the surface of the eye’s corneal epithelium, where the mucous membrane must additionally achieve structural integrity despite blinking, and remain transparent in order to enable vision. I will present results on the growth dynamics, concentration, and rheology of a model corneal epithelial mucous layer, all of which can be viewed as important parameters for tribological experiments at this interface. Additionally, I will explore the ways in which these dynamics and material properties can be modulated by altering environmental conditions.

9:30 am - 10:00 am
Viability of Corneal Epithelial Cells at the Air-Gel Interface
Christopher O'Bryan, Tristan Hormel, Tapomoy Bhattacharjee, Gregory Sawyer, Thomas Angelini, University of Florida, Gainesville, FL

Corneal epithelial cells are responsible for providing lubrication at the ocular surface and protecting the inner ocular structures from external environmental factors. Immortalized human corneal epithelial (hTCEpi) cells grown at an air interface share many of the characteristics of human corneal epithelium *in vivo*, including apoptotic cell death of surface cells and differentiation. However, the traditional method of air-lifting cultures provides limited control of substrate mechanical properties, preventing a systematic *in vitro* studyof cell behavioral modulations due to mechanical perturbations. Recent work has shown that liquid-like solids (jammed microgels with tunable mechanical properties) are capable of supporting cell growth. Culturing hTCEpi cells on this gel would allow for *in vitro* friction studies with substrate properties analogous to those found *in vivo*. In this study, we investigate the long term viability and function of hTCEpi cells grown at this air–gel interface.

10:00 am - 10:30 am - Break

10:30 am - 11:00 am

Preparation andTribological Characterization of Biomimetic Patterned Polymer Textures as Skin Coating Models

Marina Ruths, Ruting Jin, Xin Xu, University of Massachusetts Lowell, Lowell, MA, Colette Cazeneuve, Jeanne Chang, Gustavo Luengo, L'Oreal Research and Innovation, Aulany Sous Bois, France

In order to obtain natural effects in cosmetics, we look for ways to transfer topographic patterns in coatings and treatments. Block and random copolymers were used to prepare biomimetic self-assembled patterned surfaces and their tribological properties were measured at sliding speeds relevant to cosmetic skincare applications. AFM showed different µm and nm size structures obtained by controlling the polymer concentration and annealing. Friction forces were measured with SFA at a low sliding speed of 3 µm/s and at a more realistic speed of 10 cm/s. Glassy polymer surfaces showed static friction at low speed, whereas only kinetic friction was found for polymers above T_g. A random roughness pattern with sawtooth-like cross section, made from a polymer above its T_g, gave high friction at low speed, but its friction coefficient was reduced at high speed due to less time for local entanglement and relaxations. The results will be discussed in the light of their cosmetic implications.

11:00 am - 11:30 am

Direct Contact Induced Damage in Cellular Monolayers

Samuel Hart, Juan Manuel Uruena, Angela Pitenis, Kyle Schulze, Greg Sawyer, Thomas Angelini, University of Florida, Gainesville, FL

Cellular behavior is mainly driven by the cell’s ability to sense mechanical stimuli in the microenvironment and elicit a biochemical response. This process, known as mechanotransduction, is essential to physiological development, and is implicated in wound healing, and cancer metastasis. In vitro cellular experiments have utilized atomic force microscopy and micro-pipette aspiration to apply normal and shear forces, and assess fluctuations in mechanical properties. Additional cellular mechanics tests probed their mechanosensitive response by focusing on changes in cell contractility, dynamic behaviors, and the accompanying underlying biochemical signals. However, small levels of extracellular shear stress can cause cell damage and often death through multiple mechanisms. These threshold levels of stress have not been established. Here, microtribology measurements were performed to determine the critical stresses that drive cells down the multiple and possible pathways of death.

11:30 am - 12:00 pm

Cell Friction

Juan Manuel Urueña, Angela Pitenis, Kyle Schulze, Tapomoy Bhattacharjee, Tristan Hormel, Samantha Marshall, Samuel Hart, Eric McGhee, Alex Bennett, Thomas Angelini, Greg Sawyer, University of Florida, Gainesville, FL

The human body is composed of hundreds of sliding interfaces that provide virtually frictionless motion for millions of cycles each year for a lifetime. Our health and quality of life are strictly dependent upon the ability of these interfaces to maintain ample aqueous lubrication in a wide range of sliding speeds and loading conditions. Mucin, a glycosylated protein with a large mesh size (~300 nm) found in synovial fluid, the tear film, the lungs, and the lining of the esophagus, provides protection and lubrication. Understanding the tribological interactions of mucin in vitro is important because it can provide insight on how mucin provides lubrication across biological interfaces and protection from applied stresses in vivo. Here, tribological experiments were performed on a monolayer of mucin-producing human corneal epithelial cells (hTCEpi) at very low contact pressures (< 1 kPa) using a spherical shell hydrogel probe for ~ 10,000 cycles without observing any damage.

Session Chair: B. Jalalahmadi, Sentient Science, Buffalo, NY
Session Vice Chair: H. Grillenberger, Schaeffler Technologies AG & Co.KG, Herzogenaurach, Germany

1:30 pm - 2:00 pm
Application of a Semianalytical Elastic - Plastic Rough Surface Contact Model to Interpret Experimental Observations of Rolling Contact Fatigue Damage.
Achilleas Vortselas, Pawel Rycerz, Francesco Manieri, Amir Kadiric, Imperial College London, London, United Kingdom

Under the rolling contact fatigue conditions found in machine elements such as rolling bearings and gears, obtaining an accurate representation of the material's 3D stress history is crucial in predicting fatigue damage onset and progression. This requires a discretisation of the contact surface and a model capable of accounting for the nonlinearities involved with roughness, surface and subsurface plasticity and cracks. The present work utilises an efficient semianalytical model of three-dimensional rough surface contact, including plasticity along the lines of Chiu's solution for stresses and displacements in a half space due to a cuboidal volume, and a damage criterion. The model is employed to interpret pitting and micropitting damage evolution in concentrated rough contacts observed experimentally on a triple-contact rolling fatigue rig under varied roughness, peak pressure, and slide-to-roll ratio.

2:00 pm - 2:30 pm
Rolling Contact Fatigue of Refurbished Case Carburized Bearings
Aditya Walvekar, Farshid Sadeghi, Purdue University, West Lafayette, IN

In the current investigation, continuum damage mechanics based elastic-plastic FE model was developed to quantify the RCF life of the refurbished case carburized bearings. The hardness gradient and residual stress distribution due to carburization process is considered. To simulate the refurbishing process, damage accumulation was calculated for a set number of fatigue cycles with the original bearing geometry. A layer of original surface was then removed, but the fatigue damage accumulated prior to refurbishing was preserved. The refurbished geometry was subjected to additional fatigue cycles until failure. From the results of the model, it was found that greater depth of the regrinding and more fatigue cycles prior to refurbishing enhance the total fatigue life of refurbished bearing. The model predicted that it is more advantageous to refurbish the through hardened bearing than the case carburized bearing.

2:30 pm - 3:00 pm
White Etching Cracks Detection Using Multiple Sensors
Manuel Zuercher, Institute of process Machinery and System Engineering, Erlangen, Germany, Walter Holweger, Schaeffler Technologies AG , Herzogenaurach, Germany, Sören Barteldes, QASS GmbH, Wetter, Germany, Boris Goj, 5microns GmbH, Ilmenau, Germany, Ling Wang, National Centre for Advanced Tribology at Southampton, Southampton, United Kingdom, Eberhard Schlücker, Institute of process Machinery and System Engineering, Erlangen, Germany

White Etching Cracks are known to cause significant amount of damages on roller bearings often as early as 20% of bearings calculated life. A lot of research has been conducted to identify the drivers which led to this type of bearing damages and the overall outcome suggests that there are more than one reasons for White Etching Cracking. At the institute of Process Machinery and Systems Engineering in Erlangen a bearing test rig has been built where White Etching Cracks have been created reproducibly under a range of conditions. In addition, a number of sensing techniques have been used to investigate their ability to detect the formation of WEC in the bearings at its early stages. These sensors, including acoustic as well as electrostatic sensors, have been found to be able to detect White Etching Cracks at different points of its formation process. The results from the study of WEC detection in real time using these sensors will be presented in this contribution.

3:00 pm - 3:30 pm - Break

8E Hanover F

Seals II

Session Chair: N. Brunetiere, Institut Pprime - CNRS, Futuroscope, France
Session Vice Chair: K. Malik, Ontario Power Company, Pickering, Ontario, Canada

1:30 pm - 2:00 pm
Numerical Simulation of Surface Roughness Effects on the Mixed Lubrication Characteristics of Hydraulic Seals.
Abdelhak Azzi, Pprime, Futuroscope Chassenuil, France

The aim of this study is to analyze the effects of the surface roughness on mixed lubrication characteristics of a hydraulic seals. The model is based on coupling the non-linear (hyper-elastic) structural behavior of the seal with the fluid flow and a stochastic asperities contact model within the lubricated zone. A modified Reynolds equation taken into account both roughness effects at low film thickness and mass conserving is coupled with a FE software (Abaqus). Different operation conditions (velocity, fluid pressure…) are considered. Steady-state (constant velocities) conditions are investigated. The results show a significant influence of the roughness stochastic parameters on the hydraulic seal characteristics in terms of film thickness, pressure and leakage.

2:00 pm - 2:30 pm
Numerical Analysis of the Hydrodynamic Characteristics of Viscoseal Running Under Different Steady Conditions in Laminar and Turbulent Flow Regime.
Mohamed Jarray, Dominique Souchet , Yann Henry, Aurelian Fatu, Pprime institute, University of Poitiers, Poitiers, France

In the present work, the hydrodynamic characteristics of a viscoseal, considering both laminar and turbulent regime, are numerically analyzed using CFD techniques.
In most of cases, for small clearance ratio, lubricant flow is laminar. But, under certain conditions, such as those associated with grooves of large depth, or lubricants with low viscosities operating at high speed, turbulence may occur. In the literature, relatively little consideration has been given to the effects of turbulence in viscoseals. To this end, on the basis of computational experiments under incompressible and steady conditions, recommendations regarding the inclusion of turbulence in viscoseal design are formulated. Parametric studies covering a range of operating speeds, fluid conditions and geometric configurations, has been done in order to improve the understanding and to help further development of this sealing technology.

2:30 pm - 3:00 pm - Seals Business Meeting

3:00 pm - 3:30 pm - Break

8B Hanover C

Metalworking VI

1:30 pm - 2:00 pm - Open Session

8D Hanover E

Tribochemistry III

Session Chair: P. Egberts, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada
Session Vice Chair:

1:30 pm - 2:00 pm
Tribochemistry Under Boundary Lubrication
Stephen Hsu, The George Washington University, Washington, DC

There are two components in Tribochemistry: 1) normal chemistry under the system temperature and pressure without rubbing; 2) chemistry stem from surface contact beyond the normal chemistry. In boundary lubrication, these two sets of chemical reactions interact with one another, resulting in the formation of oil insoluble, lubricating films, and sludge. When the chemistry does not work properly, this will result in seizure and wear. While the antiwear chemistry by additives has been carefully studied and the emerging picture relatively known, the tribochemistry of friction reduction is not well understand. In our drive toward higher fuel economy, tribochemistry that influences the level of friction is of interest. We have studied monolayer lubricating film formation and the resulting shear strength using an apparatus that we designed and built. This presentation will discuss the fundamental issues in friction control and the influence of molecular structures and speed.

2:00 pm - 2:30 pm
Influence of Morphologies of Synthetic Magnesium Silicate Hydroxide on Their Tribologicl Properties
Bin Wang, Qiuying Chang, Kai Gao, Beijing Jiaotong University, Beijing, China

This work aims to study the tribological performance of synthetic magnesium silicate hydroxide (MSH) with different morphologies as lubricant additives in the SAE 5W-30. MSH powders of different morphologies were synthesized hydrothermally with different reaction time and stirring speeds. XRD, SEM and TEM analysis of MSH were performed to detect their structures and morphologies. The tribological properties of MSH powders were evaluated using a four-ball friction and wear tester and worn surfaces were investigated by SEM, EDX and nano indenter. The results showed that the morphologies of synthetic MSH changed with different reaction time and stirring speeds and had a significant effect on their tribological properties. Synthetic MSH of spherical morphology with reaction time 12h and stirring speed 400r/min had best trobological properties under certain conditions. Such effects can be attributed to the formation of a denser layer which mainly contained Si, Mg, O on the friction surface.

2:30 pm - 3:00 pm
Comparative Tribological Properties of Synthetic Magnesium Silicate Hydroxide and Serpentine Powder as Lubricant Additive
Kai Gao, Qiuying CHANG, Bin WANG, Beijing Jiaotong University, Beijing, China

Using MgO and SiO_2 as precursors, Magnesium Silicate Hydroxide (MSH) nanoparticles were synthesized with a hydrothermal method under alkaline conditions. Tribological properties of synthetic MSH powders and serpentine powders (a magnesium silicate mineral) dispersed in base oil on steel-to-steel friction pairs were compared. The tribological test results showed that both additives could improve

the friction-reduction and anti-wear properties of base oil. Meanwhile, the synthetic MSH dispersed in base oil showed more stable and excellent tribological properties.SEM, EDX, RAMAN and nano-indentation analysis demonstrated that tribofilms with high hardness were formed on the worn surfaces, whether serpentine powders or MSH nanoparticles were added into the lubricating oil. The tribofilm on the worn surface lubricated with base oil containing synthetic MSH was more complete, which was responsible for better tribological properties.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Coupling Between Refrigerant-surface Chemistry and Lubrication Conditions.
Stéphane Tromp, LaMCoS - INSA Lyon, Villleurbanne, France, Laurent Joly, ILM, Villeurbanne, France, Manuel Cobian, LTDS - ECL, Lyon, France, Nicolas Fillot, LaMCoS - INSA Lyon, Villleurbanne, France

In refrigeration systems the compressors are lubricated with an oil-refrigerant mixture. An excessive amount of refrigerant entering the compressor is undesired. Moreover, the weight reduction is a major issue in transport industry. Decrease the weight using the working fluid (refrigerant) as a lubricant is one of the possible solution. However, the refrigerants are low-viscosity fluids, so that the width of lubricant films can reach the nanometric scale locally. Chemical reactions and physical processes at the interface between the surface and the refrigerant could then be of primary importance. To understand how physical chemistry of interfaces and refrigerant flows interact, and in particular how severe flow conditions can affect chemical changes for the confined liquids and the liquid/solid interfaces, we combine ab initio calculations together with large scale molecular dynamics. We will then investigate the consequences on the lubrication behavior.

4:00 pm - 4:30 pm
Analysis of Gear Oil Additive Interactions Using X-Ray Absorption Near Edge Structure (XANES) Spectroscopy Analysis of Gear Oil Additive Interactions Using X-Ray Absorption Near Edge Structure (XANES) Spectroscopy
Michael Costello, BASF, Tarrytown, NY

An investigation of gear oil in the High Frequency Reciprocating Rig (HFRR) was undertaken to determine the chemical species formed in their tribofilms. Several variations of a commercial gear oil package were placed in an HFRR and run for both 2 and 8 hours at elevated temperatures, after which the films formed on the surface of the rubbed disks were examines with X-Ray Absorption Near Edge Structure (XANES) Spectroscopy. It was found that the P and S L-edge spectra reveal significant differences in the chemical structure of the films formed after 2 and 8 hours, respectively. In particular, the shorter 2 hours runs tended to display rapid formation of low friction S-containing surface species, while the 8 hour tests revealed the slower formation of P-containing species on the surface.

8G Regency V

Lubrication Fundamentals VI

1:30 pm - 3:30 pm - Open Session

8H Regency VI

Wear IV

Session Chair: A. Alazemi, Mechanical Engineering Department, Purdue University, West Lafayette, IN
Session Vice Chair: A. Ghosh, Sentient Science, Indianapolis, IN

1:30 pm - 2:00 pm
Effect of Lubricant on the Reliability of Cental Implant Abutment Screw Joint: An In-vitro Laboratory and Three-dimension Finite Element Analysis
Tingting Wu, Haiyang Yu, State Key Laboratory of Oral Diseases, West China Hospital of Stomatology, Sichuan University, Chengdu 610041, China, Chengdu, China

This study investigated the effect of lubricants on the stability of dental implant-abutment connection. As lubricants, graphite and vaseline were coated on the abutment screw surface, respectively, and a blank without lubricant served as the control. The total friction coefficient (μ_{tot}), clamping force, fatigue behavior and detorque of the joint combined with dynamic cyclic loading were measured under different lubricating conditions. Further, a three-dimensional finite element analysis was used to investigate stress distribution, in conjunction with experimental images. In conclusion, the lubricant cannot effectively improve the reliability of dental implant-abutment connection. Keeping the interfaces of implant-screw uncontaminated and strengthening the surface of the screw may be recommend for clinical operation and future design.

2:00 pm - 2:30 pm - Open

2:30 pm - 3:00 pm - Open Slot

3:00 pm - 3:30 pm - Break

8I Regency VII

Synthetics & Hydraulics III

Session Chair: R. Davidson, Afton Chemical Corp, Richmond, VA
Session Vice Chair: D. Kohler, Evonik Oil Additives, Horsham, PA

1:30 pm - 2:00 pm
Tertiary-alkyl Primary Amines (TAPA) as Building Blocks for Formulated Fluids
Gagan Srivastava, Ashish Kotnis, John Cuthbert, Andrew Larson, The Dow Chemical Company, Freeport, TX

Tertiary-alkyl primary amines (TAPAs) are versatile chemicals that have unique properties which make them highly attractive as lubricant additives. Comparative property measurements demonstrating their advantages over similar additives will be presented. TAPAs are most commonly employed in combination with acidic, phosphorus containing esters to act as anti-wear additives in formulated lubricants. Such lubricants are often used in high load automotive applications, such as, in the engine or the transmission, and in other industrial applications, such as, in compressors or industrial gear boxes. They also enhance the performance by increasing the alkalinity of the lubricant, thereby improving the detergency and deposition resistance of the fluid. Examples about different levels of improvement associated with different levels of TAPA addition will be presented.

2:00 pm - 2:30 pm
A Novel Microfluidic Rheometer to Quickly and Accurately Measure Viscosity of Concentrated Dispersions

Matt Vanden Eynden, Formulaction, Inc, Worthington, OH, Patrick Abgrall, Patrycja Adamska, Yoann Lefeuvre, Gerard Meunier, Formulaction, L'Union, France

Understanding the behavior of liquid materials under varying shear rates will help deliver quality results when subjected to different conditions during an application process and can help reduce the risk of developing a too viscous or too thin of a sample. But, obtaining the viscosity of concentrated dispersions while using a rotational rheometer can suffer from inconsistencies at high shear rates and temperatures. Here, we use a novel instrument that utilizes a co-flow microfluidic principle to obtain the viscosity of various products as a product is 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. Here, we will show how certain concentrated dispersions behave at varying shear rates and temperatures. Comparison to mechanical rheometers and literature values will be discussed.

2:30 pm - 3:00 pm
Tribological Performance of a New Type of Di-block Copolymers for Optimum Viscosity Modifications
Xingliang He, Michael Desanker, Jie Lu, David Pickens, Tracy Lohr, Northwestern University, Evanston, IL, Ning Ren, Xiurong Cheng, Frances Lockwood, Valvoline , Lexington, KY, Tobin Marks, Yip-Wah Chung, Qian Wang, Northwestern University, Evanston, IL

A new class of di-block copolymers-based viscosity modifiers (VM), consisting of coiled polymer blocks and long-chain branched polymer blocks, is designed and synthesized for better thermo-thickening and shear-thinning performance in mixed- and hydrodynamic lubrication regimes. Chemical-tribological tests and lubrication modeling are conducted to evaluate the performance of this VM group in a typical base oil. The results indicate that the chemical structure offers a unique temporary shear-thinning capability in addition to the conventional viscosity index improvement. Specifically, alignment and rearrangement of the long-chain branched blocks under shearing results in desirable non-Newtonian fluid behaviors while the coiled block helps improve the viscosity-temperatures performance, similar to what conventional VMs do. In conclusion, the new di-block copolymers can be an excellent choice as viscosity modifications for high temperature and high shear applications.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
A Versatile Component for Formulating Superior Air Compressor Lubricants
Yaokun Han, Dow Chemical, Shanghai, China

Premium air compressor oils required good thermal oxidation stability, superior deposit control, corrosion resistance and improved lubrication performance. The market for air compressor lubricants continues to demand longer lifetime and reduced coking and varnishing. For decades, lubricant formulators have preferred polyalkylene glycols (PAGs) for their high viscosity index, excellent deposit control, and outstanding friction control, among many other advantages. However, formulating with conventional PAGs faces some limitations as they lack oil solubility. Recently introduced oil soluble PAGs (OSP) derived from butylene oxide provide compatibility with hydrocarbon oils while retaining all the advantages of conventional PAGs. Formulators can use revolutionary OSP technology as an additive or co-base stock in other base oils to meet the high performance requirements for premium air compressor oils.

4:00 pm - 4:30 pm - Synthetics & Hydraulics Business Meeting

Session Chair: J. Qu, Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: S. Bagi, Massachusetts Institute of Technology, Cambridge, MA

1:30 pm - 2:00 pm
Engine Oil Pumpability in a Modern Engine
Ricardo Gomes, Joan Souchik, Evonik Oil Additives, Horsham, PA, Thorsten Bartels, Claudia Meister, Evonik Industries AG, Darmstadt, Germany, Professor Russ, Hochschule Darmstadt, Darmstadt, Germany

The low temperature pumpability of engine oils has been a concern of OEMs and blenders for decades. If an engine starts it is essential that oil flow quickly throughout the engine providing essential lubrication to all moving parts. High oil viscosity during low temperature starts could delay oil from pumping throughout the engine. In order to predict oil viscosity at cold temperatures, OEM and industry specifications have included bench tests to measure cold temperature pumpability, most typically the pour point and the MRV TP -1 viscosity tests. Several published studies from the 1990s clearly demonstrate the value of the MRV TP-1 test for predicting pumpability. Does this hold true for modern engines? Data and videos will be presented comparing cam shaft oiling times in a modern engine for oils of differing pour point and MRV viscosity, demonstrating the value low viscosity oils provide to cold start pumpability.

2:00 pm - 2:30 pm
High Performance Engine Oil Formulated with Renewable Group III+ Base Oil – Part II. Field Testing
Paula Vettel, Novvi LLC, Emeryville, CA

Popularity and market share of Group III and PAO-based synthetic engine oil has been gaining momentum in recent years due to their ability to provide longer drain interval, enhanced fuel economy, and lower volatility. Renewable Group III+ base oils manufactured from naturally engineered farnesene were used to formulate 0W-20 engine oil with advanced performance characteristics for internal combustion engines. This unique combination of synthetic lubricant performance and great environmental benefit will be discussed and compared to other Group III engine oil in bench tests and engine tests. Details of a 100,00 mile Las Vegas taxi cab field test will be presented that show excellent performance for the renewable Group III+ engine oil.

2:30 pm - 3:00 pm
Friction Reduction in Modern Engines using Novel Lubricant Additives
Zhiqiang Liu, Ford Motor Company, Novi, MI, Farrukh Qureshi, Matt Gieselman, The Lubrizol Corp, Wickliffe, OH, Arup Gangopadhyay, Ford Motor Company, Novi, MI, Kevin Streck, The Lubrizol Corp, Wickliffe, OH, Steven Simko, Ford Motor Company, Novi, MI

This work investigates the impact of novel chemical additives on friction reduction of engine oils compared to a conventional engine oil. Friction mean effective pressure (FMEP) of piston and crankshaft assemblies of a modern gasoline engine was measured under motored conditions for two GF-5 engine oils containing novel chemicals and compared with a conventional engine oil. The results demonstrate that the FMEP observed at test temperatures of 100 and 120°C for both test fluids showed significant improvement over conventional engine oil. Laboratory tests carried out on each of the tested oils provided detailed information in the response of the fluids to frictional behavior in various lubrication regimes. Results indicate a strong dependence of friction reduction mechanism as well as roughness and morphology of tribo films on novel chemicals present in test fluids compared to the unmodified fluid. This, may in part explain friction reduction obtained from novel additive chemistry.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm - Available Slot

4:00 pm - 4:30 pm
Optimization of a Polyalkylene Glycol Axle Lubricant Formulation
John Cuthbert, Ashish Kotnis, The Dow Chemical Company, Midland, MI, Arup Gangopadhyay, Nikolaus Jost, Chintan Ved, Ford Motor Company, Novi, MI, Ali Erdemir, Giovanni Ramirez, Argonne National Laboratory, Argonne, IL

Development of new polyalkylene glycol-based axle lubricant for enhanced fuel efficiency presents many challenges. The lubricant must meet the viscometric requirements of SAE J306 Gear Lubricant Viscosity Classification while also providing reduced friction in EHL and mixed lubrication regimes. In addition, the formulation must meet all the performance requirements of API Category GL-5 service gear lubricants. This paper will focus on the formulation optimization required to enable a polyalkylene glycol-based axle lubricant to satisfy all the performance requirements of the ASTM D6121 (L-37) hypoid gear durability test. A combination of gear surface analysis, compositional analysis of lubricant and tribological methods were used to identify the failure mechanism, adjust the formulation and screen the optimized formulation anti-wear properties. The optimized formulation successfully passed all L-37 test requirements.

8M Baker

Biotribology III

Session Chair: A. Pitenis, University of Florida, Gainesville, FL
Session Vice Chair: M. Masen, Imperial College, London, United Kingdom

1:30 pm - 2:00 pm
In Situ Measurement of the Dynamic Contact Interface of Hydrogels
Eric McGhee, Angela Pitenis, Juan Manuel Uruena, Kyle Schulze, Samuel Hart, Gregory Sawyer, Thomas Angelini, University of Florida, Gainesville, FL

Direct observation of aqueous hydrogel contact is imperative for understanding friction, lubrication, and adhesion mechanisms of soft, permeable materials such as cartilage. For nearly two decades, researchers have attempted to characterize the contact geometry of a gel interface but lack the ability to perform direct in situ measurements, partially due to the refractive index of hydrogels being nearly identical to water. In this work, in situ measurements of hydrogel contact geometry were performed. Hydrogels were fluorescently dyed and loaded into contact and imaged using a confocal microscope allowing direct observation of contact. Here, the dynamic contact mechanics at the hydrogel interface have been investigated by modulating normal force, time in contact, and mesh size of the hydrogel. Results were compared against traditional contact mechanics models.

2:00 pm - 2:30 pm
The Development of Constant Pressure Probes for Low Pressure Applications
Samantha Marshall, Kyle Schulze, Juan Manuel Uruena, Eric McGhee, Angela Pitenis, Alexander Bennett, Samuel Hart, Christopher O'Bryan, Thomas Angelini, Gregory Sawyer, University of Florida, Gainesville, FL

Tribological studies on cells require meticulous control of loading in low pressure sliding conditions. We have developed methods (molded and 3D printed) to create a hemispherical hydrogel probe, with wall thickness less than 1.5 mm and radius of ~4 mm. Polyethylene glycol (PEG) and polyacrylamide (PAAm)

hydrogels were chosen as probe materials due to their low modulus, which allowed for maintenance of constant pressure during sliding. Indentation experiments were performed on a confocal microscope to determine the deformation behavior using probes dyed with fluorescent nanoparticles. From this we were able to establish contact mechanics behavior. These probes were then used to slide on single monolayers of epithelial cells to prevent cell death over long durations (over 24 hours) and sliding distances (greater than 6 m).

2:30 pm - 3:00 pm
Gels, Cells, and Mucin
Angela Pitenis, Juan Manuel Urueña, Tristan Hormel, Tapomoy Bhattacharjee, Samuel Hart, Alexander Bennett, Kyle Schulze, Samantha Marshall, Eric McGhee, Thomas Angelini, Greg Sawyer, University of Florida, Gainesville, FL

Contacting and sliding biological interfaces are vital to human health and quality of life. The ability of these interfaces to provide adequate lubricity in a poor lubricant (water) is due in part to soft, protective polymer networks on the sliding surfaces. Mucus is a biopolymer-based hydrogel lining all moist epithelia and is a critical part of the innate immune system. Current efforts are focused on characterizing the material and mechanical properties of the mucin layer of cells. Previous tribological experimentation with synthetic hydrogels in twinned (Gemini) contact over a wide range of sliding speeds not only confirmed that the mesh size is linked to the material properties, but also revealed that the friction coefficient is a function of the mesh size. This new understanding of the role of mesh size in soft matter friction provides an opportunity to conduct tribological experiments at very low pressures and shear forces with more complex biological materials like mucin.

3:00 pm - 3:30 pm - Break

3:30 pm - 4:00 pm
Friction Instabilities in Gemini Hydrogel Contacts
Sean Niemi, Kyle Schulze, Angela Pitenis, Juan Manuel Uruena, Thomas Angelini, Greg Sawyer, University of Florida, Gainesville, FL

Cellular migration, which occurs through a reach-and-retract mechanism reminiscent of stick-slip, is critical to understanding an array of biological processes from immune response to embryogenesis. Tribological interactions at these low speeds (v ~ 3 nm/s) have not been fully explored. Hydrogels when sliding in a Gemini configuration in this speed regime have been shown to exhibit friction instabilities in the form of avalanche type responses indicative of stick-slip. As a model material for low speed stick-slip, hydrogels are ideal due their high water content, permeability, tunability, and repeatability. Here, the onset of stick-slip behavior is investigated by dynamically altering velocity via exponential decay from 100 µm/s to 35 nm/s. All experiments were performed while submerged on a rotary tribometer, with self-mated hydrogels at a data acquisition rate of 10 kHz.

9A Grand Hall

Student Posters

The Effects of Ultrasonic Nanocrystalline Surface Modification (UNSM) Technique on Surface Properties of Materials and It`s Practical Applications
Bakhtiyor Urmanov, Auezhan Amanov, Young-Sik Pyun, Sun Moon University, Asan, Korea (the Republic of)

It is well known that nanocrystalline surface layer (NCSL) is structurally characterized by nano-grains (NGs), which have higher strength and better tribological properties compared to conventionally coarse

grained materials. Hence, control over grain size has long been recognized as a method to design materials with desired properties. From an industrial perspective, an ultrasonic nanocrystalline surface modification (UNSM) technique is an attractive method to increase the strength of materials by severe plastic deformation (SPD) method. This paper is intended as an introduction to the UNSM technique and surface properties along with practical applications. The UNSM technique is characterized by its excellent performance and short cycle times, resulting in lower operating costs and reduced time requirements and thus, provides the users with significant competitive advantages.

Friction of Fully Hydrogenated Diamond-Like Carbon Films using Molecular Dynamics
Hirotoshi Akiyama, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan

Fully hydrogenated diamond-like carbon (FHDLC) film shows verly low friction under specific conditions. When FHDLC is rubed by ZrO2 under H2 gas, the friction coefficient dropps to 0.0001-0.00005. In this study we simulate friction dynamics of two FHDLC films using molecular dynamics simulations. Reacting Empirical Bond Order (REBO) Potential are used to calculate formation and break of chemical bonds between carbon and hydrogen atoms. The FHDLC surfaces are prepared by heat-quench procedure. Then the dangling bonds on the surfaces are terminated by H atoms. The friction force is reduced more than 10 times by the termination.

Molecular Dynamics Simulation for Formation Process of Organic Monolayer
Masakazu Konishi, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan

All atom molecular dynamics simulations are used to simulate formation process of organic monolayer in oil environment. Palmitic acid moleucles are immersed as additives in base oil molecules of n-hexadecane. The oil film is confined between two solid walls. One side of the wall atoms are partially charged in order to model activated surface. Then the molecular dynamics of confined fluid is simulated under 1 atm, R.T. The simulation showed that first the monolayer of physically absorbed base oil molecules are formed on the solid wall, then the diffusion of additive molecules are inhibited due to the base oil film. The formation of the base oil film and decrease of diffusion coefficient of additives are related.

The Key Technologies of Designing and Manufacturing Micro Textures on the Mechanical-part Surfaces and the Relative Equipments
Hao Fu , Jinghu Ji, Yonghong Fu, Xijun Hua, Yunxia Ye, Zhengyang Kang, Tianyang Chen, Jiangsu University, Zhenjiang, China

Recently, there are three challenges of engineering practices of surface texturing for the diversity of geometrical shapes and complex operating conditions of mechanical components, such as optimal design, machining and equipment. Our group has always studied focus on the optimization design of discriminating partition surface texturing, precision and micro machining technology, processing equipment and engineering applications. The concepts of optimization design of discriminating partition surface texturing and the processing of single pulse intervals laser micro-surface texturing (SPIL) were proposed. In order to enable the manufacture of the various machinery parts surfaces by the processing of SPIL, the precision and micro laser machining equipment with high versatility has been developed. A laser surface texturing production equipment has been developed to manufacture the textured four-cylinder, which can meet the efficiency and stability of industrialization.

Anisotropy of Mechanical Planarization Machining in Sapphire Substrates
Qiufa Luo, Jing Lu, Xipeng Xu, Institute of Manufacturing Engineering, Huaqiao University, Xiamen, 361021, Fujian Province, P.R. China., Xiamen, China

The mechanical planarization machining of sapphire substrates including *c* (0001), *a* (11-20), and *m* (10-10) orientations with the sol-gel (SG) polishing pad has been performed in this paper. The polishing

results show that the *c* orientation with a surface roughness about 2 nm is smoother than the *a* and the *m* orientations, and the material removal rate (MRR) of *c* orientation is much higher than that of the others. The removal mechanism of sapphire substrate was investigated by the wear debris and subsurface structure through transmission electron microscopy. And the instrumented nanomechanical tests were applied to further reveal the removal mechanism by nanoindentation and nanoscratch. Analysis results indicate that the variation of MRRs depends on the crystalline structure and mechanical properties of sapphire substrates. In addition, the processing of sapphire substrates is mainly dominated by the mechanical removal sapphire material during mechanical planarization machining.

Superlubricity Achieved by Polyalkylene Glycol Aqueous Solutions
Hongdong Wang, Yuhong Liu, Jianbin Luo, Tsinghua University, Beijing, China

In our work, ultralow friction coefficient (COF, μ) of a polyalkylene glycol (PAG) aqueous solution has been obtained in both droplet state (40 μL) and full immersion state after a short running-in period. Here, two key factors in achieving the superlubricity state ($\mu < 0.01$) have been demonstrated: the low shearing strength of the hydrated layer and the presence of a suitable amount of free water molecules. In the initial running-in period, a decrease in contact pressure contributes to the formation of elastohydrodynamic behavior of fluid. The hydrogen-bonded PAG chains produce a hydrated layer between two sliding solid surfaces so as to lower the shear strength. The presence of free water molecules effectively weakens interactions between polymer chains. Therefore, the superlubricity state can be realized over a wide range of concentration (30–60 wt%).

Steady Flight of the Plasmonic Flying Head in the Rotary Near Field Lithography Technology
Yueqiang Hu, State Key Labratory of Tribology, Tsinghua University, Beijing, Beijing, China, Yonggang Meng, State Key Labratory of Tribology, Beijing, China, David Bogy, Computer Mechanics Lab, Berkeley, CA

Rotary Near Field Lithography (RNFL) technology provides a possibility for high resolution beyond the diffraction limit with high throughput and low cost. The plasmonic flying head (PFH) with an special designed air bearing morphology flies above the rotating substrate coated by a photoresist film within tens nanometers. The PFH focuses the incident laser beam to a spot size of sub-20 nm with enhanced field intensity by exciting surface plasmon polaritons (SPPs). Due to the viscoelastic organic photoresist, the taking off and landing problems of the PFH are the significant obstacles in the RNFL. In this work, the Load/Unload(L/U) technology is adopted to overcome the taking-off and landing problem. A novel 6-D PFH system model is proposed to study the L/U process to avoid the catastrophic collision. A new PFH morphology for the L/U application is designed and fabricated by the reaction ion etching (RIE) technique. Finally, the performance of the PFH is experimentally verified.

Efficient Numerical Analysis of Textured Hydrodynamic Bearings
Daniel Gropper, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom, Klaus-Dieter Meck, Vladimir Gviniashvili, John Crane UK Ltd, Manchester, United Kingdom

A successful application of surface texturing in hydrodynamic bearings relies heavily on efficient numerical models. In this work, several ways to enhance the computational performance of models based on the Reynolds equation are presented and compared to conventional techniques. The present approach is based on a Finite Volume discretization of the Reynolds equation and takes into account mass-conserving cavitation as well as thermal effects. It is shown that applying special discretization schemes to handle discontinuities, using non-uniform and adaptive meshes, taking advantage of multicore processing and strategically utilising different algorithms to find the bearing equilibrium are ways to study textured bearings most efficiently. Furthermore, using the results of an equivalent untextured bearing as first approximation for the textured bearing is shown to significantly reduce computation times. Results are validated through CFD data and correlated with laboratory test results.

Tribological Properties of Elecrospun Fibers Coatings: Experimental Evaluations
Sepehr Salari, Ali Beheshti, Lamar University, Beaumont, TX

Electrospun fibers have received considerable attention in numerous applications mainly due to their superior properties such as high porosity, high surface to volume ratio, and good strength as compared to base material. Although previous studies have shown mechanical properties enhancement through electrospinning, literature clearly lacks systematic reports on their wear and frictional properties. Aiming to utilize these fibers as coatings, polymeric electrospun fibers are spanned and their friction coefficient, scratch resistance, wear, hardness, and self-lubrication are assessed. Also investigated are the effects of dry and wet environments, as well as ceramic additives on their tribological performances.

Water Molecules on the Liquid Superlubricity Interfaces
Yong Liang, Yuan Gao, Liran Ma, Tsinghua University, Beijing, China, Bohong Li, Beijing Institute of Technology, Beijing, China, Deyu Liu, Jianbin Luo, Tsinghua University, Beijing, China

The concept of superlubricity has drawn a large amount of attention during recent years. However, there was no direct evidence that could interpret the underlying mechanism of superlubricity, due to the limitation in the method for the detection of interfacial molecules. By using sum-frequency vibrational spectroscopy after friction test, we were able to explore microscopic mechanism for the superlubricity in phosphoric acid system.By trapping the phosphoric acid aqueous solution between silicon nitride and silica surfaces, we have discovered that, phosphoric acid could exercise a great influence on the ordered structure of interfacial water molecules, contributing to the sum frequency generation (SFG) spectral changes during the broad OH-bonded stretching region. This work directly revealed the interfacial interaction between water and phosphoric acid molecules in liquid superlubricity interfaces, which could shed new light on the microscopic mechanism of liquid superlubricity.

Model of Fluid Pressure Distribution Under Friction Field
Pengfei Liu, Tianjin University, Tianjin, China

This research is focus on the establishment of the fluid pressure distribution model under the friction field in the grinding processing. For the reason that particles fixed on the grinding pad has a strong segmentation effect on the liquid film, the traditional fluid pressure equations, such as Reynolds equation for smooth interface cannot be used. This research proposes a new developed method to establish the model to solve the problem. This work started with establishing a new numerical model of the grinding pad’s topography, which gave the cutting height of every single particle. The new numerical modeling technique has been proposed to generate the grinding pad topography with spherical grains. The simulation result is given by software. The transient isotherm hydrodynamic lubrication equations of the liquid membrane in the contact zone are established. The numerical simulation is conducted to analyze the hydrodynamic pressure and its distribution.

The Application of the Recurrence Analysis Theory in the Chaotic System
Cong Ding, China University Of Mining And Technology, Xuzhou, Jiangsu, China

For studying the dynamic characteristics of the friction signals, the Lyapunov exponent and the Kolmogrov entropy are often utilized. However, these methods have some weakness. For instance, they require the length of the signal as long as possible which is not beneficial for distinguishing the wear state. And it cannot be avoided that the influences of the subjective factors on the calculation of the chaotic characteristic quantity in the choice of scale interval. In order to calculate the chaotic characteristic quantity more objectively,rapidly and accurately, the recurrence analysis theory is used in the field of the chaos theory. Moreover, it is be verified that the application of this theory with the Lorenz attractors. This study is very significant for the nonlinear dynamic analysis.

A Study on the Evolution of Microstructure Alterations in White Etching Cracks

Viktorija Smelova, University of Southampton, Southampton, United Kingdom, Alexander Schwedt, RWTH Aachen University, Aachen, Germany, Ling Wang, University of Southampton, Southampton, United Kingdom, Walter Holweger, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany, Joachim Mayer, RWTH Aachen University, Aachen, Germany

Formation of the subsurface White Etching Crack (WEC) has been identified as a cause of detrimental failures in a wide range of rolling contact applications. One of the characteristics of WEC is that the cracks are bordered by transformed microstructure, known as White Etching Area (WEA). Recent studies have shown that WEA has a complex microstructure containing varied size grains, hardness heterogeneity and chemical elements redistribution. Despite the significance of the problem and the amount of efforts over decades, the mechanisms of the microstructure transformation leading to the formation of WEA and WEC is still unclear. This study, presents the results from detailed microstructural analyses on WECs, formed in a series of rolling bearing test conditions, using a combination of SEM, EBSD, EDX, and TEM techniques revealing the evolution of WEC formation.

Friction-Reduction and Life-Extension Effects of Two Types of New Additives on Multialkylated Cyclopentanes Under Vacuum Condition

Songwei Zhang, Yi Li, Qi Ding, Litian Hu, Lanzhou Institute of Chemical Physics, CAS, Lanzhou, Gansu, China

Based on the requirements of high reliable, long-acting lubrication of the moving parts in spacecraft, two types of new oil-soluble additives were prepared, which were nanoparticles (oleic acid surface modified silver nanoparticles, named as OA-Ag) and ionic liquids (tri-isooctyl-tetradecylphosphonium bis-isooctyl-phosphate ionic liquids, named as [P88814] [DOP]), as lubricating additives for the synthetic hydrocarbon oil (multialkylated cyclopentanes, named as MACs). The lubricating behaviours of lubricant and additives were evaluated using vacuum four-ball tribometer in vacuum (~10^{-4} Pa) and air. Results show that MACs exhibited the transient high friction in vacuum. The addition of OA-Ag and [P88814] [DOP] could both effectively eliminate the transient high friction, and extend the acting life of MACs.

The Vacuum Tribological Properties of Annealed Newly-Developed Ti-20Zr-6.5Al-4V Alloy

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In the present study, a newly-developed Ti-20Zr-6.5Al-4V alloy is annealed at 1073 K, 1173 K and 1273 K. Then, the dry sliding tribological properties of the annealed T20Z alloy are tested in a ball-on-disc configuration in vacuum with different velocities varied from 200 rpm to 600 rpm. The XRD results show that there exists phase transformation during the sliding friction process. Scanning electron microscopy is used to analyze the wear track on the worn surface to determine the wear mechanism. At a give annealed temperature, the wear mechanisms change from mild adhesive and severe abrasive wear to severe plastic deformation and delamination, accompanied by mild abrasive wear with increasing the applied load. In addition, the severe wear is indentified to the main wear mechanism at the lower sliding velocity of 200 rpm. With increasing the sliding velocity, the abrasive wear is gradually milder and delamination wear and plastic are predominant.

Polymer Brush Lubrication of Silicon Nitride on Steel Contacts: a Colloidal Force Microscopy Study

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A greener lubrication solution based on self-assembling methods for steel on silicon nitride hybrid contacts is investigated in this study. Surface initiated atom transfer radical polymerisation (ATRP) is employed to produce oleophilic polymer brushes based on methyl methacrylate (MMA). This paper presents the synthesis and characteristics of poly(MMA) brushes that have been designed to synergize with a PAO lubricant whilst forming a strong covalent bond with the silicon nitride surface. By utilising

activators regenerated by electron transfer (ARGET) the amount of catalyst needed is reduced to ppm levels allowing polymerisations to take place in a limited amount of air. The initiators and the polymer brushes formed on silicon nitride surfaces are characterised using XPS, contact angle, gel permeation chromatography and atomic force microscopy. The lubricating effects of the polymer brushes under dry and swollen states are evaluated using lateral force microscopy with a steel colloid.

Effect of Tooth Profile Modification on Lubrication Performance of Involute Spur Gear
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Tooth profile modification is a familiar method to improve load capacity and avoid tooth failures, however, the lubrication performance of an engaged gear pair surfaces would be affected due to the change of gear micro-geometry. Firstly, a thermal elastohydrodynamic lubrication (TEHL) model of an engaged spur gear pair is developed. Film thickness, pressure, friction coefficient, temperature, etc. could be determined by the proposed model. Then, influence of different tooth profile modification parameters on the lubrication performance are investigated based on the proposed TEHL model. At the end, the lubrication performance of different operating conditions are studied under the condition of the identical tooth profile modification parameter.

Effect of Design Parameters on Lubrication Behavior of Spur Gear Pairs
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Design parameters and unavoidable profile error profoundly influence the lubrication behavior of spur gear pairs. In this study, a thermal elastohydrodynamic lubrication (EHL) model includes gear-specific time variations of all key contact parameters such as the rolling and sliding velocities, radii of curvature, and normal load, is developed initially. Film thickness, pressure, friction coefficient, temperature etc. could be achieved through the proposed model. Based on the proposed model, effects of design parameters of spur gear pairs, including pressure angle and number of tooth, on lubrication behavior is investigated. Furthermore lubrication behavior caused by profile error is also taken into consideration.

Studies on Triboluminescence Emission Characteristics of Various Kinds of ZnS Crystals
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ZnS crystal has been investigated for a long time due to its wide applications in many fields, as electroluminescence devices, photodiodes, optical thin film and so on. The luminescence properties of ZnS have been studied by using many methods, in spite of this, the luminescence mechanisms are still not well understood. Up to now, triboluminescence(TL) properties of undoped ZnS are rarely reported. We investigated the TL emission of ZnS crystals by sliding with alumina in different gas atmospheres. The results showed that there are two fluorescence peaks at 420nm and 475nm in TL spectrums of multi spectral and hot pressed ZnS respectively. This phenomenon may originate from the structural disparities in various kinds of ZnS crystals, and provide a new perspective for study on luminescence properties of ZnS material.

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