Overview

Please check the errata in your registration bag to verify course times. Some times might change slightly.

WEDNESDAY, MAY 22

Registration (7 am – 6 pm) – Second Level Omni Foyer

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

Commercial Exhibits & Student Posters
(9:30 am – Noon) – Broadway Ballroom

Wednesday Education Courses* (8 am – 5 pm)

- Advanced Lubrication 302: Advanced Lubrication Regimes – Legends A/B
- Basic Lubrication 103 – Legends C
- Metalworking Fluids 130: Metal Treating, Cleaning and Protecting Fluids – Legends E
- Synthetic Lubrication 204: Basestock Selection and Applications – Legends G

Wednesday Technical Sessions (8 am – Noon)

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

Lunch on your own (Noon – 1:30 pm)

Wednesday Technical Sessions (1:30 – 6 pm)

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

Beverage Break (10 – 10:30 am) – Broadway Ballroom

Beverage Break (3 – 3:30 pm) – Second Level Omni Foyer

Exhibition Hours

- **Wednesday, May 22** (9:30 am – Noon)

TIME	SESSION 5A Rolling Element Bearings I Legends F	SESSION 5B Wear III Music Row 1	SESSION 5C Commercial Marketing Forum V Music Row 5
8 – 8:30 am		Developing Improved Anti-Wear Additives by Leveraging from Industry Trends, C. Chretien, Solvay, p. 92	ChemGroup Delivers Huntsman Surfactants Advantages for MWF Applications, G. Wehr, p. 94
8:30 – 9 am	Roughness Effect in Rolling Contact Fatigue of Silicon Nitride, M. Mosleh, p. 90	A Study on Wear Effects From Methyl-Ester in Oil Mixtures, G. Molina, p. 92	Metall-Chemie GmbH & Co. KG: A Hidden Champion, P. Tkaczuk, p. 94
9 – 9:30 am	Experimental & Numerical Studies… Mechanisms of Surface Crack Propagation Under Rolling Contact, A. Kadiric, p. 90	Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration: Part I, D. Isaac, p. 92	Pilot Chemical: Sulfonates and Pilot's Expansion with Lubricant Additives, K. Potter, p. 94
9:30 –10 am	A Model for Hybrid Bearing Life with Surface and Subsurface Survival, A. Gabelli, p. 90	Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration: Part II, M. Kirsch, p. 92	Huntsman Petrochemicals: JEFFADD® MW Specialty Amines: Multi-functional Products Developed for Metalworking, R. Maus, p. 94
10 – 10:30 am	**Break**	**Break**	**Break**
10:30 – 11 am	An Analysis of Rolling Element Bearings Fatigue Life Reduction Caused by Debris Denting, A. Bonetto, p. 90	Understanding How Scanning Strategy Affects the Wear Behavior of 3D-Printed Stainless Steel, M. Bahshwan, p. 92	Lubrizol: A Changing Environment for Corrosion Protection, J. Kay, p. 94
11 – 11:30 am	Innovation in Testing and Calculation Methods against Surface Initiated Damage Mechanisms (SID) in Rolling Bearings, D. Merk, p. 90	High Temperature Friction and Wear Behavior of Nimonic C263, D.H. Veeregowda, p. 92	Zschimmer & Schwarz: What's New at Zschimmer & Schwarz?, T. Housel, p. 94
11:30 am – Noon	Investigation of the Dent Resistance of Instrument Bearings with NiTi-Hf Rolling Elements, S. Howard, p. 90	Investigation of the Effect of Coatings on Wear of Gas Turbine Components at Elevated Temperature, A. Sharma, p. 94	Lubrizol: Designing Energy-Efficient Hydraulic Fluid, S. Basu, p. 96

TIME	SESSION 6A Rolling Element Bearings II Legends F	SESSION 6B Biotribology I Music Row 1	SESSION 6C Commercial Marketing Forum VI Music Row 5
1:30 – 2 pm	Microstructural Improvements of Advanced Ball Bearing Materials through Alloying Elements, Powder Metallurgy and Deformation Processes, C. Della Corte, p. 110	Invited Talk – Cartilage Lubrication:Why Everything I Thought I Knew is Wrong …, I. Cohen, p. 112	SEQENS (ex-PCAS), D. Authier, p. 114
2 – 2:30 pm	The Lubricant Formulation: Driver for Premature Bearing Failures and White Etching Cracks?, K. Stadler, p. 110	Cartilage Fluid Load Support in the Migrating Contact Area: How Much Migration is Necessary?, J. Benson, p. 112	Biosynthetic Technologies – Delivering Innovations for a Sustainable Future, M. Miller, p. 114
2:30 – 3 pm	Surface Driven Formation of White Etching Cracks in Bearings Used in Wind Turbines, M. Paladugu, p. 110	Rate-Dependent Cartilage Adhesion Derived from Poroviscoelastic Relaxations, G. Han, p. 114	Bruker UMT Tribolab Friction and Wear Test Platform – Speed Up Development and Reduce Costs with the Original Benchtop Multi-Test Platform, S. Papanicolaou, p. 114
3 – 3:30 pm	**Break**	**Break**	**Break**
3:30 – 4 pm	The Evolution of Dark Etching Regions and White Etching Bands in Bearing Steel Due to Rolling Contact Fatigue, M. El Laithy, p. 110	Quantifying Adhesion in Articular Cartilage, J. Benson, p. 114	AMRRI: IIoT Meets Tribology: LubeCoach Pro 5.0, M.Johnson, p. 114
4 – 4:30 pm	The Major Acceleration Factor of White Etching Crack (WEC), Y. Toda, p. 110	Elegant Shadow Making Tiny Force Visible and Measurable, H. Lu, p. 114	Clariant: Emulsogen® MTP: Next Generation of Low Foam Multifunctional Emulsifiers, M. Perkins, p. 115
4:30 – 5 pm	Formation of White Etching Areas/Cracks on a Four Disk Rig – Influence of Electrical Current and Slip, F. Steinweg, p. 112	Biotribology Business Meeting	Sasol ISOFOL & ISOCARB for Lubricants & Metalworking Differentiated Applications, G. Khemchandani, p. 115
5 – 5:30 pm	The Influence of Material Properties and Steel Cleanliness on the Formation of Subsurface Cracking Failures Associated with Microstructural Alterations, B. Gould, p. 112		OXEA Chemicals: Advantages of Synthetic Ester Base Oils – Reasons for Growth, J. Kubitschke, p. 115
5:30 – 6 pm	Structure Change of Cementite Just Below the Sliding Surface on Ball Bearings, K. Matsumoto, p. 112		
6 – 6:30 pm	Analysis of Material Defects in Relation to Different Damage Mechanisms, J. Binderszewsky, p. 112		
6:30 – 7 pm	Rolling Element Bearings Business Meeting		

SESSION 5D Frontiers of Tribology Research I Music Row 4	SESSION 5E Tribotesting III Music Row 3	SESSION 5F Synthetic and Hydraulic Lubricants I Music Row 2	
	Why All Test Rigs Do Not Give the Same Friction and Wear Response, C. Sanchez, p. 97	Sensitivity Analysis of the FMVP Test Method to Evaluate Hydraulic Fluids for Vane Pumps, E.Georgiou, p. 98	**8 – 8:30 am**
New Advance in Superlubricity, J. Luo, p. 96	A Holistic Approach to Characterize the Tribological Performance of Lubricants Applied to New EALs in Plain Bearings, H. Brunskill, p. 97	Polymer-Enhanced Fluid Effects on Mechanical Efficiency of Hydraulic Pumps, P. Michael, p. 98	**8:30 – 9 am**
Surface and Interface Engineering for Ultra-Low Wear and Friction, A. Erdemir, p. 96	A Study on Viscosity and Lubricity, Effects of N-Butanol and its Mixtures in Oil, G. Molina, p. 97	Improving Hydraulic Efficiency by Controlling Fluid Flow Characteristics, T. Smith, p. 98	**9 – 9:30 am**
Dental Biotribology and Bionic Design, Z. Zhou, p. 96	Erosion-Corrosion of Heat-Exchanger Materials by Water/Ethylene-Glycol/Alumina Nanofluids, G. Molina, p. 97	Tribological Performance of Composite Basefluid for Hydraulic Systems, M. Cinta Lorenzo Martin, p. 98	**9:30 –10 am**
Break	**Break**	**Break**	**10 – 10:30 am**
Cobalt CMP, H. Liang, p. 96	Pump Failures: A Laboratory Method to Distinguish Between Lack of Lubricity and Presence of Abrasive Nanoparticles, P. De Vaal, p. 97	Harvesting Benefits from the Next Generation of Agriculture Lubricant Specifications, R. Gomes, p. 100	**10:30 – 11 am**
Surface Texture Recognition from Fingertip Skin Frictional Sensing, S. Ge, p. 96	The Tribolgolical Performance of Fuel-Efficient Gear Oils in a Limited Slip Differential, G. Hansen, p. 98	Fluid Effects on Low Temperature Power Consumption and Cavitation Noise in Hydraulic Systems, Z. Dai, p. 100	**11 – 11:30 am**
Application of Fluid Rheological Measurements to Improve the Accuracy of Rolling Element Bearing Torque Calculations, R. Evans, p. 96	Infrared Microscope Analysis – A Tool for Understanding Failure Analysis and Improving Equipment Reliability, K. Schomburg, p. 98	Study on Water Separation of Evaluation for Hydraulic Oil, Z. Liu, p. 100	**11:30 am – Noon**

SESSION 6D Frontiers of Tribology Reseach II Music Row 4	SESSION 6E Tribochemistry I Music Row 3	SESSION 6F Synthetic and Hydraulic Lubricants II Music Row 2	
Tribochemistry – Myths and Facts, S. Kim, p. 115	The Effect of TiO_2 Nanoparticle Addition to the Tribological Performance of MoDTC-Containing Lubricants F. Dassenoy, p. 116	Synthesis of Dibenzyl Toluene as Heat Transfer Fluid, P. Li, p. 118	**1:30 – 2 pm**
Boundary Lubrication of Polar Molecule in Aqueous Solutions Under Electric Field, Y. Meng, p. 115	One-Pot Synthesis of Serpentine@Polymer Nanoparticles with Outstanding Anti-Wear Property, Q. Chang, p. 116	A New Group V Base Oil for Low Viscosity Engine Oil, Y. Han, p. 118	**2 – 2:30 pm**
Tribological and Electric Properties of C/Cu Pairs under Dynamic Contact During Current-Carrying Sliding, Y. Zhang, p. 115	A Stress-Activated Model for Tribofilm Growth Based on a Nanoparticle Sintering Mechanism, A. Comfort, p. 117	Naphthenic Base Oils for High Performance, High Viscosity Index Hydraulic Fluids Applications, T. Norrby, p. 118	**2:30 – 3 pm**
Break	**Break**	**Break**	**3 – 3:30 pm**
Tribochemical Reaction Pathways Explored with Reactive Atomistic Simulations, A. Martini, p. 116	Tribochemistry of Ultralow Wear PTFE-Based Composites: Assessing the Role of the Sliding Environment, K. Campbell, p. 117	Performance and Implemenation of Perfluoropolyether (PFPE) Lubricants, J. Dawczyk, p. 118	**3:30 – 4 pm**
Integrated Biomechanics and Biotribology of Artificial Joints, Z. Jin, p. 116	Nanomechanics of Ultralow Wear PTFE-Based Composites: Microstructure and Mechanics of Filler Particles, C. Atkinson, p. 117	Thermodynamic Characterization of Base Oil Viscosity and Vapor Pressure, T. Karis, p. 118	**4 – 4:30 pm**
Fundamental Insights into Adhesion, Friction, and Wear through Nanoscale Contact Experiments, R. Carpick, p. 116	Promotion of Ultralow-Wear Fluoropolymer-Metal-Oxide Composites through Tribochemistry, M. Sidebottom, p. 117	Synthetics and Hydraulics Business Meeting	**4:30 – 5 pm**
Synergy of Friction and Adhesion Between Gecko Feet and Substrate for Super-Locomotion Ability, Z. Dai, p. 116	Clarifying Transfer Film Effects by Removing Them, I. Alam, p. 117		**5 – 5:30 pm**
	Ultra-Low Wear of PEALD Nitride Thin Films, T. Babuska, p. 117		**5:30 – 6 pm**
	Friction and Oxidation of MoS_2 In Low Earth Orbit: Results from the Space Tribometers, B. Krick, p. 118		**6 – 6:30 pm**

WEDNESDAY >>

TIME	SESSION 5G Engine and Drivetrain III Cumberland 1/2	SESSION 5H Nanotribology V Cumberland 3	SESSION 5I Surface Engineering I Cumberland 4
8 – 8:30 am	Effects of SAE 0W-20 Engine Oil Formulations in Taxi Cab Severe Field Service, J. Ellington, p. 100	Exploring the Limits of Contact Mechanics Models for Nano-scale Metal Contacts Using In-Situ and in Silico Techniques, S. B. Vishnubhotla, p. 102	Tribology of Micro-Textured ATSP Polymers in Synthetic Seawater, R. Gheisari, p. 104
8:30 – 9 am	Automatic Transmission Fluid VII Effects in Taxi Cab Field Service, J. Ellington, p. 100	Atomic-Scale Insights into Contacts Between Nanoscale Bodies: In-Situ Experiments and Matched Atomistic Simulations, T. Jacobs, p. 102	Analytical and Experimental Investigation of Effect of Surface Roughness on Axial Fatigue, K. Singh, p. 104
9 – 9:30 am		The Chemistry of Friction, Wear and Tribo Film Growth on 2D Materials, S. Raghuraman, p. 104	Characterization and Tribological Application of High Porosity Coatings, H. Ghaednia, p. 105
9:30 –10 am	PPD Selection for Next Generation Engine Oil Formulations, J. Mills, p. 102	Tribological Behavior Comparison of MoS_2 and Graphene Influenced by Humidity and Counter Surface Oxides, T. Arif, p. 104	Improved Wear and Fatigue Resistance of a Boron-Doped DLC Coating Deposited on UNSM Pre-Treated 52100 Steel Substrate, Z. Ren, p. 105
10 – 10:30 am	Break	Break	Break
10:30 – 11 am	Non-Invasive Monitoring of Free Surface Thin Film Layer Spread Using an Ultrasonic Continuously Repeated Chirp Longitudinal Wave, J. Kanja, p. 102	Invited Talk: Pushing Tiny Sliders, or What We Can Learn from the Controlled Translation of Really Small Objects on Well-Defined Surfaces?, U. Schwarz, p. 104	Elastic and Elastic-Plastic Analysis of an Axisymmetric Sinusoidal Surface Asperity Contact, S. Saha, p. 105
11 – 11:30 am	Hydroynamic Friction Reduction Due to Laser Texturing of IC Engine Journal Bearing Shells, T. Reddyhoff, p. 102		Low Cost Fabrication Method for Surface Textures on Engine Components, S. Hsu, p. 105
11:30 am – Noon	Fuel Economy Modeling: Engine-to-Engine Operating Regime Differences, B. Miller, p. 102	Atomic-Scale Friction Behavior of Few-Layer Graphene under Ultra-High Vacuum Conditions, P. Egberts, p. 104	Multi-Resolution Characterization of Surface Topography for Improved Properties Prediction, T. Jacobs, p. 105

TIME	SESSION 6G Engine and Drivetrain IV Cumberland 1/2	SESSION 6H Nanotribology VI Cumberland 3	SESSION 6I Surface Engineering II Cumberland 4
1:30 – 2 pm	Combustion Technologies for High-Efficiency Light-Duty Automotive Engines, A. Solomon, p. 120	In-Situ Tribofilm Growth Study of a Mechanical Sintering Nanoparticle Antiwear Additive, S. Thrush, p. 120	Tribological Behavior of 17-4 PH Stainless Steel Fabricated by Traditional Subtractive and Laser-Based Additive Manufacturing Methods, S. KC, p. 122
2 – 2:30 pm	Next Generation Wet Friction Technologies for Improving Drivetrain Efficiency, F. Dong, p.120	Tribological Behavior of Plasma Functionalized ZnO Nano-Additives, K. Vyavhare, p. 120	Laser Additive Manufacturing of Ni-Al-Cr-C Alloys: A High Temperature Sliding Wear Study, T. Torgerson, p. 122
2:30 – 3 pm	Tribological Challenges of Advanced Engine Technologies, P. Lee, p. 120	In-Situ SEM Nanomechanical Characterization of Tribofilms Derived from Inorganic Nanoparticles, K. Farokhzadeh, p. 121	The Effects of Laser Shock Peening on the Fatigue Performance of the 3D-Printed AlSi10Mg Alloy, H. Zhang, p. 122
3 – 3:30 pm	Break	Break	Break
3:30 – 4 pm	Modifications of Ferrous-Based Thermal Spray Coatings for Improved Tribological System Performance, P. Rosa, p. 120	Dislocations Associated with Stick-Slip Friction of Lubricants in Boundary Lubrication, R. Xu, p. 121	Improving Surface Finish and Wear Resistance of Additive Manufactured Nickel-Titanium by Ultrasonic Nano-Crystal Surface Modification, C. Ma, p. 122
4 – 4:30 pm	Open Discussion	PEI-RGO Nanosheets as a Nanoadditive for Enhancing the Tribological Properties of Water-Based Lubricants, C. Liu, p. 121	Increase in Mechanical Properties and Wear Resistance of Selective Laser Melted Stainless Steel 316L by Surface Modification, A. Amanov, p. 122
4:30 – 5 pm	Engine and Drivetrain Business Meeting	Study on the Quantitative Evaluation of the Surface Force Using a Scanning Probe Microscope, W. Yagi, p. 121	Patterning and Fusion of Alumina Particles on S7 Tool Steel by Pulsed Laser Remelting, S. Chen, p. 122
5 – 5:30 pm		The Molecular Arrangement and Frictional Response of SAMs of a Planar Phthalocyanine Molecule, Y. Qiao, p. 121	Surface Engineering Business Meeting
5:30 – 6 pm		Nanotribology Business Meeting	

SESSION 5J Lubrication Fundamentals V Cumberland 5	SESSION 5K Tribology of Biomaterials Cumberland 6	
Molecular Science and Engineering Application of High Performance Lubricants, W. Liu, p. 106	Invited Talk: Tribocorrosion in the Human Body: Retrieval Analysis to Fundamental Modeling, J. Gilbert, p. 108	8 – 8:30 am
The Autoxidation of Polyisobutylene Succinimide Dispersant Mimics: Products, Mechanisms and Performance Implications, J. Ruffell, p. 106		8:30 – 9 am
Relationship Between Structures and Anti-Oxidation Performance of Hindered Phenolic Antioxidants, T. Tang, p. 106	Bio-Tribocorrosion of CoCrMo During Reciprocating Sliding Against Bovine Articular Cartilage, M. Rodriguez Ripoll, p. 108	9 – 9:30 am
The Use of Microcapsulated Additives Fuel Economy Enhancement, S. Hsu, p. 106	Biomechanics of Hierarchically-Structured Enamel in Grinding Dentitions, T. Grejtak, p. 108	9:30 –10 am
Break	**Break**	10 – 10:30 am
Is Oxidation Terminated? Latest Technologies for Low Varnishing and Long-Life Turbine Oils Highlight the Need for Revised Oxidative Stability Testing, A. Mannion, p. 106	Fabrication of Cartilage-Inspired Surface Textures Using Photolithography for Orthopedic Implants, D. Choudhury, p. 108	10:30 – 11 am
Fuel Economy Low Viscosity Engine Oil Compatible with Low Speed Pre-Ignition, J. Zhao, p. 106	Friction Across Soft Matter Interfaces, A. Pitenis, p. 108	11 – 11:30 am
Evolution of ZDDP Crystallinity and Its Effect on Film Durability, M. Ueda, p. 108	Understanding the Interaction Between Contact Lens and Eye Using In-Vivo and In-Silico Techniques, R. Morecroft, p. 110	11:30 am – Noon

SESSION 6J Lubrication Fundamentals VI Cumberland 5	SESSION 6K Condition Monitoring I Cumberland 6	
Proposals to Improve the Viscosity Index Method, ASTM D2270, J. Zakarian, p. 123	Contributing Factors That Influence Oil Analysis Data, M. Holloway, p. 124	1:30 – 2 pm
Effects of Oiliness Additives on Lubrication Conditions in Rolling Bearings, T. Maruyama, p. 123	Monitoring Engine Lubricating Oil Viscosity In-Situ in a Test Marine Diesel Engine Using a Novel Ultrasonic Technique, X. Li, p. 124	2 – 2:30 pm
Mechanism of ZDDP Boundary Film Formation, H. Spikes, p. 123	Management of Lubricated Machinery Assets in an Industrial Setting, B. Johnson, p. 124	2:30 – 3 pm
Break	**Break**	3 – 3:30 pm
A Mixed Lubrication Model for Paralleled Plain Faces, Y. Wang, p. 123	Study on the Condition Monitoring System for the Sliding Surface Using Machine Learning, T. Honda, p. 124	3:30 – 4 pm
The Investigation of Oil Replenishment in a Rolling Bearing, H. Liang, p. 123	A New Approach to Onsite Oil Analysis for Industry 4.0, L. Williams, p. 124	4 – 4:30 pm
Impact of ZDDP Degradation – Influence of Engine Oil Condition on Friction and Wear, N. Doerr, p. 123	Bridging the Gap: Filter Debris Analysis, H. Neicamp, p. 124	4:30 – 5 pm
Influence of Lubricant Additive Chemistry on the Viscosity of Model Base oil Formulations, S. Poornachary, p. 124	Condition Monitoring Business Meeting	5 – 5:30 pm
Lubrication Fundamentals Business Meeting		5:30 – 6 pm

Attendees can download available 2019 STLE Annual Meeting extended abstracts and presentation slides online at www.stle.org/annualmeeting during and after the meeting.

Presentations also are available in the Annual Meeting section of the STLE 365 app (under the Events app section). Be sure to check the STLE website and 365 app for the latest updates on presentations that have been added as they become available.

Session 5A • Legends F

Rolling Element Bearings I

Session Chair:
Nikhil Londhe, The Timken Co., Canton, OH

Session Vice Chair:
Anup Pandkar, Siemens Gamesa Renewable Energy, Orlando, FL

8 – 8:30 am | Session starts at 8:30 am

8:30 – 9 am | Roughness Effect in Rolling Contact Fatigue of Silicon Nitride

Mohsen Mosleh, Keron Bradshaw, Sonya Smith, Howard University, Washington, DC, Khosro Shirvani, Rowan University, Glassboro, NJ, John Belk, ZeroTechnology, St. Louis, MO

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

9 – 9:30 am | Experimental and Numerical Studies into the Mechanisms of Surface Crack Propagation Under Rolling Contact

Amir Kadiric, Pawel Rycerz, Björn Kunzelmann, Imperial College London, London, United Kingdom

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

9:30 – 10 am | A Model for Hybrid Bearing Life with Surface and Subsurface Survival

Antonio Gabelli, Guillermo Morales-Espejel, SKF Research and Technology Development, Nieuwegein, Netherlands

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

10 – 10:30 am | Break

10:30 – 11 am | An Analysis of Rolling Element Bearings Fatigue Life Reduction Caused by Debris Denting

Alexis Bonetto, Daniel Nélias, Thibaut Chaise, LaMCoS INSA De Lyon, Villeurbanne, France, Laurent Zamponi, Airbus, Marignane, France

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

11 – 11:30 am | Innovation in Testing and Calculation Methods against Surface Initiated Damage Mechanisms (SID) in Rolling Bearings

Daniel Merk, Bernd Vierneusel, Jörg Franke, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

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

11:30 am – Noon | Investigation of the Dent Resistance of Instrument Bearings with NiTi-Hf Rolling Elements

Samuel Howard, Christopher DellaCorte, NASA, Cleveland, OH

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

JOIN US FOR OUR COMMERCIAL MARKETING FORUMS AT THE STLE CONFERENCE

stle*Nashville*
May 19-23, 2019 | Omni Hotel Nashville

MONDAY MAY 20, 8:30 AM:
Synfluid® Metallocene Polyalphaolefins (mPAOs) Grease Applications

TUESDAY MAY 21, 8:30 AM:
PAO Blending Matrix Tool: Simulations and Examples of how to Streamline Lab Blends

WHY SETTLE FOR ENERGY EFFICIENCY OR EXTREME OPERATING CONDITIONS? WE CAN HELP YOU ACHIEVE BOTH.

You caught my attention regarding the advantages of Synfluid® mPAO in greases. Is there anything else you can tell me?

PAO EXPERT | *Ken Hope, Ph. D.*

Yes! Working with Paul Bessette from Triboscience and Engineering Inc., we were able to prepare NLGI Grade 2 lithium greases with high viscosity PAOs (conventional PAO 40 and Synfluid® mPAO 65). The low temperature torque data is much lower in both starting and running conditions for the Synfluid® mPAO. This lower torque could mean the difference between equipment operating or equipment being down in harsh cold climates. In ordinary temperature conditions, it translates to energy efficiency improvements.

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Session 5B • Music Row 1

Wear III

Session Chair:
John Bomidi, Baker Hughes, The Woodlands, TX

Session Vice Chair:
Bulent Chavdar, Eaton Corp., Southfield, MI

8 – 8:30 am | Developing Improved Anti-Wear Additives by Leveraging from Industry Trends

Christelle Chretien, Solvay, Bristol, PA

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

8:30 – 9 am | A Study on Wear Effects From Methyl-Ester in Oil Mixtures

Gustavo Molina, Emeka Onyejizu, John Morrison, Valentin Soloiu, Georgia Southern University, Statesboro, GA

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

9 – 9:30 am | Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration: Part I

Daulton Isaac, Mathew Kirsch, Patrick Hellman, Andrew Foye, Air Force Research Laboratory, Wright-Patterson AFB, OH, Hitesh Trivedi, UES, Inc., Dayton, OH

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

9:30 – 10 am | Adhesive Wear Performance of Pyrowear 675 in All Metal and Hybrid Configuration: Part II

Mathew Kirsch, Daulton Isaac, Andrew Foye, Patrick Hellman, Air Force Research Laboratory, Wright-Patterson AFB, OH, Hitesh Trivedi, UES, Inc., Dayton, OH

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

10 – 10:30 am | Break

10:30 – 11 am | Understanding How Scanning Strategy Affects the Wear Behavior of 3D-Printed Stainless Steel

Mohanad Bahshwan, Tom Reddyhoff, Connor Myant, Imperial College London, London, United Kingdom

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

11 – 11:30 am | High Temperature Friction and Wear Behavior of Nimonic C263

Deepak Halenahally Veeregowda, Fabio Alemanno, Ducom Instruments Europe B.V, Groningen, Netherlands, Ahmad Afiq Bin Pauzi, TNB Research, Kuala Lumpur, Malaysia

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

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5B

11:30 am – Noon | Investigation of the Effect of Coatings on Wear of Gas Turbine Components at Elevated Temperature

Akshat Sharma, Purdue University, West Lafayette, IN

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

Session 5C • Music Row 5

Commercial Marketing Forum V

8 – 8:30 am | ChemGroup Delivers Huntsman Surfactants Advantages for MWF Applications

Gregory Wehr, ChemGroup. Inc., Louisville, KY

Emulsifiers are a critical additive in water-miscible MWFs. ChemGroup strives to meet the needs of the MWF markets providing advantaged solutions where: 1) emulsifiers must perform under increasingly tough conditions, while maintaining low foam characteristics; 2) stricter regulations and limited availability of additives has increased the need for products with cleaner labeling; and 3) formulators seek safer emulsifiers with a broad range of benefits. Huntsman SURFONIC® SM, LF, & MW series of surfactants are ideally suited to meet the needs of the MWF market; as high performance emulsifiers with low foaming characteristics; used as either primary or secondary emulsifiers; and very good environmental, health, and safety profiles.

ChemGroup also remains keenly focused on bringing forward environmentally-friendly performance advances in MWF and functional fluid formulations with Shell's Gas-To-Liquids Technology and product lines of GTL Fluids, GTL Solvents, and GTL Normal Paraffin.

8:30 – 9 am | Metall-Chemie GmbH & Co. KG

A Hidden Champion

Piotr Tkaczuk, Metall-Chemie GmbH & Co. KG, Hamburg, Germany

Metall-Chemie GmbH & Co. KG: Experienced, Focused on Solutions, Reliable & Flexible. Development, production and the global distribution of lubricant additives are our core business.

In addition to our sales offices in Hamburg and Shanghai, we are represented by a global network of selected sales partners in numerous countries and regions of the world. All our products are of high quality and meet our customers' technical and legal requirements. Our product range, long experience and solid knowledge in consulting on technical issues make Metall-Chemie GmbH & Co. KG a reliable partner for the lubricants industry. Metall-Chemie GmbH & Co. KG stands for:

- Technical knowledge and production expertise
- Consistently high and controlled product quality, dependability, global supply security and availability

9 – 9:30 am | Pilot Chemical

Sulfonates and Pilot's Expansion with Lubricant Additives

Kenny Potter, Pilot Chemical Co., Cincinnati, OH

Bringing new light to industry challenges with corrosion protection, from metalworking fluids to SN+ compliant motor oils, Pilot Chemical has expanded its product line to meet these challenges head on. Pilot's expansion on core technologies and investment in a new state of the art innovation center has better positioned the company to partner with businesses and resolve formulation challenges. New capabilities include overbasing with Magnesium or zinc, carboxylation, and increased sulfonation and neutralization technology. Proprietary ice-cold sulfonation technology is used to produce Pilot's Aristonate® synthetic sulfonates, including Aristonate® S-4600 which can fully emulsify a 100N naphthenic base oil using 18 parts concentrate to 82 parts of oil. In this presentation we will review Pilot's new capabilities, as well as compare the performance of the Aristonate® S-4600 emulsifier package against a natural sulfonate emulsifier package.

9:30 – 10 am | Huntsman Petrochemicals

JEFFADD® MW Specialty Amines: Multi-functional Products Developed for Metalworking

Ronald Maus, Huntsman Petrochemical LLC, Everberg, Belgium

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

10 – 10:30 am | Break

10:30 – 11 am | Lubrizol

A Changing Environment for Corrosion Protection

Janet Kay, Ben Faber, Britt Minch, Amelia Hadler, The Lubrizol Corp., Wickliffe, OH

The modern manufacturing world has increasing demands for effective rust prevention, focused on performance and sustainability. Traditional chemistries have been the rust prevention standard for over 90 years but are now evolving to meet these changing demands. This paper will explore a new innovative chemistry that addresses these industry challenges and will discuss how this product delivers exceptional performance and reduced complexity while mitigating future supply risk.

11 – 11:30 am | Zschimmer & Schwarz

What's New at Zschimmer & Schwarz?

Tyler Housel, Zschimmer & Schwarz, Lansdale, PA

In 2019, Zschimmer & Schwarz opened its state-of-the-art esterification plant in Ivey, Georgia. It has been a year of significant change at Zschimmer & Schwarz, so this presentation will be an opportunity to discuss the highlights and look to the future with 20/20 vision. 1) Portfolio review: Synthetic Esters and beyond Advances in product quality, efficiency, and consistency, 2) New product development:

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Fire-resistant hydraulic fluids (private label), 3) Early stage research: Water-based emulsion lubricants for high temperature applications including food processing.

11:30 am – Noon | Lubrizol

Designing Energy-Efficient Hydraulic Fluid

Shubhamita Basu, The Lubrizol Corp., Wickliffe, OH

Hydraulic systems, commonly used in the construction, mining, forestry and manufacturing industries, are facing a shift towards more compact systems, higher pressure and power densities to meet the constant demand of higher throughput. Thus, both equipment and the lubricant are forced to operate under higher stress leading to unforeseen downtime. Modern hydraulic fluids need to be designed such that it helps the equipment last longer – reliably and efficiently. In the absence of industry standard tests, Lubrizol developed scientific ways to measure efficiency and flow properties and identified ways to minimize flow losses in the hydraulic system. This presentation will highlight fluid formulations developed using Lubrizol's LucantTM viscosity modifiers and suitable antiwear additive packages that improve energy efficiency without compromising on durability.

Session 5D • Music Row 4

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

Session Chair:
Qian (Jane) Wang, Northwestern University, Evanston, IL,
Yonngang Meng, Tsinghua University, Beijing, China

8 – 8:30 am | Session starts at 8:30 am

8:30 – 9 am | New Advance in Superlubricity

Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

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

9 – 9:30 am | Surface and Interface Engineering for Ultra-Low Wear and Friction

Ali Erdemir, Argonne National Laboratory, Lemont, IL

Great strides have been made recently in the design and synthesis of superslick materials, coatings, and lubricants that are able to afford extremely low friction and wear coefficients under both dry and lubricated conditions. When considering the fact that friction and wear related energy losses account for nearly a quarter of the global energy output at these days, such super slick surfaces may help in achieving a sustainable energy future that is also environmentally sensible. This presentation will provide an overview of recent advances in friction control technologies and summarize recent works on new materials, coatings and lubricants providing some of the lowest friction and wear coefficients. Overall, these and other novel approaches are leading the way for the design and fabrication of next generation surfaces, interfaces, and lubricants that can help toward the realization of a secure and sustainable energy future.

9:30 – 10 am | Dental Biotribology and Bionic Design

Zhongrong Zhou, Jing Zheng, Tribology Research Institute, Southwest Jiaotong University, Chengdu, Sichuan, China

Development of wear-resistant machine parts based on the anti-wear mechanisms of bio-models plays an important role in upgrading equipment manufacturing level. In this study, natural teeth were selected as bio-models, and dental anti-wear mechanism and its bionics were investigated. It is found that human teeth have multiple-level anti-wear material composition and structure, which is the intrinsic factor of dental excellent anti-wear performance. Salivary pellicle lubrication plays an important role in reducing tooth friction, and remineralization is an important way to decrease dental tribo-corrosive damage. Notched sill structure on molar surface increases working stress and enhances the fragmentation of materials. Based on the multiple coupling anti-wear mechanism of teeth, some tribological design methods are explored. Relevant biomimetic methods provide theoretical support for the development of tooth-shaped grinding head with high crushing efficiency and its prototype.

10 – 10:30 am | Break

10:30 am – 11 am | Cobalt CMP

Hong Liang, Texas A&M University, College Station, TX

Recent advancement in chemical-mechanical polishing (CMP) has made it possible to planarize various metals, active or passive. The key fundamental issue is the synergy of chemical-mechanical interaction on metallic surfaces. Here we present electrochemical-tribological study of cobalt. We found that a layer of oxide was formed on Co during polishing. The thickness of the oxide layer is affected by the pH value, contact pressure, and relative surface speed. In the range of pH 5.0 – 8.0, oxidation dominates. In that of 8.0 – 9.0, mechanical wear takes control. The synergy of mechanically induced material removal and oxidation in the polishing process depends on the mechanical power and electrochemical reaction. Details will be discussed during presentation.

11 – 11:30 am | Surface Texture Recognition from Fingertip Skin Frictional Sensing

Shirong Ge, China University of Mining and Technology, Beijing, China

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

11:30 am – Noon | Application of Fluid Rheological Measurements to Improve the Accuracy of Rolling Element Bearing Torque Calculations

Ryan Evans, William Hannon, Praveen Pauskar, The Timken Co., North Canton, OH

Rolling element bearing torque and power losses arise because of rolling and sliding friction. Sliding losses occur at the bearing roller end-flange interface, or due to pivoting or skewing of the rollers, as well as conformal microslip. In most applications these losses constitute half of the total bearing power losses. In a properly designed bearing, these losses are brought about by lubricant shear. A detailed understanding of

contacts within bearings thus require adequate lubricant rheological models. This work applies the Yasutomi and the Carreau-Yasuda models to the prediction of shear losses in a rolling element bearing. Lubricant property measurements are obtained using a falling body low shear viscometer, a Couette high shear viscometer, and friction results are presented using a ball on disk arrangement. Results demonstrate the effects of viscosity models from the perspective of bearing torque.

Session 5E • Music Row 3

Tribotesting III

Session Chair:
Jun Xiao, RTEC Instruments, Inc., San Jose, CA

Session Vice Chair:
Oluwaseyi Ogunsola, Shell Oil Co., Houston, TX

8 – 8:30 am | Why All Test Rigs Do Not Give the Same Friction and Wear Response

Carlos Sanchez, Peter Lee, Michael Moneer, Southwest Research Institute, San Antonio, TX

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

8:30 – 9 am | A Holistic Approach to Characterize the Tribological Performance of Lubricants Applied to New EALs in Plain Bearings

Henry Brunskill, Peak to Peak Measurement Solutions/University of Sheffield, Sheffield, United Kingdom, Scott Beamish, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

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

9 – 9:30 am | A Study on Viscosity and Lubricity Effects of N-Butanol and its Mixtures in Oil

Gustavo Molina, John Morrison, Cesar Carapia, Valentin Soloiu, Georgia Southern University, Statesboro, GA

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

9:30 – 10 am | Erosion-Corrosion of Heat-Exchanger Materials by Water/Ethylene-Glycol/Alumina Nanofluids

Gustavo Molina, Fnu Aktaruzzaman, Valentin Soloiu, Mosfequr Rahman, Georgia Southern University, Statesboro, GA

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

10 – 10:30 am | Break

10:30 – 11 am | Pump Failures: A Laboratory Method to Distinguish Between Lack of Lubricity and Presence of Abrasive Nanoparticles

Philip De Vaal, University of Pretoria, Pretoria, South Africa

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

5E

11 – 11:30 am | The Tribolgolical Performance of Fuel-Efficient Gear Oils in a Limited Slip Differential

Gregory Hansen, Southwest Research Institute, San Antonio, TX

In developing a new axle efficiency test for the US Army, it was made known that a combat vehicle (the General Dynamics Land Systems Stryker) utilizes limited slip differentials. Additional compatibility work was needed to ensure that fuel efficient gear oil formulations would not compromise performance of this vehicle. Limited slip clutch performance testing was carried out on both an SAE No. 2 test machine, and a Bruker TriboLab. Comparisons were made between the different test parts, rigs, and oil formulations in order to assess frictional performance and chatter. DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.

11:30 am – Noon | Infrared Microscope Analysis – A Tool for Understanding Failure Analysis and Improving Equipment Reliability

Keith Schomburg, PerkinElmer, Magnolia, TX

Fourier Transform Infrared (FTIR) Spectroscopy is used routinely in the analysis of new and in-service lubricants to determine such chemical attributes as oxidation, nitration, sulfation, water and soot. A valuable accessory to the FTIR instrument that can be used for analysis of micro environments is the FTIR microscope. The main advantage of the FTIR microscope is the ability to focus the IR beam with optical apertures on sample sizes ranging from 5 to 500 µm in size. Once the sample position is identified, the FTIR microscope may be operated in transmission, reflectance or ATR modes allowing for the analysis of liquids, solids and viscous samples. For this presentation the basic principles and techniques of FTIR micro analysis will be discussed and selected example spectra from the in-situ analysis of various lubricant thin films will be shown with emphasis on using these techniques for failure analysis in the lubricants industry.

Session 5F • Music Row 2

Synthetic & Hydraulic Lubricants I

Session Chair:
Rob Davidson, Afton Chemical Corp., Richmond, VA

Session Vice Chair:
Patrice Cusatis, BASF Corp., Tarrytown, NY

8 – 8:30 am | Sensitivity Analysis of the FMVP Test Method to Evaluate Hydraulic Fluids for Vane Pumps

Emmanuel Georgiou, Dirk Drees, Michel De Bilde, Falex Tribology NV, Rotselaar, Belgium, Michael Anderson, Falex Corp., Sugar Grove, IL

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

8:30 – 9 am | Polymer-Enhanced Fluid Effects on Mechanical Efficiency of Hydraulic Pumps

Paul Michael, Milwaukee School of Engineering, Milwaukee, WI, Ashlie Martini, Michelle Len, University of California, Merced, Merced, CA

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

9 – 9:30 am | Improving Hydraulic Efficiency by Controlling Fluid Flow Characteristics

Timothy Smith, The Lubrizol Corp., Hazelwood, Derbyshire, United Kingdom

Improvements in hydraulic efficiency can be achieved by using a hydraulic fluid that has been specifically designed for this purpose. However the design and formulation of such a fluid is not trivial. Careful analysis of the rheological behaviour of a fluid is crucial for understanding how it might improve energy efficiency. Optimization of the bulk viscosity is well understood to be a key parameter. Surprisingly, the retention of this optimal bulk viscosity by formulating high viscosity index fluids does not appear to contribute to energy efficiency in our studies. Herein we demonstrate that the complex fluid flow characteristics must be considered in order to formulate an effective energy efficient hydraulic fluid. A geometry change in the flow channel, such as an elbow or valve, induces secondary flows that result in a loss of fluid momentum. With appropriate formulating components, these secondary flows can be reduced to provide a striking improvement in hydraulic efficiency.

9:30 – 10 am | Tribological Performance of Composite Basefluid for Hydraulic Systems

M. Cinta Lorenzo Martin, Oyelayo Ajayi, Julie Nguyen, George Fenske, Argonne National Laboratory, Lemont, IL

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

10 – 10:30 am | Break

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5F

10:30 – 11 am | Harvesting Benefits from the Next Generation of Agriculture Lubricant Specifications

Ricardo Gomes, Brian Hess, Joan Souchik, Evonik Oil Additives, Horsham, PA

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

11 – 11:30 am | Fluid Effects on Low Temperature Power Consumption and Cavitation Noise in Hydraulic Systems

Zheng Dai, Petro-Canada Lubricants, Mississauga, Ontario, Canada, Kimberly Rodriguez, University of California, Merced, CA, Paul Michael, Milwaukee School of Engineering, Milwaukee, WI

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

11:30 am – Noon | Study on Water Separation of Evaluation for Hydraulic Oil

Zhongguo Liu, Dalian Lubrication R&D Institute, Dalian, Liaoning, China

Hydraulic oils are one of most important groups of industrial lubricants. With the rapid development of hydraulic systems, the excellent demulsibility of hydraulic oil is another key requirement in the process of practical work. Herein, a method of demulsibility based on ASTM 1401 was established to improve the practical demulsibility of fresh hydraulic oil. 12 kinds of demulsifiers were evaluated for the formulation of hydraulic oil using a more effective improved test method and confirmed the appropriate dosage. Improvement of hydraulic oil exhibited the excellent demulsibility after a field trial and correlated well with the result of improved test method. The results of this study will be providing a referential method for the design of lubricants.

Session 5G • Cumberland 1/2

Engine & Drivetrain III

Drivetrain, Transmission, Gears, Clutch

Session Chair: R. Chandramohanan, Borg Warner, Arden, NC

8 – 8:30 am | Effects of SAE 0W-20 Engine Oil Formulations in Taxi Cab Severe Field Service

JoRuetta Ellington, Andre Dawson, Brian Hess, Evonik Oil Additives, Horsham, PA, Boris Eisenberg, Evonik Resource Efficiency GmbH, Darmstadt, Germany

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

8:30 – 9 am | Automatic Transmission Fluid VII Effects in Taxi Cab Field Service

JoRuetta Ellington, Andre Dawson, Brian Hess, Evonik Oil Additives, Horsham, PA, Jennifer Holtzinger, Evonik Resource Efficiency GmbH, Darmstadt, Germany

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

9 – 9:30 am | WITHDRAWN Motor Oil, Fuel Economy and Real Driving Emissions in the Era of E-Mobility

Boris Zhmud, Applied Nano Surfaces, BIZOL Lubricants, Uppsala, Sweden

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

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5G

9:30 – 10 am | PPD Selection for Next Generation Engine Oil Formulations

Justin Mills, Joan Souchik, John Maxwell, Evonik Oil Additives, Horsham, PA

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

10 – 10:30 am | Break

10:30 – 11 am | Non-Invasive Monitoring of Free Surface Thin Film Layer Spread Using an Ultrasonic Continuously Repeated Chirp Longitudinal Wave

Joseph Kanja, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom

Thin film layers are seen in many applications such as the oil distribution around a gearbox casing and the oil that forms ahead of an approaching piston ring.Measuring thickness of these films provides essential information useful for performance control and monitoring. Performing these measurements can prove to be difficult. However,ultrasound enables measurement indirectly.Piezoelectric transducers on a component back face emit ultrasound waves and receive the waves that bounce off the front face.The magnitude of the reflected wave is dependent on the film thickness at the front face.Pulse-echo ultrasound technique is usually used to perform these measurements.However,as the film becomes thinner,the reflected echoes overlap.In this work,we propose the use of an ultrasonic continuously repeated chirp longitudinal wave to magnify the effect of the film.Multiple reflections occur within the component to form a standing wave whose amplitude spectrum is dependent on the film thickness.

11 – 11:30 am | Hydroynamic Friction Reduction Due to Laser Texturing of IC Engine Journal Bearing Shells

Tom Reddyhoff, Sorin Vladescu, Daniele Dini, Imperial College, South Kensington, United Kingdom, Mark Fowell, Volvo Trucks, Göteborg, Sweden

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

11:30 am – Noon | Fuel Economy Modeling: Engine-to-Engine Operating Regime Differences

Brendan Miller, Shelby Skelton, Chevron Oronite Co. LLC, Richmond, CA

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

Session 5H • Cumberland 3

Nanotribology V

Session Chair:
Prathima Nalam, University of Illinois at Urbana-Champaign, Champaign, IL

Session Vice Chair:
Nikolay Garabedian, University of Delaware, Newark, DE

8 – 8:30 am | Exploring the Limits of Contact Mechanics Models for Nanoscale Metal Contacts Using In-Situ and in Silico Techniques

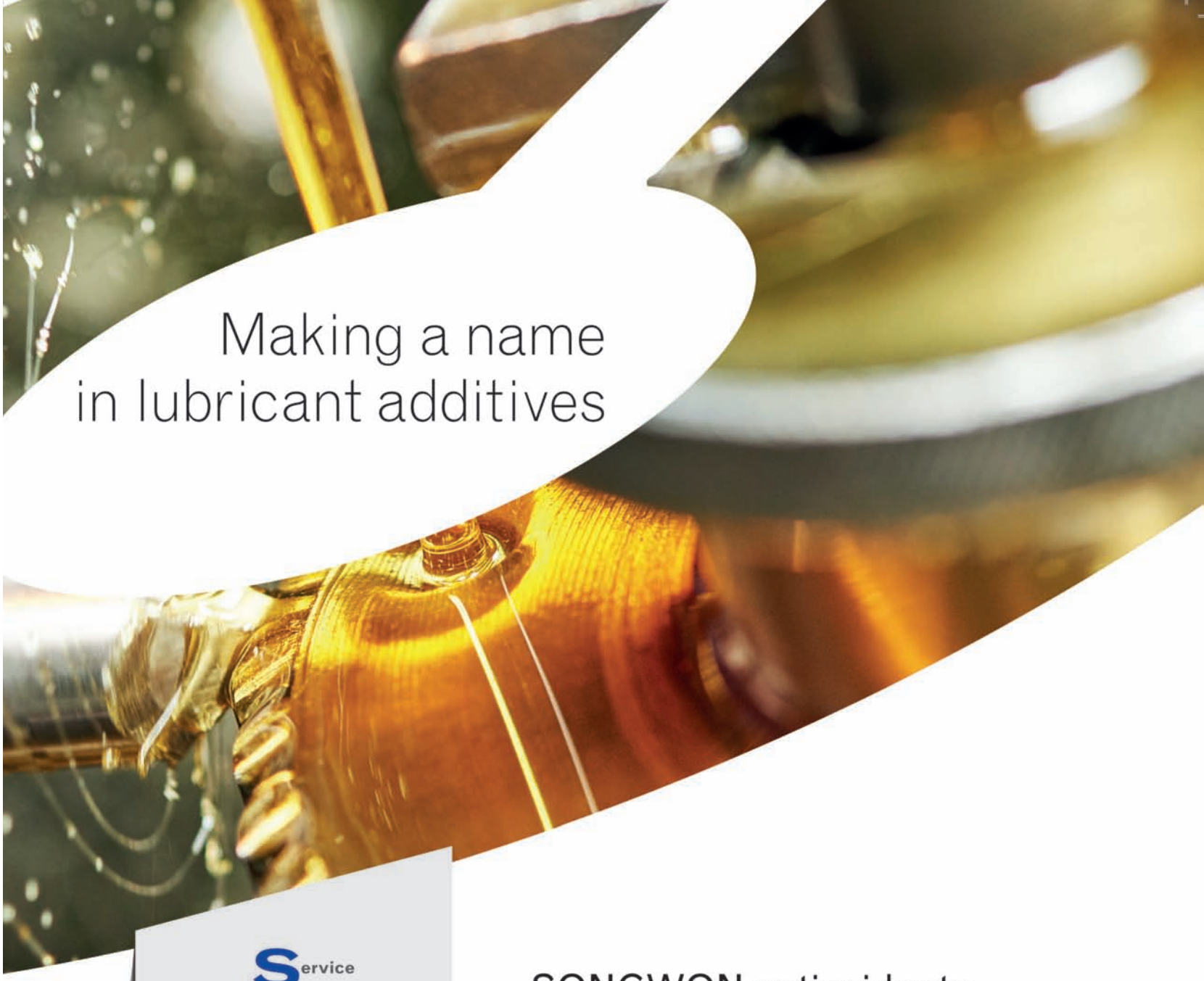
Sai Bharadwaj Vishnubhotla, Subarna Khanal, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, Ashlie Martini, University of California, Merced, Merced, CA

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

8:30 – 9 am | Atomic-Scale Insights into Contacts Between Nanoscale Bodies: In-Situ Experiments and Matched Atomistic Simulations

Tevis Jacobs, Sai Bharadwaj Vishnubhotla, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Rimei Chen, Xiaoli Hu, Ashlie Martini, University of California, Merced, Merced, CA

In probe-based microscopy, nanomanufacturing, and small-scale devices, performance often depends on contacts between nanoscale bodies. Adhesion, deformation, and thermal or electrical transport across the contact can be load-dependent and difficult to predict. Traditional continuum-based contact models rely on assumptions that may not hold at the nanoscale. Here we used experiments and simulations to quantitatively investigate nanoscale asperities during formation, loading, and separation of contact. Experimentally, controlled-load tests were performed inside of a transmission electron microscope, enabling high-resolution measurement of contact properties with simultaneous characterization of materials structure and geometry. Molecular dynamics simulations were performed on matched nanocontacts with



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the same materials, geometry, and loading conditions. The results demonstrate deviations from traditional models because of atomic-scale interactions.

9 – 9:30 am | The Chemistry of Friction, Wear and Tribo Film Growth on 2D Materials

Shivaranjan Raghuraman, Jonathan Felts, Texas A&M University, College Station, TX

The phenomenon of friction has been studied for a few centuries, yet, its physical and chemical origin is as elusive as ever. Friction force can depend on the chemical composition of surfaces in contact, temperature, direction of sliding and the contact stress between the surfaces. We explore the chemical origins of sliding friction between a silicon AFM tip pushing and sliding on graphene oxide surface. Our results reveal that mechanochemical wear distinctly depends on both the normal and lateral force applied by the AFM tip. Our theory of velocity dependent wear based on transition state theory quantitatively relates the friction evolution to the bonded states of oxygen groups between the silicon tip and graphene. This knowledge can be extended to quantitatively predict the friction force between two surfaces of known composition and thereby efficiently design surfaces to mitigate wear.

9:30 – 10 am | Tribological Behavior Comparison of MoS_2 and Graphene Influenced by Humidity and Counter Surface Oxides

Taib Arif, Tobin Filleter, University of Toronto, Mississauga, Ontario, Canada, Guillaume Colas, FEMTO-ST Institute, Besançon, Bourgogne Franche-Comté, France

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

10 – 10:30 am | Break

10:30 – 11:30 am | Invited Talk: Pushing Tiny Sliders, or What We Can Learn from the Controlled Translation of Really Small Objects on Well-Defined Surfaces?

Udo Schwarz, Yale University, New Haven, CT

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

11:30 am – Noon | Atomic-Scale Friction Behavior of Few-Layer Graphene under Ultra-High Vacuum Conditions

Philip Egberts, Peng Gong, University of Calgary, Calgary, Alberta, Canada

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

Session 5I • Cumberland 4

Surface Engineering I

Session Chair:
Giovanni Ramirez, Bruker Nano Surfaces, San Jose, CA

Session Vice Chair:
Suvrat Bhargava, TE Connectivity, Middletown, PA

8 – 8:30 am | Tribology of Micro-Textured ATSP Polymers in Synthetic Seawater

Reza Gheisari, Texas A&M University, College Station, TX

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

8:30 – 9 am | Analytical and Experimental Investigation of Effect of Surface Roughness on Axial Fatigue

Kushagra Singh, Farshid Sadeghi, Purdue University, West Lafayette, IN

A finite element approach to model effect of surface roughness on fatigue of tensile specimen is presented, along with experimental validation on 4130 steel specimen. To model progressive material degradation during fatigue process, continuum damage mechanics with jump-in cycles approach was used. Voronoi tessellation was used to represent material microstructure as well as surface roughness. The parameters of tessellation were obtained from actual grain size distribution and grain directionality as observed in the specimen during SEM imaging. Surface roughness was modeled based on Ra obtained from experimental measurements of surface profile. Three levels of roughness were chosen

for this study, including one smooth surface finish as per ASTM standard. Fatigue lives distribution resulting from simulation was in good agreement with experimental results.

9 – 9:30 am | Characterization and Tribological Application of High Porosity Coatings

Hamed Ghaednia, Arup Gangopadhyay, Brian Almeria, Ford Motor Co., Dearborn, MI

Engineering surfaces are often decorated with scratches, grooves and textures which act as oil retention features. However, the common practice to reduce friction, is to reduce the surface roughness. These two concepts need to be balanced to achieve the optimized state of a surface. Recently, the application of high porosity coatings has offered a novel method to optimize oil retention while keeping the top surface smooth. These surfaces are constructed of a super smooth top plateau and isolated micron-scale pockets also known as surface porosity. The current work describes the background and tribological benefits of high porosity coatings deposited on an engine bore. The friction has been assessed using a ring on liner rig and tested against various other coatings such as PVD and DLC. Characterization techniques have been developed to define the surfaces. This includes 2D profile analysis, 3D surface analysis and cluster analysis to characterize pore depth, size and distribution.

9:30 – 10 am | Improved Wear and Fatigue Resistance of a Boron-Doped DLC Coating Deposited on UNSM Pre-Treated 52100 Steel Substrate

Zhencheng Ren, Haifeng Qin, Gary Doll, Yalin Dong, Chang Ye, The University of Akron, Akron, OH

In this work, a boron-doped diamond-like carbon (BC/a-C:H) coating was developed and deposited on 52100 steel by magnetron sputtering process, which combines the high hardness of B4C and low friction of DLC. The coating structure and composition were characterized by Raman Spectrum and X-ray photoelectron spectroscopy (XPS) respectively. All specimens were tested in sliding, rolling and mixed mode contact conditions, and the result proved that the highest wear and fatigue resistance of coating was obtained when B/C ratio is around 1%. Ultrasonic Nanocrystalline Surface Modification (UNSM) was applied prior to the coating on 52100 steel substrate to induce a grain refinement layer. Benefited from the increased hardness and compressive residual stress resulted from the grain refinement layer, UNSM increased the adhesion between coating and substrate and improved both wear and fatigue performance of coating regardless of the coating composition.

10 – 10:30 am | Break

10:30 – 11 am | Elastic and Elastic-Plastic Analysis of an Axisymmetric Sinusoidal Surface Asperity Contact

Swarna Saha, Robert Jackson, Auburn University, Auburn, AL

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

11 – 11:30 am | Low Cost Fabrication Method for Surface Textures on Engine Components

Stephen Hsu, Govindaiah Patakamuri, The George Washington University, Washington, DC

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

11:30 am – Noon | Multi-Resolution Characterization of Surface Topography for Improved Properties Prediction

Tevis Jacobs, Abhijeet Gujrati, Subarna Khanal, University of Pittsburgh, Pittsburgh, PA, Lars Pastewka, University of Freiburg, Freiburg, Germany

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

Registration Available for STLE Certification Exams

All four of STLE's certification exams: Certified Lubrication Specialist™, Oil Monitoring Analyst I and II™ and Certified Metalworking Fluids Specialist™ will be conducted currently on Thursday, May 23 from 9 am to Noon in the Omni Nashville Hotel, Mockingbird 2. Individuals must be registered for exams in advance, however, onsite registration is available on a limited basis.

For more information, stop by the STLE Registration Desk in the Omni Nashville Hotel – Second Level Foyer. Registration and sign-in starts at 8:30 am, and the exams start promptly at 9 am.

- **Exam Fees: First exam: $440 (STLE member), $590 (Non-member)**
- **Retake exam $220 (STLE member), $295 (Non-member)**

Session 5J • Cumberland 5

Lubrication Fundamentals V

Session Chair:
Kuldeep Mistry, The Timken Co., North Canton, OH

8 – 8:30 am | Molecular Science and Engineering Application of High Performance Lubricants

Weimin Liu, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, Gansu, China

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

8:30 – 9 am | The Autoxidation of Polyisobutylene Succinimide Dispersant Mimics: Products, Mechanisms and Performance Implications

Jonny Ruffell, Moray Stark, Thomas Farmer, Duncan Macquarrie, University of York, York, United Kingdom

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

9 – 9:30 am | Relationship Between Structures and Anti-Oxidation Performance of Hindered Phenolic Antioxidants

Tom Tang, Smith Scott, Glenn Kenreck, Amaron Barr-Cook, Gertrude Jacobs, SI Group, Orangeburg, SC

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

9:30 – 10 am | The Use of Microcapsulated Additives Fuel Economy Enhancement

Stephen Hsu, Govindaiah Patakamuri, The George Washington University, Washington, DC, Timothy Cushing, GMC, Warren, MI

Microcapsules provide timed-release of additives to replenish depleted or degraded additive during service. As such, it has tremendous potential for long lasting lubrication effectiveness. In view of the movement towards autonomous systems throughout our society in the future, this technology will enable long drain intervals, smart lubricants, self-healing and deliver the right additive to the right location on demand. We have demonstrated that such capsules can be made, scaled up, and their effectiveness demonstrated in the bench tests. How they will fare in actual engine environment? This presentation will report such an attempt.

10 – 10:30 am | Break

10:30 – 11 am | Is Oxidation Terminated? Latest Technologies for Low Varnishing and Long-Life Turbine Oils Highlight the Need for Revised Oxidative Stability Testing

Alex Mannion, Eugene Scanlon, Ryan Fenton, Jeff Schoonmaker, Michael Hoey, Thomas Rühle, BASF Corp., Florham Park, NJ

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

11 – 11:30 am | Fuel Economy Low Viscosity Engine Oil Compatible with Low Speed Pre-Ignition

Jiayang Zhao, Sinopec Lubricant Co., Ltd., Beijing, China

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

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5J

11:30 am – Noon | Evolution of ZDDP Crystallinity and Its Effect on Film Durability

Mao Ueda, Amir Kadiric, Hugh Spikes, Imperial College London, London, United Kingdom

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

Session 5K • Cumberland 6

Tribology of Biomaterials

Biotribology & Materials Joint Session

Session Chair:
Dipankar Choudhury, University of Arkansas, Fayetteville, AR

Session Vice Chair:
Shabnam Bonyadi, University of Illinois at Urbana-Champaign, Urbana, IL

8 – 9 am | Invited Talk: Tribocorrosion in the Human Body: Retrieval Analysis to Fundamental Modeling

Jeremy Gilbert, Clemson University, Charleston, SC

Mechanically assisted crevice corrosion (MACC) of medical alloys is a major concern in total joint arthroplasties, in particular, total hip replacements. In these devices, metal alloys including Ti-, CoCrMo, and stainless steel alloys are in contact with other metals or hard surfaces and engage in a complex conjoint failure mode that consists of tribological, electrochemical and biological processes. This presentation will summarize the nature and extent of damage seen in retrieved total hip replacements to demonstrate the severe and wide ranging nature of alloy damage that can occur. It will also provide insights into bench-top testing methods to study the implant and basic surface tribocorrosion processes including fretting corrosion and fretting initiated crevice corrosion. In addition, some basic modeling approaches recently developed will be presented to show how one might be able to directly predict current and potential response over time for arbitrary tribocorrosion processes.

9 – 9:30 am | Bio-Tribocorrosion of CoCrMo During Reciprocating Sliding Against Bovine Articular Cartilage

Manel Rodriguez Ripoll, Bojana Stojanovic, Friedrich Franek, AC2T Research GmbH, Wiener Neustadt, Austria, Christoph Stotter, Christoph Bauer, Thomas Klestil, Stefan Nehrer, Danube University Krems, Krems, Austria

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

9:30 – 10 am | Biomechanics of Hierarchically-Structured Enamel in Grinding Dentitions

Tomas Grejtak, Tomas Babuska, Xiu Jia, Brandon Krick, Lehigh University, Bethlehem, PA, Siddhartha Pathak, University of Nevada-Reno, Reno, NV, Stephen Hendricks, Gregory Erickson, Florida State University, Tallahassee, FL

Dental tissues of grazing animals are designed to be subjected to high surface stresses over millions of loading cycles. The enamel tissue is a ceramic-like bio-composite showing remarkable wear resistance, strength, toughness, and controlled crack propagation. The secret to the exceptional biomechanics of this tissue lies in the hierarchically-structured enamel prism. In this work, for the first time, the mechanical and wear properties of the enamel tissues of various animals, across nano- to whole-tooth scale are evaluated. Hardness, fracture and wear-relevant material attributes relationship to the underlying structure are evaluated by using a combination of structural, morphological and chemical microscopy tools with multi-scale mechanical testing. The tribological properties are used to develop 3D wear models to determine how the tissue arrangement and topology of the composite grinding surfaces self-wear to optimal topography for long-term functionality.

10 – 10:30 am | Break

10:30 – 11 am | Fabrication of Cartilage-Inspired Surface Textures Using Photolithography for Orthopedic Implants

Dipankar Choudhury, Gabriel Dharwadker, Evelyn Smith, Josh Goss, Min Zou, University of Arkansas, Fayetteville, AR

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

11 – 11:30 am | Friction Across Soft Matter Interfaces

Angela Pitenis, University of California, Santa Barbara, Santa Barbara, CA

Tear film stability and ocular epithelial health are closely coupled and both are essential for comfort. During contact lens wear frictional forces at the ocular interfaces are difficult to measure in vivo. This work aimed to measure the effects of shear stresses on human corneal epithelial (hTCEpi) cells in vitro by sliding a soft probe against cell layers. Tribological experiments were performed in cell culture conditions: 37±0.2°C, 5% CO_2, and >80% RH. Over 10,000 cycles, the normal force was Fn = 218.6±20.3 μN, the friction force was Ff = 12.8±3.2 μN, friction coefficient was μ = 0.058 ±0.008, and shear stresses were ~ 60 Pa.

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Molecular biology assays revealed increased expression of pro-apoptotic (DDIT3, FAS) and pro-inflammatory genes (IL-1b, IL-6, MMP9) in cells subjected to high shear stresses (~65 Pa), yet low shear stresses (~30 Pa) did not elicit significant changes in gene expression compared to controls. This work may assist in the informed design of medical implants.

11:30 am – Noon | Understanding the Interaction Between Contact Lens and Eye Using In-Vivo and In-Silico Techniques

Rachel Morecroft, Yunok Craze-Romero, Raman Maiti, University of Sheffield, Sheffield, United Kingdom, William Kay, Stephen Connell, Pete Toomey, Royal Hallamshire Hospital, Sheffield, United Kingdom

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

Session 6A • Legends F

Rolling Element Bearings II

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

Session Vice Chair:
Nikhil Londhe, The Timken Co., Canton, OH

1:30 – 2 pm | Microstructural Improvements of Advanced Ball Bearing Materials through Alloying Elements, Powder Metallurgy and Deformation Processes

Christopher DellaCorte, NASA, Cleveland, OH

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

2 – 2:30 pm | The Lubricant Formulation: Driver for Premature Bearing Failures and White Etching Cracks?

Kenred Stadler, SKF GmbH, Schweinfurt, Germany, Arnaud Ruellan, SKF B.V., Nieuwegein, Netherlands

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

2:30 – 3 pm | Surface Driven Formation of White Etching Cracks in Bearings Used in Wind Turbines

Mohanchand Paladugu, The Timken Co., North Canton, OH

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

3 – 3:30 pm | Break

3:30 – 4 pm | The Evolution of Dark Etching Regions and White Etching Bands in Bearing Steel Due to Rolling Contact Fatigue

Mostafa El Laithy, Ling Wang, Terry Harvey, University of Southampton, Southampton, Hampshire, United Kingdom, Bernd Vierneusel, Martin Correns, Toni Blass, Schaeffler Technologies GmbH & Co. KG, Schweinfurt, Germany

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

4 – 4:30 pm | The Major Acceleration Factor of White Etching Crack (WEC)

Yujiro Toda, NSK Ltd., Fujisawa, Kanagawa, Japan

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

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acceleration factor of WEC formation. It is spontaneously generated by friction between the drive belt and pulley, and is accumulated by insulation of oil film. Besides, the effect of grease component has been investigated.

4:30 – 5 pm | Formation of White Etching Areas/Cracks on a Four Disk Rig – Influence of Electrical Current and Slip

Florian Steinweg, Institute for Materials Applications in Mechanical Engineering, RWTH Aachen University, Aachen, Germany, Adrian Mikitisin, Central Facility for Electron Microscopy, RWTH Aachen University, Aachen, Germany

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

5 – 5:30 pm | The Influence of Material Properties and Steel Cleanliness on the Formation of Subsurface Cracking Failures Associated with Microstructural Alterations

Benjamin Gould, Aaron Greco, Nicholaos Demas, Argonne National Laboratory, Argonne, IL

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

5:30 – 6 pm | Structure Change of Cementite Just Below the Sliding Surface on Ball Bearings

Kenji Matsumoto, Honda R&D Co., Ltd., Haga-gun, Tochigi, Japan, Naoaki Yoshida, Kyushu University, Kasuga, Fukuoka, Japan

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

6 – 6:30 pm | Analysis of Material Defects in Relation to Different Damage Mechanisms

Joerg Binderszewsky, Toni Blass, Wolfram Kruhoeffer, Joerg Loos, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

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

6:30 – 7 pm | Rolling Element Bearings Business Meeting

Session 6B • Music Row 1

Biotribology I

Session Chair:
Samuel Hart, University of Florida, Gainesville, FL

Session Vice Chair:
Eric McGhee, University of Florida, Gainesville, FL

1:30 – 2 pm | Invited Talk: Cartilage Lubrication: Why Everything I Thought I Knew is Wrong …

Itai Cohen, Cornell University, Ithaca, NY

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

2 – 2:30 pm | Cartilage Fluid Load Support in the Migrating Contact Area: How Much Migration is Necessary?

Jamie Benson, David Burris, University of Delaware, Newark, DE

The accepted hypothesis for cartilage interstitial fluid load support under joint loading is that contact migration leaves insufficient time for fluid exudation. However, it's also evident that the benefits of migration dissipate as range of motion approaches contact length. This study quantifies the coupled effects of migration length, probe radius, normal force, and contact stress on cartilage fluid load support. Testing was performed on cartilage plugs using varied probe sizes, loads and track lengths. Fluid load support depended primarily on migration length per unit contact length (S*) and maintained a maximal magnitude (F*=100%)

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at S*>10. At S*<10, it varied as a sigmoidal function falling to F*=50% by S*»0.1. This transition migration length (F*=50%), was independent of probe and increased slightly with load. Given the relatively short tracks (S*~1) and high stresses in the joint (sigma~0.5-5MPa), this suggests that migration contributes less to fluid load support than expected.

2:30 – 3 pm | Rate-Dependent Cartilage Adhesion Derived from Poroviscoelastic Relaxations

Guebum Han, Corinne Henak, Melih Eriten, University of Wisconsin-Madison, Madison, WI

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

3 – 3:30 pm | Break

3:30 – 4 pm | Quantifying Adhesion in Articular Cartilage

Jamie Benson, David Burris, University of Delaware, Newark, DE

The primary function of cartilage is to support varying loads while sustaining joint lubrication. Its unique ability to balance low friction under heavy loads has been studied extensively over the past decade. Yet, there remains a lack of research into the adhesive properties of cartilage. This study directly quantifies the relationship between works of adhesion and indentation depth, and probe size. Micro-indentation testing was performed on N=5, 19 mm diameter osteochondral plugs under varied indentation depths (5, 50, 500 mm) and probe sizes (diameter: 6.4, 3.9, 2.4 mm) and we found that works of adhesion increased with increasing indentation depths and increasing probe sizes. We measured an effective work of adhesion to be 4600 mJ/m2—two orders of magnitude larger than rubber against glass (70 mJ/m2). These findings fill a significant gap in our understanding of cartilage and the functional implications adhesion has in contact mechanics.

4 – 4:30 pm | Elegant Shadow Making Tiny Force Visible and Measurable

Hongyu Lu, Wei Yin, Yonggang Meng, Yu Tian, Tsinghua University, Beijing, China, Yelong Zheng, Tianjin University, Tianjin, China

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

4:30 – 5 pm | Biotribology Business Meeting

Session 6C • Music Row 5

Commercial Marketing Forum VI

1:30 – 2 pm | SEQENS (ex-PCAS)

David Authier, SEQENS, Greenville, SC

SEQENS is an integrated global leader in specialty ingredients and pharmaceutical synthesis. Our Lubricants Business Line offers an extensive range of solutions for metalworking, metal protection, industrial lubricants and greases. These include extreme pressure, antiwear, anticorrosion, antirust, emulsifying additives and packages, as well as calcium sulfonate greases. We also provide a wide range of custom manufacturing solutions. The flexibility of SEQENS plants enables to offer comprehensive solutions, thanks to small or high production batch size, adjustable process parameters, customized packaging and labelling, as well as worldwide logistics. Our 3,200 employees are located at 24 manufacturing sites, five sales offices and three R&D centers, generating a turnover close to 1 billion euros.

2 – 2:30 pm | Biosynthetic Technologies – Delivering Innovations for a Sustainable Future

Mark Miller, Travis Thompson, Biosynthetic Technologies, Rancho Santa Margarita, CA

Biosynthetic Technologies (BT) specializes in developing and commercializing high-performance, sustainable chemical ingredients that can be used in a variety of applications. BT products are bio-based, biodegradable, and non-toxic. Lubricants are BT's first target market with current R&D efforts focused on developing a wide range of biosynthetic base oil viscosities using the estolide technology. Estolides offer lubricant formulators a powerful combination of both performance and environmental benefits providing them with the tool kit necessary to design cutting-edge environmentally friendly products. BT's first commercial biosynthetic base oil is BT75, an ISO VG 680 product, with samples available today and large-scale manufacturing coming online Q3 2019.

2:30 – 3 pm | Bruker UMT Tribolab Friction and Wear Test Platform – Speed Up Development and Reduce Costs with the Original Benchtop Multi-Test Platform

Steve Papanicolaou, Bruker Nano Surfaces, San Jose, CA

Small to medium lubricant companies do not have the capital, lab space, or humans to run multiple single use lubricant testers like their larger competitors. Yet these smaller companies are the ones developing exciting new and specialized formulations with the need for qualification testing. Currently these testing needs are met by third party resources that can be costly with long lead times. The Bruker Nano Surfaces UMT Tribolab is the perfect platform to eliminate this problem. From R&D formulation development, to QA/QC, and even application specific component level testing, the UMT Tribolab can meet these testing needs. With an expandable platform, its capabilities grow along with your company. We will be highlighting exciting new test modules as well as announcing a very big partnership and demonstrate why the UMT Tribolab belongs at home in your lab!

3 – 3:30 pm | Break

3:30 – 4 pm | AMRRI: IIoT Meets Tribology: LubeCoach Pro 5.0

Mike Johnson, Advanced Machine Reliability Resources, Inc., Franklin, TN

Building accurate, thorough & effective machine lubrication work plans has previously required the time & attention of skilled lubrication engineers. With the erosion of this skill set the lubricant supply community finds itself needing to satisfy customer needs with low-experience personnel (which creates liability posibilities), or asking

customers to wait, neither of which is appealing. LubeCoach Pro is a solution to this problem. LubeCoach Pro provides the entry level and the experienced technical specialist with the means to accurately, thoroughly, rapidly, and succinctly create detailed machine lubricaiton work plans that will deliver superior results. The plan is customized to the production environment and the supplier product array to deliver a comprehensive and functional solution. Suppliers will be able to deliver engineering work in half the previously required time, and with uniform consistency between service personnel, and customized to vendor product preferences.

4 – 4:30 pm | Clariant: Emulsogen® MTP: Next Generation of Low Foam Multifunctional Emulsifiers

Meredith Perkins, Clariant, Mt. Holly, NC

As the need for continuous productivity is required, machines are getting faster and operational severity is increasing. In this challenging market it is essential for a formulator to select the right additive for their application. Our objective is to deliver the best application solution for a long-lasting and sustainable business. Clariant has turned toward their strength in surfactant technology for the answer. The Emulsogen® MTP emulsifier series is designed to be low-foam and multifunctional. This presentation highlights the detailed study we have conducted, evaluating characteristics such as foaming behavior, emulsification strength, and hard water stability. In addition, the Emulsogen® MTP product line is a label-free, globally registered technology with low temperature storage stability, making this series the ideal solution for metal working formulators.

4:30 – 5 pm | Sasol ISOFOL & ISOCARB for Lubricants & Metalworking Differentiated Applications

Govindlal Khemchandani, SASOL, Westlake, LA

The Sasol portfolio of high purity Guerbet alcohols (ISOFOL) provides excellent oxidative stability in lubricant formulations. The various grades ranging from C12 to C 24-26, allows formulators to select the most appropriate ISOFOL to optimize and tune features of finished lubricants. ISOFOL 12, 16 and 20 are widely used as coupling agents in synthetic and semi-synthetic metalworking fluids. The heavier alcohols, ISOFOL 20 and 24-26S as well as ISOFOL esters, provide higher lubricity, low pour point, hydrolytic stability, low Noack and outstanding oxidative stability. ISOFOL esters can be potential candidates for GF-6 engine oil applications to improve the Noack value, lubricity, CCS and engine cleanliness. The presentation will introduce the ISOFOL product portfolio and provide innovative prototype differentiated applications for product development in the areas of lubricants and metalworking fluids.

5 – 5:30 pm | OXEA Chemicals: Advantages of Synthetic Ester Base Oils – Reasons for Growth

Jens Kubitschke, OXEA GmbH, Monheim Am Rhein, Germany

Synthetic esters are the base oil of choice when biodegradability or low volatility at low viscosities is required. Driven by the trends of being more energy efficient and sustainable, these properties are becoming increasingly important. As an integrated producer of carboxylic acids, alcohols, polyols, amines and esters, OXEA provides the knowledge and products to deal with these ongoing trends. According to the Vessel General Permit (VGP) and the EU Ecolabel, lubricants used in applications with potential loss to the environment don't necessarily have to be biobased, but being readily biodegradable is mandatory. Depending on their molecular structure, synthetic esters fulfill this requirement. Due to the variety of possible combinations of carboxylic acids and polyols to prepare an ester, properties can be tailor-made according to customer and industry requirements and will accommodate even the most demanding applications.

Session 6D • Music Row 4

Joint STLE/CTI Symposium on Frontiers of Tribology Research II

Lubricant and Chemistry

Session Chair:
Yonggang Meng, Tsinghua University, Beijing, China and Qian (Jane) Wang, Northwestern University, Evanston, IL

1:30 – 2 pm | Tribochemistry – Myths and Facts

Seong Kim, Pennsylvania State University, University Park, PA

Unlike thermal, photochemical, and electrochemical reactions which are initiated by electronic excitation or transition within or among reactant molecules, tribochemical reactions are initiated by mechanical actions imposed onto the molecules by the solid surface. From a chemist's point of view, the most elusive question is how mechanical energy of friction is channeled into chemical reaction coordinates. This question is related to the magnitude of the critical activation volume which can be obtained from Arrhenius-type analysis of the load or shear stress dependence of reaction yields or rates. Recent progresses in experimental approaches and computations methods provide a great deal of insights into the physical meaning of the critical activation volume in tribochemical reactions. This talk will review these recent progresses.

2 – 2:30 pm | Boundary Lubrication of Polar Molecule in Aqueous Solutions Under Electric Field

Yonggang Meng, Jun Zhang, Tsinghua University, Beijing, China

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

2:30 – 3 pm | Tribological and Electric Properties of C/Cu Pairs under Dynamic Contact During Current-Carrying Sliding

Yongzhen Zhang, Feng Ni, Chenfei Song, Yanyan Zhang, Zhenghai Yang, Bao Shangguan, Henan University of Science and Technology, Luoyang, Henan, China

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

3 – 3:30 pm | Break

6D

3:30 – 4 pm | Tribochemical Reaction Pathways Explored with Reactive Atomistic Simulations

Ashlie Martini, University of California, Merced, Merced, CA

Low friction and wear in lubricated mechanical components is in part enabled by protective films that form through chemical reactions between additive molecules in the lubricant and the surfaces, where the reactions are driven by shear forces. However, the mechanisms of film formation are still poorly understood, primarily because the process occurs inside a moving contact. One approach to exploring such processes is reactive molecular dynamics simulations that model reactions between additive molecules and surfaces at the atomic scale. Such simulations have shed light on the fundamental mechanisms of tribochemistry, including the role of shear to not only accelerate chemical reactions but to open new reaction pathways. This presentation will demonstrate the use of reactive simulations to explore shear driven reactions through examples including polymerization in vapor phase lubrication and the onset of film formation on ferrous surfaces.

4 – 4:30 pm | Integrated Biomechanics and Biotribology of Artificial Joints

Zhongmin Jin, Southwest Jiaotong University, Chengdu, China

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

4:30 – 5 pm | Fundamental Insights into Adhesion, Friction, and Wear through Nanoscale Contact Experiments

Robert Carpick, University of Pennsylvania, Philadelphia, PA

New tribological insights from atomic force microscopy are presented. First, nanocontacts with 2-dimensional materials like graphene are discussed, where friction depends on the number of layers. An initial model attributing this to puckering [1] is now enhanced by molecular dynamics simulations showing a strong role of energy barriers due to interfacial pinning [2]. I will then discuss nanoscale asperity-on-asperity sliding experiments conducted using a nanoindentation apparatus inside a transmission electron microscope, allowing for atomic-scale resolution of contact formation, sliding, and adhesive separation of two silicon nanoasperities. Forming and separating the contacts without sliding revealed small adhesion forces; sliding caused adhesion to increase nearly 20 times. We attribute this effect to the removal of passivating surface species like hydrogen, followed by re-adsorption after separation. [1] C. Lee et al. Science, 328, 76 (2010). [2] S. Li et al. Nature 539, 541 (2016).

5 – 5:30 pm | Synergy of Friction and Adhesion Between Gecko Feet and Substrate for Super-Locomotion Ability

Zhendong Dai, Institute of Bio-inspired Structure and Surface Engineering, Nanjing, Jiangsu, China

Geckos have been studied for many years for their excellent moving abilities on various substrates, including any inclines, even ceilings, and various rough surfaces. However, how gecko adapt its contact between feet and various substrate to obtain reliable attachment is still unclear, here we report our studies on the gecko adhesive mechanism, synergy of friction and adhesion, bio-inspired adhesive materials and gecko-inspired robot to move on various substrates. We designed an experiment and measured the contact/ tribo-electrifiction between gecko toe and substrate, the results suggested that tribo-electrification enhanced van der Waals force between gecko toe and substrate is the basic mechanism. Our studies show that geckos prefer to detach from substrate by toe abduction, instand of peeling from substrate. We developed gecko-inspired robot and carried out experiments on micro-gravity simulating status.

Session 6E • Music Row 3

Tribochemistry I

Materials Tribology and Nanotribology Joint Session

Session Chair:
Istiaque Alam, University of Delaware, Newark, DE

Session Vice Chair:
Arnab Bhattacharjee, University of Delaware, Newark, DE

1:30 – 2 pm | The Effect of TiO_2 Nanoparticle Addition to the Tribological Performance of MoDTC-Containing Lubricants

Fabrice Dassenoy, Pushkar Deshpande, Clotilde Minfray, Thierry Le Mogne, Ecole Centrale de Lyon, Ecully, France, Istvan Jenei, University of Stockholm, Stockholm, Sweden, Benoit Thiebaut, TOTAL, Solaize, France

Nanoparticles as lubricant additives have been widely investigated in recent years. Lamellar structured nanoparticles like MoS_2 or WS_2 show the most remarkable friction modifier properties. Ceramic oxides nanoparticles like TiO_2, ZrO_2, $Al2O_3$, have also been studied for their tribological properties and were found to be good in friction or wear reduction. However, interactions between the nanoparticles and other lubricant additives can lead to either exacerbated properties or lower lubricant performance. The aim of this work was to study the consequences of the addition of TiO_2 nanoparticles on the tribological properties of a lubricant containing MoDTC. Significant reduction in friction coefficient and wear was observed when TiO_2 nanoparticles were blended with MoDTC compared to MoDTC alone. A thorough characterization of the tribofilms was carried out in order to understand the mechanisms of friction reduction.

2 – 2:30 pm | One-Pot Synthesis of Serpentine@Polymer Nanoparticles with Outstanding Anti-Wear Property

Qiuying Chang, Hao Zhang, Beijing Jiaotong University, Beijing, China, Pavlo Rudenko, Tribotex, Colfax, WA

Core-shell nanoparticles (NP) of Serpentine@polymer were synthesized hydrothermally. The synthetic conditions of duration, temperature and gelatin concentration were examined to screen the optimized NP in term of tribological property. The characterization of the NPs was conducted with Scanning Electronic Microscopy (SEM), High Resolution Transmission Electronic Microscopy (HRTEM), X-Ray Diffractometer (XRD), Fourier Transform Infra Red Spectrometer (FTIR) and X-Ray Photoelectron Spectroscopy (XPS). The anti-wear property of the resultant NPs as Extreme Pressure (EP) lubricant additive was carried out with a four-ball tribometer. The results showed novel EP additive exhibited remarkable anti-wear performance under extreme pressure conditions with formation of distinct boundary tribofilm. This materials offer possibility of formulating industrial lubricants without sulphur and phosphorus where restrictive limits are often imposed.

2:30 – 3 pm | A Stress-Activated Model for Tribofilm Growth Based on a Nanoparticle Sintering Mechanism

Allen Comfort, Steven Thrush, US Army TARDEC, Warren, MI

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

3 – 3:30 pm | Break

3:30 – 4 pm | Tribochemistry of Ultralow Wear PTFE-Based Composites: Assessing the Role of the Sliding Environment

Kasey Campbell, Cooper Atkinson, Tomas Babuska, Brantley Balsamo, Christopher Junk, Brandon Krick, Lehigh University, Bethlehem, PA, Mark Sidebottom, Miami University, Oxford, OH

The friction and wear properties of polytetrafluoroethylene (PTFE) (K~ 5 x 10-4 mm3/Nm) have been studied well over a decade. It has been shown that adding fillers such as - alumina and polyether ether ketone (PEEK) can greatly improve the wear rate of the unfilled PTFE up to four orders of magnitude (K~1-5x10-8mm3/Nm). This observation is attributed to the formation of a robust transfer film created by bonds formed by carboxylate end groups that bond to the counter sample and fillers. This behavior has been observed in ambient (humidity controlled), dry nitrogen and high vacuum conditions and has further supported the need for water to be present. Yet, when these composites are submerged in water, the wear rate is drastically increased, and the composite wears comparably to the unfilled material. To further assess the wear mechanism of the composite, it will be submerged in oil. SEM, XPS, and FTIR was used to understand and probe any chemical alterations during oil submersion.

4 – 4:30 pm | Nanomechanics of Ultralow Wear PTFE-Based Composites: Microstructure and Mechanics of Filler Particles

Cooper Atkinson, Lehigh University, Bethlehem, PA, Mark Sidebottom, Miami University, Oxford, OH, Tomas Babuska, Tomas Grejtak, Brantley Balsamo, Kasey Campbell, Brandon Krick, Christopher Junk, Lehigh University, Bethlehem, PA, Heidi Burch, DuPont Co., Wilmington, DE

Fluoropolymers including polytetrafluoroethylene (PTFE) and perfluoroalkoxy polymer (PFA) are often used due to their thermal and chemical resistance, as well as their low friction coefficient. The high wear rate of fluoropolymers has been reduced by ~10,000 times through the addition of porous, micron-sized alumina particles. The success of alumina as a filler material motivated the experimentation of other micron-sized oxide, ceramic and metal fillers in low concentrations (1-10 wt %). The role of the mechanical properties of the particles was evaluated through nanomechanical testing, wear testing and microstructural characterization. It was determined that, in addition to tribochemistry, the wear performance relies on the mechanical properties and structure of the filler particles. Additionally, the polymers were tested over a broadened pressure and velocity range, contributing to a more complete understanding of the wear reduction mechanisms in ultralow wear fluoropolymer systems.

4:30 – 5 pm | Promotion of Ultralow-Wear Fluoropolymer-Metal-Oxide Composites through Tribochemistry

Mark Sidebottom, Miami University, Oxford, OH, Christopher Junk, Tomas Babuska, Kasey Campbell, Cooper Atkinson, Brandon Krick, Lehigh University, Bethlehem, PA, Holly Salerno, Heidi Burch, Gregory Blackman, DuPont Co., Wilmington, DE

Composites of nanostructured-metal oxide particles (e.g., alumina) and polytetrafluoroethylene (PTFE) have exhibited wear rates 10,000x lower than unfilled PTFE. This reduction in wear is attributed to the tribochemical reinforcement of the composite surface and the development of a thin, robust transfer film on the countersurface. Recently, the tribochemical framework of the ultralow PTFE alumina composites has been extended to Perfluoroalkoxy Polymer (PFA), a melt processible fluoropolymer. The increased ease of manufacturing of PFA-alumina composites may lead to easier incorporation into current bearing and seal applications. Through designed experimentation and materials characterization techniques, a number of factors were identified that can affect wear of these composites by two or more orders of magnitude. These influencing factors include testing environment and hardness of metal-oxide filler particles, which can inhibit the ultralow wear mechanism of these composites.

5 – 5:30 pm | Clarifying Transfer Film Effects by Removing Them

Istiaque Alam, David Burris, University of Delaware, Newark, DE

The fact that tribological performance correlates strongly to transfer film morphology is interpreted either as evidence that high quality transfer films cause low friction and wear or evidence that low friction and low wear sliding causes high quality transfer films. This work aimed to elucidate this causal relationship for a particularly well-studied material family by eliminating its transfer film. Alumina-PTFE composites were subjected to indexed reciprocation to eliminate the transfer film; standard reciprocation was used as a control. Three distinct alumina fillers known to produce low wear, moderate wear, and high wear when added to PTFE were used to gain insight into how each affects debris creation, debris size, counterface abrasion, transfer film morphology, tribochemistry, and other attributes of interest. Given the orders of magnitude differences in the wear rates reported for these materials, we observed surprising similarities.

5:30 – 6 pm | Ultra-Low Wear of PEALD Nitride Thin Films (STLE Early Career Award Winner)

Tomas Babuska, Nicholas Strandwitz, Brandon Krick, Lehigh University, Bethlehem, PA, Mark Sowa, Veeco CNT, Boston, MA, Alexander Kozen, U.S. Naval Research Laboratory, Washington, DC, Guosong Zeng, Lawrence Berkeley National Laboratory, Berkeley, CA

Typical commercial nitride films such as TiN are deposited using PVD techniques such as magnetron sputtering. Recently, plasma enhanced atomic layer deposited TiN, VNand TiVN thin films have shown interesting tribological behavior and superb performance over their traditional PVD counterparts; in one instance, low friction (μ~0.16) and ultralow wear rates (K ~ 2x10-9 mm3/Nm and less) were measured in TixV1-xN thin films that are electrically conductive. These materials exhibit wear rates approaching those of diamond but are deposited in a low deposition temperature, conformal plasma-ALD process, and are thus highly promising for a wide array of industrial applications that require low thermal budget in microelectronics, MEMS/NEMS, biomedical implants, aerospace components and consumer products. The highly controlled thickness and conformality of the ALD process is useful for systems that require tight dimensional tolerances and complex surfaces (MEMS/NEMS, implants).

6E

6 – 6:30 pm | Friction and Oxidation of MoS_2 In Low Earth Orbit: Results from the Space Tribometers

Brandon Krick, Tomas Babuska, Lehigh University, Bethlehem, PA, John Curry, Michael Dugger, Nicolas Argibay, Somuri Prasad, Sandia National Laboratories, Albuquerque, NM, Christopher Muratore, University of Dayton, Dayton, OH, Andrey Voevodin, University of North Texas, Denton, TX, John Jones, Air Force Research Laboratory, Dayton, OH, W. Gregory Sawyer, University of Florida, Gainesville, FL

Nearly 8 years ago, eight tribometers returned from their journey in low earth orbit. Of the eight samples, half were MoS2-based coatings. On orbit friction data suggests significant impacts of atomic oxygen on their tribological performance. Postflight characterization and tribology experiments confirms the detrimental effects of atomic oxygen. Detailed studies of microstructure and surface chemistry of various MoS_2 coatings provides a promising outlook in ways to address oxidation of MoS_2 composites.

Session 6F • Music Row 2

Synthetic & Hydraulic Lubricants II

Session Chair:
Lauren Huffman, The Dow Chemical Co., Midland, MI

Session Vice Chair:
Rob Davidson, Afton Chemical Corp., Richmond, VA

1:30 – 2 pm | Synthesis of Dibenzyl Toluene as Heat Transfer Fluid

Peng Li, Zhongguo Liu, Daxin Sun, Chaoliang Wei, Chao Yang, Xianzhen Gao, Yanbo Zheng, Dalian Lubricating Oil Research and Development Institute, Dalian, Liaoning, China

Dibenzyl toluene is a synthetic heat transfer fluid and safety for the people and environment because of its chemical composition. SO_4^{2-}/TiO_2 solid super acid was using as a catalyst for the synthesis of dibenzyl toluene, which is an environmentally benign process when solid acid catalyst was used. The conversion of benzyl chloride is 99.0%. The final product was further separated by molecular distillation and further characterized using GC, IR, TG and NMR compared with market product. The results show that the dibenzyl toluene exhibit much better thermal stability, which would be applied to the operations requiring high temperature heating.

2 – 2:30 pm | A New Group V Base Oil for Low Viscosity Engine Oil

Yaokun Han, The Dow Chemical Co., Shanghai, China

A continued move to lower viscosity lubricants is becoming a trend in the development of modern automotive lubricants. Lower viscosity lubricants are known to contribute to improved fuel economy benefits. However, it is well known that lower viscosity base oils of the same chemical family are normally more volatile with lower viscosity index. Low viscosity base oils which have both a high viscosity index and a low NOACK volatility are highly desired but also a great technical challenge. A new series oil soluble polyalkylene glycols were designed and developed to combat this challenge. These new group V base oils exhibited performance benefits of high VI, good lubricity, low temperature viscosity and Noack volatilities at low viscosity.

2:30 – 3 pm | Naphthenic Base Oils for High Performance, High Viscosity Index Hydraulic Fluids Applications

Thomas Norrby, Jinxia Li, Nynas AB, Nynashamn, Sweden

In this follow-up of last year's STLE paper, we show how Naphthenic speciality wax-free base oils bring value to hydraulic fluid formulations for low temperature application in aviation and mobile applications. Wax-free NSP are a good starting point, as the low viscosity naphthenic base oils have pour point and kinematic viscosity rivalled only by PAO, but brings much higher solvency, supporting high VI Improver additive treat rate, and are available at a small fraction of the cost of other base fluids. Typical aviation hydraulic fluid formulations would have a low starting base oil viscosity, e.g. a KV @ -54 °C of 400 cSt, combined with high treat rates of VII yielding final fluid VI in the range of 250 to 400, and with a KV @ -54 °C of less than 3000 cSt, meeting e.g., Defence Standard 91-48/2. Other outdoor and mobile hydraulic applications utilize VG 15, 22 and 32, which in a similar fashion can be made from low viscosity base oils and appropriate VI Improvers.

3 – 3:30 pm | Break

3:30 – 4 pm | Performance and Implemenation of Perfluoropolyether (PFPE) Lubricants

Joanna Dawczyk, Janet Wong, Imperial College London, London, United Kingdom

Perfluororpolyethers (PFPEs) are a group of fluorinated synthetic fluids which find use as high-performance lubricants owing to their exceptional thermo-oxidative stability. Their high viscosity index (VI), low vapour pressure together with high oxidative stability has facilitated the application of PFPE as a lubricant in aerospace, vacuum pumps and gas turbines. Despite their outstanding properties, PFPEs failed to provide adequate protection of plain roller bearings, which are used in widely used high vacuum pumps. The current research aims to better understand the cause of this failure by making fundamental studies of PFPE performance in both EHD and mixed lubrication conditions. Potential methods of delaying bearing failure are investigated, including the incorporation of additives.

4 – 4:30 pm | Thermodynamic Characterization of Base Oil Viscosity and Vapor Pressure

Tom Karis, TEK Data Systems, Aromas, CA, Raj Shah, Koehler Instrument Co., Inc., Holtsville, NY

The goal of this work is to investigate the molecular parameters governing the vapor pressure and viscosity of base oils. Kinetic rate theory is employed to extract the activation free energy from the vapor pressure and viscosity vs. temperature data for synthetic hydrocarbon base oils with a range of molecular weight, polarity, and isomerism. Thermodynamic properties are derived from the slope and intercept of the Arrhenius plot for vapor pressure and viscosity. The slope provides the activation energy, and the intercept provides the activation entropy. Decreasing the viscosity without increasing the vapor pressure should be possible by increasing the flow activation entropy without increasing the vaporization activation entropy. However, it is still not clear exactly how molecular structure and composition changes can accomplish this optimization. We discuss the feasibility of applying non-equilibrium molecular dynamics to calculate the flow activation entropy.

4:30 – 5 pm | Synthetics and Hydraulics Business Meeting


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Session 6G • Cumberland 1/2

Engine & Drivetrain IV

Special Panel – Advanced Fuel-Efficiency Engine and Drivetrain Hardware Technologies

Session Chair:
Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

This special session intends to present, share, and discuss new and prospective engine and drivetrain technologies for improved fuel economy without sacrifices on reliability, durability, or emission control. Topics to be discussed include: tribological challenges of advanced engine technologies, next generation wet friction technologies for improving drivetrain efficiency, combustion technologies for high-efficiency light-duty automotive engines, and modifications of ferrous based thermal spray coatings for improved tribological system performance.

1:30 – 2 pm | Combustion Technologies for High-Efficiency Light-Duty Automotive Engines

Arun S, Solomon, General Motors R&D, Warren, MI

Emerging engine technologies to meet regulations by reducing emissions and boosting fuel economy, while delivering the best overall powertrain performance is discussed. Downsized, boosted gasoline engines are a megatrend for light duty automotive engines for improving part-load efficiency. Potential efficiency opportunities exist by upgrading fuel properties and lowering variability in properties across regions. Investigations to resolve role of lube oils, additives, and deposits in causing LSPI continue to be needed.

2 – 2:30 pm | Next Generation Wet Friction Technologies for Improving Drivetrain Efficiency

Feng Dong, BorgWarner, Inc., Auburn Hills, MI

Recent automotive transmission designs have been more focused on improving efficiency, shift quality and NVH characteristics due to the stringent emissions and fuel economy regulations. Various transmission types include 8, 9 even 10 speed automatic transmissions, DCT and hybrid drivetrain have been developed to meet customer and government requirements. Wet friction clutch has been identified as one of the key areas affecting automotive drivetrain efficiency. In this presentation we will discuss different approaches to improve wet friction clutch efficiency including new friction material technology, friction plate and clutch pack design, and modeling.

2:30 – 3 pm | Tribological Challenges of Advanced Engine Technologies

Peter Lee, Southwest Research Institute, San Antonio, TX

As vehicle manufacturers work towards meeting ever stringent environmental controls and improved fuel economy, advanced engine technologies become increasingly important. Such technologies include combustion strategies, variable compression and valve timing, lighter materials, increased fuel line pressures, increasingly complex air handling, stop-start and hybridization. All these have effects on the lubrication, friction and wear of these advanced engines. This presentation will explore the tribological challenges and benefits of using various advanced engine technologies.

3 – 3:30 pm | Break

3:30 – 4 pm | Modifications of Ferrous-Based Thermal Spray Coatings for Improved Tribological System Performance

Paulo Rosa, Comau, Southfield, MI

In the development of increasingly higher efficiencies in powertrain, development engineers have had to make decisions balancing structural weight and tribological requirements. Adaptation of coatings in these systems has enabled the designs to become lighter and better tribologically. As such, new trend in powertrain is replacement of cast iron liners with thermal spray coatings on parent bores. Significantly this has created an alternative to the traditional wear insert approach with its inherent thermal and weight inefficiencies, now a PTWA coating reduces surface temperatures and its morphology changes the tribology system. Comau has been developing and working with partners in expanding this, by leveraging the finish coating process and feedstock modifying the coatings composition and both structural and metallurgical morphology. We will demonstrate such modifications and how they enhance the friction and wear performance beyond known values for typical ferrous based feedstock.

4 – 4:30 pm | Open Discussion

4:30 – 5:30 pm | Engine and Drivetrain Business Meeting

Session 6H • Cumberland 3

Nanotribology VI

Session Chair:
Kalyan Mutyala, Argonne National Laboratory, Lemont, IL

Session Vice Chair:
Zhe Chen, Penn State University, State College, PA

1:30 – 2 pm | In-Situ Tribofilm Growth Study of a Mechanical Sintering Nanoparticle Antiwear Additive

Steven Thrush, Allen Comfort, US Army TARDEC, Warren, MI

A research effort was conducted to investigate tribofilm formation mechanisms of a novel nanoparticle antiwear additive. Spherical 10 nanometer diameter zirconium oxide nanoparticles were dispersed in polyalphaolefin synthetic base oil and tested between AISI 52100 steel counterfaces in a ball on flat tribometer with a slide to roll ratio of 50%. The apparatus allowed tribofilm thickness data to be tracked in-situ at set intervals. Tribofilms reaching a maximum film thickness of ~150 nanometers were measured. A previous study investigated nanoparticle concentration, which was expanded to include temperature and load to further understand parameters affecting tribofilm generation. Contrary to the chemical tribofilm formation processes of traditional antiwear additives like zinc dialkyldithiophosphate, testing suggests the primary mechanism of tribofilm growth for zirconium oxide is nanoparticle adsorption followed by particle accumulation and sintering.

2 – 2:30 pm | Tribological Behavior of Plasma Functionalized ZnO Nano-Additives

Kimaya Vyavhare, Pranesh Aswath, Univeristy of Texas at Arlington, Arlington, TX, Ali Erdemir, Argonne National Laboratory, Lemont, IL

An innovative approach of coating ZnO nanoparticles through plasma polymerization was employed to ensure dispersion and delivery of beneficiary chemical species to tribological contacts. A rotary plasma reactor was used to encapsulate ZnO nanoparticles with methacrylate and boron rich plasma coatings. Tribological behavior of these nano-additives with and without ZDDP was examined using cylinder on flat reciprocating test setup. In situ electrical contact resistance

measurements were recorded to understand dynamics of tribofilm formation with these functionalized ZnO nano-additives. Additionally, surface analysis techniques like XPS and XANES were used to elucidate chemical makeup of the tribofilms formed at rubbing surfaces. Experimental results suggests that coated ZnO nanoparticles contribute to enhance antifriction and antiwear performance compare to uncoated ones, when used by themselves or in a mixture with ZDDP.

2:30 – 3 pm | In-Situ SEM Nanomechanical Characterization of Tribofilms Derived from Inorganic Nanoparticles

Kora Farokhzadeh, Praveena Manimunda, Joseph Lefebvre, Syed-Asif Syed-Amanulla, Steven Shaffer, Bruker Nano Surfaces, San Jose, CA

Nanoparticles are introduced in lubricants due to their ability to augment load bearing capacity and maintain low friction in boundary lubrication regime. To implement model lubricants on larger scales, it is essential to gain detailed understanding of the mechanisms of lubrication and tribofilm formation in mixed or boundary lubrication regimes. In this study, base oil with suspended MoS_2, ZrO_2 and CeO_2nanoparticles were used to lubricate steel-steel interfaces. The tribofilms generated during pin-on-disk experiments were characterized using in-situ SEM nanomechanical testing instrument. In-situ SEM nanoScratch tests revealed the adhesion strength as well as shear characteristics of tribofilms. Further, the nanoparticles were tested in combination with fully formulated engine oil, to understand the effect of conventional additives on tribofilm characteristics. Combination of in-situ SEM and macro-scale tribological tests revealed the interfacial phenomena at different length scales.

3 – 3:30 pm | Break

3:30 – 4 pm | Dislocations Associated with Stick-Slip Friction of Lubricants in Boundary Lubrication

Rong-Guang Xu, Yongsheng Leng, The George Washington University, Washington, DC

Improved understanding of squeezing and friction behaviors of lubricant films under extreme confinement at nanometer scales can lead to strategies for preventing surface failure and efficient energy usage. Shearing of a solidified simple nonpolar film under nanoconfinement is studied by using a liquid-vapor molecular dynamics simulation method. We find that, in contrast with the shear melting and recrystallization behavior of the solidlike phase during the stick-slip motion, interlayer slips within the film and wall slips at the wall-film interface are often observed. The ordered solidified film is well maintained during the slip. However, repeated film dilation and collapse of the lubricant film during the stick-slip friction are observed, which is associated with the nucleation, propagation and annihilation of dislocations found in the solidlike film. These novel observations may provide new insights into the mechanical behaviors of lubricant films and thus improved lubricant design.

4 – 4:30 pm | PEI-RGO Nanosheets as a Nanoadditive for Enhancing the Tribological Properties of Water-Based Lubricants

Chengcheng Liu, Deguo Wang, Yanbao Guo, China University of Petroleum-Beijing, Beijing, China

In order to enhance dispersion of graphene in water and obtain high effective water-based lubrication nanoadditives, polyethylenimine-reduced graphene oxide (PEI-RGO) nanosheets were synthesized via an improved Hummer's method and water bath method. The physical and chemical properties of the product were characterized using FTIR, Raman spectroscopy, SEM and TEM. PEI-RGO nanosheets had an excellent dispersibility and stability as a nanoadditive for water-based lubricants. The steel-steel ball-plate tribotest results revealed that the lubrication properties of water-based lubricant significantly improved by adding PEI-RGO nanosheets. Compared with pure deionized water, the friction coefficient and wear rate had 52.3% and 43.4% reduction, respectively, when the content of PEI-RGO in water was 0.05 wt%. The graphene adsorption occurred on the wear surfaces of steel plate suggested PEI-RGO nanosheets formed a lubricating layer, thus leading to the superior tribological properties.

4:30 – 5 pm | Study on the Quantitative Evaluation of the Surface Force Using a Scanning Probe Microscope

Wataru Yagi, Tomomi Honda, University of Fukui, Fukui, Japan, Kazushi Tamura, Idemitsu Kosan Co., Ltd., Ichihara, Japan

There are two types of friction modifiers (FMs) used as lubricant additives: Reaction film FMs (RF-FMs) and adsorption film FMs (AF-FMs). While RF-FMs provide good performance in severe condition, AF-FMs excels in mild condition. These empirical evidences lead us to combining these two FMs to cover broader condition. However, the effects of their combination are highly complicated due to the interaction between these FMs. If the interaction force of AF-FMs with various materials can be evaluated, it would help us to improve tribological performances of lubricants. Although a scanning probe microscope (SPM) seems suitable for this application, we found some obstacles to achieve proper measurements of pull-off force due to static electricity, laser position, sample deformation and so on. In this study, we thoroughly investigated those effects on pull-off force quantitatively. We will propose a calibration method of an SPM and present some important aspects of the forces acting on AF-FMs.

5 – 5:30 pm | The Molecular Arrangement and Frictional Response of SAMs of a Planar Phthalocyanine Molecule

Yijun Qiao, Yuhong Liu, Tsinghua University, Beijing, China

The researches on molecular arrangement of self-assembled monolayers (SAMs) are the demand of novel lubricants in micro world, such as in micro-electro-mechanical system. It also promotes the understanding of mechanism of friction energy dissipation. A phthalocyanine derivative, which has a planar structure, formed SAMs with four kinds of molecular arrangement. A growth model of the SAMs was established. The edge-on arrangements with different orientation angles and face-on arrangement of SAMs were revealed by analyzing the thickness, adhesion and surface potential measured by AFM and KPFM. Friction experiments by lateral force microscopy indicates that the molecular arrangement and deformation of SAMs are closely related to its frictional response. The edge-on SAMs reduce friction by 72%, more efficiently than the face-on ones, comparing with bare substrate. This work helps the understanding of the microscopic friction mechanism based on molecular arrangement and deformation.

5:30 – 6 pm | Nanotribology Business Meeting

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Session 6I • Cumberland 4

Surface Engineering II
Additive Manufacturing

Session Chair:
Prabhjot Singh, GE Global Research, Albany, NY

Session Vice Chair:
Harpal Singh, Sentient Science Corp., Idaho Falls, ID

1:30 – 2 pm | Tribological Behavior of 17-4 PH Stainless Steel Fabricated by Traditional Subtractive and Laser-Based Additive Manufacturing Methods

Sanjeev KC, Auburn University, Auburn, AL

This study investigates if additive manufacturing processes meet the desired mechanical and wear properties of conventionally fabricated wrought counterparts. The wear rate of 17-4 PH SS disks fabricated by both laser powder bed fusion (L-PBF) manufacturing method and conventional processes was compared under dry and lubricated conditions. The results showed difference between lubricated and dry condition for friction and wear for both L-PBF and wrought samples. The conventionally wrought samples tend to have a higher wear rate for dry, but its opposite for the lubricated condition because the lubrication changed the dominant wear mechanism from adhesion to surface fatigue and abrasion. The wear rate for the dry condition showed that the wear rate is dependent on load, where a 30 N load had higher wear rate than 10 N, for both samples. The results showed that additively manufactured parts had good potential to be an alternative to wrought parts in terms of friction and wear behavior.

2 – 2:30 pm | Laser Additive Manufacturing of Ni-Al-Cr-C Alloys: A High Temperature Sliding Wear Study

Tyler Torgerson, Srinivas Mantri, Rajarshi Banerjee, Thomas Scharf, The University of North Texas, Denton, TX

Laser Engineered Net Shaping (LENS™) permits the processing of novel, tailored hybrid composites with unique microstructures that are not possible to achieve via conventional melt or solid-state powder techniques. Such novel microstructures include solid solution/precipitation strengthened metallic matrices with a distribution of reinforcing in situ formed hard ceramic and solid lubricant phases. In this study, three such novel composites composed of Ni-18Al-11Cr-9C, Ni-14Al-8Cr-29C, and Ni-12Al-2Cr-45C (in at.%) were processed by LENS™. The dry sliding friction and wear behavior of the composites were studied at room temperature and 500°C to determine the chemical and microstructural evolution during wear. Due to the variation in graphite content in the composites, different microstructures and morphologies of nickel aluminide (′ phase), chromium carbide and graphite phases were formed during solidification that were determined to affect the mechanical and tribological properties.

2:30 – 3 pm | The Effects of Laser Shock Peening on the Fatigue Performance of the 3D-Printed AlSi10Mg Alloy

Hao Zhang, Zhencheng Ren, Ruixia Zhang, Chang Ye, Yalin Dong, The University of Akron, Akron, OH

Although rapid solidification during additive manufacturing could introduce refined and homogeneously distributed eutectic silicon phase, which enhances the mechanical properties of AlSi10Mg alloy, it also leads to high tensile residual stress that deteriorates the fatigue properties of the alloy. In this work, laser shock peening (LSP) is applied to process DMLM-processed AlSi10Mg alloy. After LSP process, the surface hardness of the AlSi10Mg alloy increased from 132.8 HV to 144.8 HV. Besides, the tensile residual stress induced by rapid cooling was converted to the compressive residual stress on the top surface. As the result of the hardness increase and residual stress conversion, the rotation bending fatigue life increased to 1.8 times and 2.8 times under the test loads of 100 MPa and 60 MPa, respectively. This study indicates that the fatigue resistance of 3D-printed AlSi10Mg alloy can be tailored by LSP process efficiently.

3 – 3:30 pm | Break

3:30 – 4 pm | Improving Surface Finish and Wear Resistance of Additive Manufactured Nickel-Titanium by Ultrasonic Nano-Crystal Surface Modification

Chi Ma, Haifeng Qin, Zhencheng Ren, Hao Zhang, Gary Doll, Yalin Dong, Chang Ye, The University of Akron, Akron, OH, Mohsen Andani, Narges Moghaddam, Hamdy Ibrahim, Mohammad Elahinia, The University of Toledo, Toledo, OH

Additive manufactured nickel-titanium (NiTi) alloys possess poor surface finish and sub-surface porosity, which leads to disappointing mechanical performance and potential release of toxic element Ni. This study utilizes ultrasonic nano-crystal surface modification (UNSM) to improve surface finish and harden the surface. With a tungsten carbide tip, UNSM simultaneously impacted and burnished the surface at an ultrasonic frequency (20 kHz). After treatment, the surface roughness was reduced from 12.1 to 9.0 m and surface porosity was significantly decreased by 10 times. Surface hardness was found to increase from 304 to 408 Hv, corresponding to a 34.2% increase. UNSM swept and burnished the metal surface, pushing roughness peaks towards valleys. Meanwhile, ultrasonic strikes induced compressive residual stress and extensive dislocations. Therefore, improved surface finish, lower porosity and hardened surface layer were achieved, which leads to higher wear and corrosion resistance.

4 – 4:30 pm | Increase in Mechanical Properties and Wear Resistance of Selective Laser Melted Stainless Steel 316L by Surface Modification

Auezhan Amanov, Jun-Seok Roh, Young-Sik Pyun, Sun Moon University, Asan, The Republic of Korea

This paper presents the microstructure, mechanical properties and wear resistance of stainless steel 316L manufactured by selective laser melting (SLM) method. Stainless steel 316L was treated by ultrasonic nanocrystal surface modification (UNSM) technology. It was found that UNSM technology was able to increase the mechanical properties and to reduce the surface roughness of the as-printed stainless steel 316L that may be attributed to the grain size refinement and elimination of pores from the surface, respectively. Moreover, the friction coefficient of the as-printed stainless steel 316L was reduced and the wear resistance was increased after UNSM treatment. The friction behavior and wear mechanisms were also discussed based on the obtained SEM images of the wear tracks. Results provide an insight on how to improve the mechanical properties, friction and wear behavior of stainless steel 316L manufactured by SLM method by tailoring the microstructure and surface conditions.

4:30 – 5 pm | Patterning and Fusion of Alumina Particles on S7 Tool Steel by Pulsed Laser Remelting

Shixuan Chen, Melih Eriten, University of Wisconsin-Madison, Madison, WI

Microscale pulsed laser alters microstructure and finish of thin surface layer through rapid melting and solidification. This study explores its potential to create a composite layer by adding nano/microparticles. In particular, surface of S7 tool steel dip-coated with alumina particles is treated by pulsed laser. Electron microscopy, chemical characterization and scanning wear tests are conducted on the processed surface. Rapid laser pulses are found to redistribute the alumina into patterns aligned with pulse geometry. Super-heating and cooling cycles during each pulse, and heat treatment due to consecutive pulses neighboring a

surface patch result in microstructural changes as well as diffuse interface between patterned alumina and steel substrate. Diffuse interface of alumina patterns exhibits more wear-resistance compared to the dip-coated alumina coating. Thus, pulsed laser remelting simultaneously achieves patterning and enhanced-fusion of alumina particles on steel substrates.

5 – 5:30 pm | Surface Engineering Business Meeting

Session 6J • Cumberland 5

Lubrication Fundamentals VI

Session Chair:
Marc Ingram, Ingram Tribology Ltd., Carmarthen, United Kingdom

Session Vice Chair:
K. Garelick, Afton Chemical Corp, Richmond, VA

1:30 – 2 pm | Proposals to Improve the Viscosity Index Method, ASTM D2270

Jack Zakarian, JAZTech Consulting, LLC, Orinda, CA

In previous papers, the author has shown that the Viscosity Index rating scale (ASTM D2270) suffers from the following problems: (1.) Low viscosity oils are assigned significantly lower VIs than deserved; (2.) The 0 VI & 100 VI reference oil series are formed from a patchwork of inconsistent data; (3.) The calculation method changes for VI>100 in order to prevent erratic behavior. In this paper, the author proposes new rating methods designed to fix the above problems while retaining those features of the VI scale that are familiar to and desired by users.

2 – 2:30 pm | Effects of Oiliness Additives on Lubrication Conditions in Rolling Bearings

Taisuke Maruyama, Masayuki Maeda, NSK Ltd., Fujisawa, Kanagawa, Japan, Ken Nakano, Yokohama National University, Yokohama, Japan

Various studies have been already reported on the effects of oiliness additives (e.g., stearic acid) on tribological performances. However, it has not been clarified the breakdown processes of their boundary films in EHD contacts of practical bearings. In the previous studies, the authors have developed the electrical impedance method which simultaneously measures the thickness and breakdown ratio of oil films in EHD contacts. Besides, it has been confirmed that the method measures the oil film thickness with high accuracy comparable to the optical interferometry, which is applicable to practical bearings. In the present study, the effects of oiliness additives on lubrication condition in rolling bearings have been investigated by the electrical impedance method, especially to clarify the breakdown processes.

2:30 – 3:00 pm | Mechanism of ZDDP Boundary Film Formation

Hugh Spikes, Imperial College London, London, United Kingdom

ZDDPs (zinc dialkyl- and diaryldithiophosphates) have been used in engine oils as anti-wear and ep additives for more than seventy years and it now seems probable that they will continue in this role for the foreseeable future. However a number of factors suggest that the selection of optimal ZDDP molecular structure is becoming increasingly important. One is the need to reduce phosphorus volatility to meet current engine oil specifications. It has been show that ZDDP molecular structure plays a significant role in determining boundary friction and thus fuel economy. The rate of tribofilm formation by ZDDP is also strongly structure-dependent and if too rapid can lead to micropitting wear. Unfortunately we still know relatively little about the influence of ZDDP molecular structure of ZDDP film formation. This presentation therefore describes new work to explore the impact of molecular structure on the rate and mechanisms of ZDDP tribofilm formation in thin film conditions.

3 – 3:30 pm | Break

3:30 – 4 pm | A Mixed Lubrication Model for Paralleled Plain Faces

Yuechang Wang, Gaolong Zhang, Ying Liu, Tsinghua University, Beijing, China

The experimental work of the conformal contacts such as plain face have proved that the flat-on-flat surface can form a hydrodynamic effect under lubricated condition. Limited numerical model have proposed to simulate the lubrication phenomenon. In the present work, we extend some well-developed numerical techniques in the simulation of non-conformal contact surfaces to the conformal contact surfaces. The proposed method is verified by the experimental works of former researchers. Then the effect of the scale of the surface topography on the simulation of the tribologcial performance is studied. The results show that the scale has dramatically influence on the simulation results. Only with proper scale, the simulation can get the results which are matched with the experiments.

4 – 4:30 pm | The Investigation of Oil Replenishment in a Rolling Bearing

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

The formation of EHL film formed between the ball and the ring in a rolling bearing is strongly affected by the oil replenishment into the rolling track following the passage of the preceding balls. This paper directly observes and measures lubricant films in the rolling track using a custom-made, model ball bearing rig and uses a simulation model to investigate the mechanism of replenishment in a rolling bearing. The contact pressures and rotational speeds employed are commensurate with those present in a real rolling bearing. The results are presented to illustrate the influence of multiple factors including entrainment speed, oil fill level, interval time between passage of adjacent balls, and oil viscosity on oil films in and around the contact.

4:30 – 5 pm | Impact of ZDDP Degradation – Influence of Engine Oil Condition on Friction and Wear

Nicole Doerr, Serhiy Budnyk, Andjelka Ristic, Marcella Frauscher, Adam Agocs, AC2T Research GmbH, Wiener Neustadt, Austria

Tribochemical behavior of zinc dialkyl dithiophosphate (ZDDP) antiwear additives is a key criterion for engine oil performance and strongly depends on operating and environmental conditions. In order to understand tribochemical mechanisms from the molecular level and their effect on micro/macroscopic tribocontact surface, engine oils collected from passenger cars at different stages of the oil change interval were compared with engine oils artificially altered in the laboratory. The (ZDDP) degradation products were identified by mass spectrometry (MS) to classify the engine oils according to the degree of degradation. Steel surfaces obtained by tribo-experiments with engine oils from the field and the laboratory were analysed by X-ray photoelectron spectroscopy (XPS). Correlations between operating conditions, engine oil conditions, tribolayers, friction and wear were established.

6J

5 – 5:30 pm | Influence of Lubricant Additive Chemistry on the Viscosity of Model Base oil Formulations

Sendhil Poornachary, Xin Yi Tee, Jim Lee, Ann Chow, A*STAR Institute of Chemical and Engineering Sciences, Singapore, Singapore

This study aims to provide an improved understanding of the mechanisms underpinning the functional property of viscosity modifiers (VMs). Steady state rheology measurements were performed to investigate the effects of additive chemistry and concentration on the viscosity of model base oils. Polyalkyl methacrylates was chosen as model VM with different pendant functional groups attached to the polymer backbone. Either pure or a mixture of organic solvents were used as base oils. Trends between viscosity, additive chemistry and concentration could be established, with insights into polymer-polymer and polymer-solvent interactions. The viscosity modifying ability of a polymer additive was found to be dependent on the base oil composition. Ongoing work is focused on establishing the effect of temperature on viscosity modification, and microstructural characterization of the oil solutions using in-situ SAXS to further discern the effect of additive structure on lubricant oil performance.

5:30 – 6 pm | Lubrication Fundamentals Business Meeting

Session 6K • Cumberland 6

Condition Monitoring I

Session Chair:
Daniel Walsh, Spectro Scientific, Chelmsford, MA

Session Vice Chair:
Kemberlee Snelling, TRICO Corp., Davison, MI

1:30 – 2 pm | Contributing Factors That Influence Oil Analysis Data

Michael Holloway, ALS Tribology, Highland Village, TX

The tests that are used for oil analysis have been designed to provide repeatable and reproducable data yet there are various factors that will influence the data. Lubricant chemistry, enviromental considerations, and slight deviations in the test methods protocols can have dramatic effects on the results. This presentation explores the various influences that can effect metal concentrations, particle analysis, contamination analysis, and oil condition analysis.

2 – 2:30 pm | Monitoring Engine Lubricating Oil Viscosity In-Situ in a Test Marine Diesel Engine Using a Novel Ultrasonic Technique

Xiangwei Li, Tomos Brenchley, Olivia Manfredi, Henry Brunskill, Rob Dwyer-Joyce, University of Sheffield, Sheffield, United Kingdom, Matthias Stark, Winterthur Gas & Diesel, Winterthur, Switzerland

Lubrication between engine piston and liner is vital to prevent direct metal-metal contact and scuffing on the interior of liner and maintain the efficiency of a marine diesel engine. Lubricant injection time and rate is dependent on viscosity of the lubricant. Measurement of the lubricant viscosity in feeding channel in-situ is important in efficient injection control and it also provides a robust way to monitor the quality of the lubricant oil. A bespoke in-situ viscosity sensor is developed and implemented on the lubrication oil feeding channel of a test engine using a novel ultrasonic technique. The lubricant oil is oscillated ultrasonically by a shear polarised transducer. The sensitivity is improved using an acoustically soft material sandwiched between the oil and the transducer. Tests found the ultrasonic signal varied with the engine operating conditions, which suggest that the measurement of lubricant viscosity would enable real-time feedback into injection control system.

2:30 – 3 pm | Management of Lubricated Machinery Assets in an Industrial Setting

Bryan Johnson, Arizona Public Service, Tonopah, AZ

Optimal management of lubricated assets in an industrial environment has a high rate of return to the organization. Lubricated machinery are a primary concentration of maintenance efforts and are a significant cost center. The implementation of elements within a lubrication program that are endorsed by the organization's management are responsible for the effectiveness of the program. Asset management is garnering additional emphasis in industry and is being driven by standard such as the ISO 55000(x). This ISO series includes three documents that provide requirements and guidelines. The International Council for Machinery Lubrication (ICML) has generated standards that are based upon the ISO requirements with an emphasis on optimizing lubricated machinery assets to improve reliability and cost. Twelve primary elements asset management will be presented and discussed in the context of improving the quality of lubrication programs in industrial environments.

3 – 3:30 pm | Break

3:30 – 4 pm | Study on the Condition Monitoring System for the Sliding Surface Using Machine Learning

Tomomi Honda, Yuka Hashimoto, Yusuke Mochida, University of Fukui, Fukui, Japan, Kazuhiko Sugiyama, Yumiko Nakamura, Chikako Takatoh, Ebara Corp., Fujisawa, Kanagawa, Japan

This study aims to propose a cost- and time- effective system that detect the signs of breakdown during equipment operation by using machine learning to identify abnormalities. We conducted wear tests in contaminated oil and used multiple sensors to collect data regarding the friction force, the electrical contact resistance, the acoustic emission (AE) signal, and vibration. An appropriate learning sample was selected using k-fold cross-validation. The electrical contact resistance was found to contribute relatively little to the detection of abnormalities, whereas the friction coefficient contributed greatly. Furthermore, the AE signal and the vibration detected local changes on the sliding surface. Consequently, we found that machine learning can judge whether monitoring data are normal or abnormal.

4 – 4:30 pm | A New Approach to Onsite Oil Analysis for Industry 4.0

Lisa Williams, Spectro Scientific, Chelmsford, MA

In the dawn of Industry 4.0, new tools are available for standardizing oil analysis programs on a global scale. Condition monitoring by lubricant analysis is one of the basic tools of predictive maintenance programs; however, thus far, industries have struggled managing programs on a global scale, standardizing knowledge world-wide and capturing global program success. Through the use of on-site oil analysis tools, we will explore the benefits of pairing fluid intelligence software with an on-site oil analysis laboratory at a steel mill and demonstrate the value of new technologies available in the Industry 4.0 Era.

4:30 – 5 pm | Bridging the Gap: Filter Debris Analysis

Henry Neicamp, POLARIS Laboratories, Indianapolis, IN

The purpose of oil filters is to prevent contamination and wear debris from circulating through oil systems. While that's good for your equipment, it hides problems during fluid analysis. Filter debris analysis helps you see the whole picture of what's happening in your oil system. By back-flushing the filter to release captured particles, samples can be collected and additional testing performed. Leveraging this in-depth analysis helps pinpoint the source of the wear and can even determine the cause of breakdowns. Additional value can be found in trend analysis over several filter tests on the same unit.

5 – 5:30 pm | Condition Monitoring Business Meeting