Overview

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

TUESDAY, MAY 21

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

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

Commercial Exhibits and Student Posters
(9:30 am – Noon & 2 – 5:30 pm) – Broadway Ballroom

Tuesday Technical Sessions (8 am – Noon)

- 3D • Wear I – Music Row 1
- 3E • Commercial Marketing Forum III – Music Row 5
- 3F • Metalworking Fluids III – Music Row 4
- 3G • Tribotesting I – Music Row 3
- 3H • Fluid Film Bearings III – Music Row 2
- 3I • Engine and Drivetrain I – Cumberland 1/2
- 3J • Nanotribology III – Cumberland 3
- 3K • Environmentally Friendly Fluids I – Cumberland 4
- 3L • Lubrication Fundamentals III – Cumberland 5
- 3M • 2D Materials I – Materials & Nanotribology Joint Session – Cumberland 6

President's Awards Luncheon/Business Meeting
(Noon – 2:00 pm) – Legends Ballroom

Tuesday Technical Sessions (2 – 6 pm)

- 4D • Wear II – Music Row 1
- 4E • Commercial Marketing Forum IV – Music Row 1
- 4F • Metalworking Fluids IV – Music Row 4
- 4G • Tribotesting II – Music Row 3
- 4H • Materials Tribology III – Music Row 2
- 4I • Engine and Drivetrain II – Cumberland 1/2
- 4J • Nanotribology IV – Cumberland 3
- 4K • Environmentally Friendly Fluids II – Cumberland 4
- 4L • Lubrication Fundamentals IV – Cumberland 5
- 4M • 2D Materials II – Materials & Nanotribology Joint Session – Cumberland 6
- 4N • Discussion Roundtables – Legends A

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

Exhibitor Appreciation Break (3 – 4 pm) – Broadway Ballroom

Exhibition Hours

- **Tuesday, May 21** (9:30 am – Noon) & (2 – 5:30 pm)
  Closed for Presidents Luncheon (Noon – 2 pm)

  Exhibitor Appreciation Hour (3 – 4 pm)
  Evonik Raffle (3:30 pm) – Must be present to win.

TIME	SESSION 3D Wear I Music Row 1	SESSION 3E Commercial Marketing Forum III Music Row 5	SESSION 3F Metalworking Fluids III Music Row 4
8 – 8:30 am	Effects of Shoe Design and Progressive Wear on Traction Performance, S. Hemler, p. 58	Vanderbilt Chemicals: New Corrosion Inhibitors and Their Application in Engine Oils, V. Gatto, p. 60	Effect of Different Organic Acids in Organosilanes/ Organic Acids Combo Systems as Stain/Corrosion Inhibitors in Metalworking Fluids for Application on Aluminum Alloys, H. Kim, p. 61
8:30 – 9 am	Methods to Study the Life of an Asperity Subjected to Tribological Contact, A. Bhattacharjee, p. 58	Chevron Phillips Chemical Co.'s PAO Blending Matrix Tool: Simulations and Examples of How to Streamline Lab Blends, K. Hope, p. 60	Substitution of Zinc Stearate in Cold Extrusion Processes, W. Rehbein, p. 61
9 – 9:30 am	Gait Parameters of Shoe Wear: A Case Study of the Shoe Wear Rate by Individual Gait Parameters, E. Pliner, p. 58	Sea-Land Chemical Company: Boot Scootin' Distribute, J. Altstadt, p. 60	A Dynamic Industry Needs Dynamic Additives – State of the Art Wetting Agents, K. Wirz, p. 61
9:30 –10 am	Ash-Induced Wear on Biomass Pre-Conversion Equipment, K. Lee, p. 58	Lockhart Chemical Company: Products, Service, Capability & Flexibility – The Keys to Longevity, D. Mylie, p. 60	High-Oil Emulsions for MWFs Based on Heavy Naphthenic Base Oils, T. Norrby, p. 61
10 – 10:30 am	Break	Break	Break
10:30 – 11 am	Predicting Slip Risk Based on Footwear, S. Hemler, p. 58	Croda: New Products from Croda and an EcoLabel Update, S. Davis, p. 60	Foam Mechanism for Soluble Oils, R. Golden, p. 61
11 – 11:30 am	Influence of Film Structure on Vane Pump Protection, X. Fang, p. 58	King Industries Inc.: High Temperature Performance with NA-LUBE® KR Alkylated Naphthalenes, R. Dworet, p. 60	Evaluation of Performance Properties of Slideway Lubricants, J. Hogan, p. 61
11:30 am – Noon	The Role of Counterface Roughness Orientation in the Thermal Effects on the Deposition of PEEK Transfer Films, C. Schwartz, p. 60	Münzing: Next Generation 3D Siloxane Technology Based Defoamers, J. Mykietyn, p. 61	Vulnerability and the Art of Metalworking Fluid Formulation, N. Clarkson, p. 62
	SESSION 4D **Wear II** **Music Row 1**	**SESSION 4E** **Commercial Marketing Forum IV** **Music Row 5**	**SESSION 4F** **Metalworking Fluids IV** **Music Row 4**
2 – 2:30 pm	Effects of Unevenly Worn Cage Pockets on the Service Life of a Solid Lubricated Rolling Bearing, R. Dahiwal, p. 72	Afton Chemical Corp.: Afton Chemical's Key Driver Seminar: Pushing the Limits – The Pressures that Drive Hydraulic Fluids to New Heights, R. Leonhardt, p. 72	A New Generation of Anti-Wear Solutions and Staining Inhibitors for Metalworking Fluids, C. Hedoire, p. 73
2:30 – 3 pm	Modeling of Low Wear of Rough Disc in Sliding Contact with Flat Ring, P. Pawlus, p. 72		Application of Predictive Safety Screening Tools in GHS Labeling and TSCA New Chemical Notifications: A Small Company Perspective, P. Spencer, p. 73
3 – 4 pm	Exhibitor Appreciation Break	Exhibitor Appreciation Break	Exhibitor Appreciation Break
4 – 4:30 pm	Impact of Wear Models on the Local Behavior of Railroad Brake Pad, M. Renouf, p. 72	Lanxess Germany GmbH: Additive Packages for Challenging Hydraulic Applications, S. Sandhoefner, p. 73	Boundary Lubricant Additive Response Comparisons on Aluminum Alloys Using Twist Compression Tests (TCT), T. McClure, p. 73
4:30 – 5 pm	Surface Damage from Micro-Slip: Analytical versus F.E.M. Approach, I. Lawal, p. 72	Eastman Chemical: When and Why to Use Synergex™ Multifunctional Amine Additives for Metalworking Fluids, C. Johnson, p. 73	Tribological and Anti-Corrosion Property of IF–WS_2 Particle in Aqueous System, G. Chaubey, p. 74
5 – 5:30 pm	Evolution of the Contact Interface: Towards the Introduction of a Tribological Circuit in a Multi-Scale and Multi-Physics Modeling, V. Magnier, p. 72	Evonik: DYNAVIS® Technology Propels Mine Operators into a New Era of Operating Economics – With Higher Profits and Lower Costs Performance Demonstration: Open-Cast Coal Mine Siberia, Russia, L. Zunner, p. 73	Surface Integrity Analysis of the Hardened Bearing Steel Ground Under Different Cooling-Lubrication and Cutting Conditions, R. Da Silva, p. 74
5:30 – 6 pm	Wear Business Meeting	BASF: New Non-Antagonistic Oil-Soluble Corrosion Inhibitor: IRGACOR® L 844, A. Mannion, p. 73	Tribological Approach of Grinding Stainless Steel with Semi Synthetic-Based Cutting Fluid, R. Da Silva, p. 74

SESSION 3G Tribotesting I	SESSION 3H Fluid Film Bearings III	SESSION 3I Engine and Drivetrain I	
Music Row 3	**Music Row 2**	**Cumberland 1/2**	
In-Situ Measurement of Friction by Causing Nano-Scale Slip with a High-Powered Ultrasonic Wave, R. Dwyer-Joyce, p. 62	Dynamic Performance Analysis of Hydrostatic Oil Film Considering Oil Pad Damage Under Extreme Working Conditions, Z. Liu, p. 63	DD13 Liners – Batch Consistency and Scuffing Initiation, P. Lee, p. 64	**8 – 8:30 am**
Development of a Test Procedure, System and Process for High Throughput Tribological Testing of Used Oil Samples as Part of a Condition Monitoring Protocol, G. Plint, p. 62	TEHD Analysis of Dynamic Behavior of a Planetary Star Gearbox Journal Bearing Due to Misalignment Torque, B. Pap, p. 63	Real-Time Wear Mapping of a 2.0L Turbocharged Gasoline Direct Injection Engine, P. Lee, p. 64	**8:30 – 9 am**
Florescent Nanoparticle – Assisted Probing of Fluidic Behavior on 3D Printed Surfaces, P. Renner, p. 62	Comparison of CFD-FSI and Reynolds Equation Based Approaches in the Prediction of Dynamic Coefficients of a Convergent-Divergent Slider Bearing with an Eeforming Liner, T. Snyder, p. 63	Effect of Surface Textures on Fuel Economy, S. Hsu, p. 64	**9 – 9:30 am**
Contamination Impact on Gas-Phase Synthesized Graphene and Graphene Platelets Effectiveness as a Lubricant Additives in Bio-Derived Oil and PAO, G. Krauss, p. 62	Thermal Characteristics of a Vertical Hydrostatic Guideway System with Ballscrew Drive of Precision Milling Machines, H. Huang, p. 63	Experimental Research on the Tribological Performance of Laser Textured Cylinder Liner, B. Yin, p. 64	**9:30 –10 am**
Break	**Break**	**Break**	**10 – 10:30 am**
The Influence of Operating Parameters and Viscometrics in Energy Efficiency in Rolling Sliding Concentrated Contacts, M. Dubey, p. 62	Numerical and Experimental Investigations of the Performance of Pocketed Thrust Bearings Operating in Micro-Electro-Mechanical Systems, P. Wang, p. 64	A Comparison of Tribosystems, Wear Mechanism and Lubricant Effects in Silent and Roller Timing Chains, R. Mourhatch, p. 66	**10:30 – 11 am**
Testing the Wear Life of Sandpaper, K. Budinski, p. 63	Determination of Inducer Shape Influence on Acoustic Levitation Characteristics, B. Bastian, p. 64	Friction and Wear Investigations on Chain Joints of Timing Chains, A. Becker, p. 66	**11 – 11:30 am**
Insoluble Residues from Thin Films of Hydraulic Fluids and Engine Oils after Prolonged Heating, S. Asadauskas, p. 63	… Analysis of An Elliptical Journal Bearing with Varying Supply Rate: A Look at Starvation, C. Watson, p. 64	Real-Time Measurements of Piston Ring and Liner Lubrication in a Marine Diesel Engine Using Ultrasound, X. Li, p. 66	**11:30 am – Noon**

SESSION 4G Tribotesting II	SESSION 4H Materials Tribology III	SESSION 4I Engine and Drivetrain II	
Music Row 3	**Music Row 2**	**Cumberland 1/2**	
A New High Resolution Ultra-High Vacuum Tribometer Based on a Unique 6-Axis Force Sensor, J. Fontaine, p. 74	Synthesis of a Self-Lubricating Composite by in Situ Formation of Graphene in Alumina Matrix During Ball Milling, A. Kasar, p. 76	Effects of Ionic Liquids on Micropitting Behavior for Rear Axle Lubrication, S. Roy, p. 77	**2 – 2:30 pm**
New Developments in Non-Invasive Ultrasonic Lubricant Film Thickness, Viscosity, and Cavitation Sensors – A Review of Case Studies, H. Brunskill, p.74	Out of Thin Air: In-Situ Formation of Diamond-Like Nanocomposite Films, M. Jones, p. 76	Compatibility Between Ionic Liquids and Friction Modifiers, W. Li, p. 77	**2:30 – 3 pm**
Exhibitor Appreciation Break	**Exhibitor Appreciation Break**	**Exhibitor Appreciation Break**	**3 – 4 pm**
Scuffing Performance of Low-Viscosity Gear Oil Containing ZrO_2 Nanocrystals, N. Demas, p. 76	Tribological Behavior of Self-Lubricating Alumina Composites with In Situ Formation of Boron Nitride and Aluminum Borate, P. Menezes, p. 76	Alloy-Dependence of the Antagonistic Effects between Soot and ZDDP, J. Qu, p. 78	**4 – 4:30 pm**
Do You Count Water and Antifoam as Containment Particles or Not?, T. Canty, p. 76	Novel Composite Lubricant for Reducing Wear and Friction Under Extreme Contact Pressure and Long Duration, A. Ahmadi, p. 77	Impact of Amine-Based Friction Modifiers on ZDDP Tribofilms, J. Dawczyk, p. 78	**4:30 – 5 pm**
Low Temperature Testing of Greases, K. Pondicherry, p. 76	Graphite Nanoplatelets as Reinforcement in the Self-Lubricating Nanocomposites, E. Omrani, p. 77	New Organic Friction Modifiers for Wet-Clutch Motorcycle Engine Oils, D. Gillespie, p. 78	**5 – 5:30 pm**
Tribotesting Business Meeting	Tribological Considerations of Fouling in Air-Cathode Assisted Iron-Electrocoagulation (ACAIE), A. Kumar, p. 77		**5:30 – 6 pm**

TUESDAY >>

TIME	SESSION 3J Nanotribology III Cumberland 3	SESSION 3K Environmentally Friendly Fluids I Cumberland 4	SESSION 3L Lubrication Fundamentals III Cumberland 5
8 – 8:30 am	Block Copolymer Nanoparticles Prepared via Polymerisation-Induced Self Assembly for Use as a Friction Modifier in Motor Oils, L. Pratt, p. 66	Positive Effects of Mono-Unsaturation on Hydraulic Fluid Performance, S. Asadauskas, p. 67	Towards a Fundamental Understanding of Organic Friction Modifier Additives, S. Campen, p. 68
8:30 – 9 am	Scale Dependent Tribological Behavior of Steel on MoS_2 Co-Deposited Commercial Lubricants with Macroscopic and Nanoscale Contacts, P. Serles, p. 66	Ecolabel 2018 and VGP2018 II – Changes and Challenges in 2019, P. Vettel, p. 67	Research on Polyalkylene Glycols Superlubricity System, W. Liu, p. 68
9 – 9:30 am	Experimental Investigation of Friction and Wear Behavior of 52100 Steel Against Nano-Coated Mild Steel Subject to Refrigerant Lubrication, Z. Khan, p. 67	Soybean Oil: Lubricating Performance, R. Brentin, p. 68	Influence of the Oil Additives and Their Molecular Structure on the Wetting and Friction Performance, M. Kalin, p. 70
9:30 –10 am	A Direct Experimental Link Between Atomic-Scale and Macro-Scale Friction, N. Garabedian, p. 67	Evaluation of Water-Soluble Polymers for Aqueous Lubricants, E. Willett, p. 68	Traction Curves and Rheological Properties of Some Lubricating Fluids, R. Erck, p. 70
10 – 10:30 am	Break	Break	Break
10:30 – 11 am	Invited Talk: Nanotribology of Tunable Polymer Coatings, M. Ruths, . 67	Performance Comparison of Hydraulic Oil Blends Made with Vegetable-Based Fluids – Evaluations of High-Oleic, Low-Oleic Vegetable Oils as well as a Mineral Oil Blend, D. Adams, p. 68	Effect of Different Running-In Stages on Fatigue Life of Mixed-Lubricated Circular Contacted Machine Elements, H.Cao, p. 70
11 – 11:30 am		Bio-Based Base Oils for Performance Lubricants, B. Saha, p. 68	The Tribological Characteristics of Selected Base Oils under Oscillatory Sliding Conditions, S. Masilela, p. 70
11:30 am – Noon	Metallic Coating Characterization with Nanoindentation Measurements, J. Despard, p. 67	Estolides – The Latest in High Viscosity Biosynthetic Base Oils, J. Bredsguard, p. 68	The Role of Fatty Amine Chemistry in Friction Reduction, T. Stein, p. 70
	SESSION 4J **Nanotribology IV** **Cumberland 3**	**SESSION 4K** **Environmentally Friendly Fluids II** **Cumberland 4**	**SESSION 4L** **Lubrication Fundamentals IV** **Cumberland 5**
2 – 2:30 pm	Invited Talk: Evolution of Tribological Contacts by Multiscale Simulations, I. Szlufarska, p. 78	High Viscosity Esters to Boost Lubricant Performance Profile, M. Hof, p. 80	Fatty Acid Ionic Liquids (FAILs): Anion Effect on Physicochemical, Environmental and Tribological Properties, D. Blanco, p. 81
2:30 – 3 pm		A Peculiar Observation of "Gelling" in Bio-Derived Phosphonate Ester, M. Cinta Lorenzo Martin, p. 80	Exploration of Macroscale Superlubricity Enabled by Hydrated Ions, T. Han, p. 81
3 – 4 pm	Exhibitor Appreciation Break	Exhibitor Appreciation Break	Exhibitor Appreciation Break
4 – 4:30 pm	Nanotribology of Graphene in Hexadecane, P. Nalam, p. 78	New Class of Biolubricants Based on the Unique Fatty Acid Structure of Chinese Violet Seed Oil, D. Berman, p. 80	Lubricating Titanium Using a Vegetable Oil Containing Ionic Liquids, H. Duan, p. 81
4:30 – 5 pm	Tuning Friction at Material-Nanoparticle-Liquid Interfaces with an External Electric Field, J. Krim, p. 78	The Issues Facing the EAL Industry: The Stability of Oil and the Eco-Friendliness, A. Cholli, p. 81	Impacts of Glyceride and Ionic Liquid Additives on Tribological Properties of Water-Based Drilling Mud, M. Ji, p. 81
5 – 5:30 pm	Sliding over 10,000 Times Faster: QCM Integrated Microtribometry to Probe Friction Fundamentals via Single-Crystal MoS_2, N. Garabedian, p. 80	Environmentally Friendly Fluids Business Meeting	Evaluation of Greases Used in Rail Journal Bearings, K. Mistry, p. 81
5:30 – 6 pm	Tribofilm Growth Mechanisms of ZrO_2 Nanoparticle Additives in a Fully Formulated Low Viscosity Gear Oil, M. Elinski, p. 80		

SESSION 3M
2D Materials & Nanotribology I

Cumberland 6

Friction on 2D Materials: Friction Contrast between Graphene, MoS_2 and Graphene-MoS_2 Heterostructures, M. R. Vazirisereshk, p. 70		8 – 8:30 am
Interlayer Friction and Superlubricity in Single-Crystalline Contact Enabled by 2D Flake-Wrapped AFM Tips, Y. Liu, p. 71		8:30 – 9 am
Pressure- Induced Friction Collapse of Graphite Flake Sliding on Muscovite Surfaces, B. Liu, p. 71		9 – 9:30 am
Robust Microscale Superlubricity in Graphite/ Hexagonal Boron Nitride Layered Heterojunctions, Y. Song, p. 71		9:30 –10 am
Break	**Break**	10 – 10:30 am
Raman Spectroscopy as an Effective Tool to Detect Interaction on 2D Material Interfaces, X. Zhou, p. 71		10:30 – 11 am
Friction Modulation on Graphene: Underlying Substrate, Atomic Roughness, Defects, and Beyond, J. Liu, p. 71		11 – 11:30 am
Eliminating Delamination of Graphite Sliding on Diamond Like Carbon, Y. Gongyang, p. 71		11:30 am – Noon

SESSION 4M
2D Materials & Nanotribology II

Cumberland 6

SESSION 4N
Discussion Roundtables

Legends A

Run-In Behaviors of Solid Lubricants, J. Curry, p. 82		2 – 2:30 pm
Modified Molybdenum Disulfide for Improved Wear Resistance in Antifriction Coatings, M. Mushrush, p. 82		2:30 – 3 pm
Exhibitor Appreciation Break	**Exhibitor Appreciation Break**	3 – 4 pm
Superlubricity at Macroscale in Oil-Free Rolling/ Sliding Contacts (STLE Early Career Award Winner), K. Mutyala, p. 82	• The Influence of Electrical Current and Water Intrusion on the Failure Mode of Surface Initiated Damage (SID), D. Merk, p. 84	4 – 4:30 pm
Simultaneous In-Situ Formation of MoS_2 and Carbon-Containing Tribofilms, M. Rodriguez Ripoll, p. 82	• How Big is the (Tribo-)Mechanical versus Chemical Influence on Bearing Steels (In the Sub-Surface) with Respect to Overall Performance?, K. Stadler, p. 84	4:30 – 5 pm
Calculations of Energy Barriers to Sliding Friction in MoS_2 in the Presence of Water and Oxygen, A. Hinkle, p. 82	• How to Eliminate the Root Cause of Wear as well as the Boundary Lubrication Regime, K. K. Chao, p. 84	5 – 5:30 pm
Tribological Properties of Different Nano-Sized Layered Double Hydroxides as Oil-Based Lubricant Additives, H. Wang, p. 82	• Fluid Characterization Beyond Viscosity Measurement in EHD, M. Jungk, p. 84	5:30 – 6 pm
Material Tribology Business Meeting	• How Can We Make Tribology Attractive . . ., Especially in Teaching?, S. Wirsching & S. Schwarz, p. 84	6 – 6:30 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 3D • Music Row 1

Wear I

Session Chair:
Mathieu Renouf, University of Montpellier, Montpellier, France

Session Vice Chair:
Arnab Ghosh, Sentient Science, Idaho Falls, ID

8 – 8:30 am | Effects of Shoe Design and Progressive Wear on Traction Performance

Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Previous research has shown variation in performance across shoes labeled as slip-resistant (SR) [1]. This research assessed how progressive shoe wear affects traction and fluid pressure measurements of SR shoes. Eight participants wore two types of SR shoes alternating every month walking a total of at least 75 km in each shoe. After each month, available coefficient of friction (ACOF) and fluid pressure measurements were recorded while each shoe was mechanically slid across a contaminated surface with embedded fluid pressure sensors. Fluid force measurements were then calculated. ACOF and fluid force were each affected by the number of months of wear ($p<.0001$, $p<.0001$), the heel type ($p=0.0443$, $p<.0001$), and the interaction between the two variables ($p<.0001$, $p<.0001$), respectively. This research shows that shoe design affects both performance at baseline and the progression of performance across the shoe's life. 1. Jones, T, et al. Applied Ergo, v70, pgs 134-135, 2018.

8:30 – 9 am | Methods to Study the Life of an Asperity Subjected to Tribological Contact

Arnab Bhattacharjee, Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

Friction and wear are consequences of complex phenomena that occur within a buried tribological interface. Directly interrogating these phenomena often requires methods to penetrate the contact interface in real time or methods to separate the contact without disturbing the processes. Engines, and many other applications involve self-mated metals, which virtually precludes the former. We have challenged ourselves to develop interrupted methods to study the life of a sperity in self-mated metallic contacts. The goal here was to break and recreate tribological contact with repositioning errors of 150 nm or less. Validation testing demonstrated that, with methods that are relatively easy to duplicate, contact locations can be replaced with a repositioning error of ±100 nm. Additionally, validation experiments with self-mated steel and a neat PAO lubricant demonstrate that the tribological contacts can be broken and replaced without any statistically significant effect on the wear rate.

9 – 9:30 am | Gait Parameters of Shoe Wear: A Case Study of the Shoe Wear Rate by Individual Gait Parameters

Erika Pliner, Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

Elastomeric wear is dependent on the cyclical loading conditions. Therefore, outsole shoe wear is likely to be dependent on an individual's gait pattern (i.e. frictional shoe forces and shoe sliding distance). This study presents a case study comparing the gait patterns of two individuals with different shoe wear rates. Participants were asked to wear two pairs of shoes (Shoes A and B) in their day-to-day life until the shoes were deemed unsafe to wear. One participant's wear style is referred to as 'Fast Wear', wearing shoes A and B after 86 and 238 km, respectively. The other participant is referred to as 'Slow Wear', wearing shoes A and B after 407 and 1255 km, respectively. During gait, the Fast Wear participant had higher frictional forces (27-31%) and sliding distances (27-65%) than the Slow Wear participant. The relationship between sliding distance and wear rate is consistent with Archard's wear equation. Gait patterns may influence tread wear consistent with tribology theory.

9:30 – 10 am | Ash-Induced Wear on Biomass Pre-Conversion Equipment

Kyungjun Lee, Jun Qu, James R. Keiser, Oak Ridge National Laboratory, Oak Ridge, TN, Erik Kuhn, Edward Wolfrum, National Renewable Energy Laboratory, Denver, CO

There is growing interest in using biomass as a renewable energy source, however some biomass pre-processing equipment has been reported to have wear issues. In a NREL low-temperature conversion reactor, the stainless steel plug screw feeder experiences severe wear, especially in processing high-ash biomass. In this study, the wear issue was investigated by identifying the wear modes and correlating them to the biomass ash species and contents. Characterization was performed on the worn screw feeder to reveal the wear mechanism, as well as on the extrinsic ash from biomass feedstock to analyze the ash particle size distribution, particle shape, and chemical composition. To understand the ash abrasiveness, bench-scale 3-body abrasion wear tests were carried out with selected ash samples and the screw feeder material. The worn surfaces generated during the bench test were examined and the morphology and composition were correlated to those of the actual worn screw feeder.

10 – 10:30 am | Break

10:30 – 11 am | Predicting Slip Risk Based on Footwear

Sarah Hemler, Kurt Beschorner, University of Pittsburgh, Pittsburgh, PA

This study assessed whether the under-shoe fluid load during a simulated slip could be predicted based on the size of the worn region. Four shoes underwent an abrasive wear procedure to generate localized wear in the heel. Periodically, fluid pressure sensors embedded in the flooring recorded under-shoe fluid pressures during a simulated slip. Fluid force was then calculated. The film thickness of the contaminant was predicted using a derivation of Reynold's equation for thrust bearings [1] based on the size of the shoe wear region. Linear regression analysis showed that the fluid force was affected by predicted film thickness ($p <.0001$). Therefore, the fluid film thickness predictions based on the size of the worn shoe region were able to predict the under-shoe hydrodynamics. This model may have potential in determining when worn shoes should be replaced.

[1. Proctor & Coleman, J Occup Acc, Vol. 9, No. 4, pp. 269-285, 1988]

11 – 11:30 am | Influence of Film Structure on Vane Pump Protection

Xinggao Fang, Mark Devlin, Phillipe Ezanno, Afton Chemical Corp., Richmond, VA

Additives play a critical role in keeping vane pumps in power transmissions from damage. A systematic study on additives that form surface films has been carried out using modified ASTM D7403 a method for indicating wear characteristics of hydraulic fluids in a constant volume vane pump. A wear mechanism has been identified. Practical fluids with balanced needs for transmission hardware protection wil be discussed.

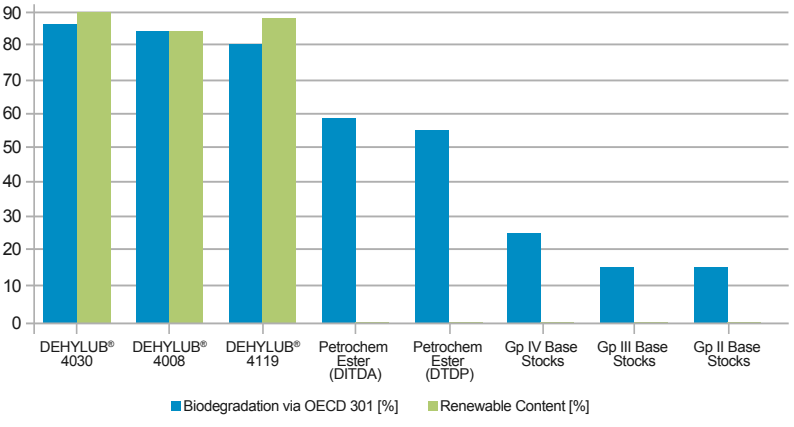
Biolubricants help OEMs achieve sustainability and performance objectives

Today, natural-based specialty chemicals are allowing lubricant manufacturers to achieve their performance and sustainability objectives while also offering more environmentally-friendly solutions to the end consumer market. The Bio-Lubricants portfolio of ester base stocks and additives from Emery Oleochemicals provides more natural alternatives that have a lower impact on the environment to meet increasingly stringent industry and regulatory requirements.

A common misperception is that green products are more expensive or that they don't perform as well as chemistries that are entirely derived from petroleum.

Emery's portfolio of DEHYLUB® Esters not only offers superior biodegradation and sustainability attributes in the form of high renewable content, they are also cost-competitive and comparable, or at times superior, to petroleum base stocks.

DEHYLUB® Esters offer superior biodegradation and renewable content



As the largest producer of Oleochemicals in the Americas, Emery Oleochemicals provides security of supply for our high-performance DEHYLUB® Esters. Our 179 year heritage combined with our 60+ year history of technical expertise and ongoing innovation in esters technology allows us to make a difference to the industry. As an example, many of our DEHYLUB® Esters are on the LuSC-list which provides OEMs the flexibility to formulate finished fluids that will be readily granted the European Ecolabel approval and that can be used in marine lubricant applications per the EPA's VGP regulations. Our products are also suitable for a multitude of other industrial fluid markets including metalworking fluids, hydraulic fluids, automotive applications, greases, and oilfield lubricants.

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Visit Us at STLE Booths # 511 & 513

Visit **www.emeryoleo.com/Bio-Lubricants.html**
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Emery Oleochemicals

11:30 am – Noon | The Role of Counterface Roughness Orientation in the Thermal Effects on the Deposition of PEEK Transfer Films

Cris Schwartz, Mark Placette, Iowa State University, Ames, IA

Poly(ether ether ketone) exhibits excellent wear resistance against steel counterfaces, because of the deposition of a durable transfer film. This can drastically reduce polymer wear in many cases. It has been observed that PEEK will not deposit a sustained transfer film when sliding parallel to the roughness orientation of the metal. The investigators exposed a PEEK material to sliding parallel and perpendicular to the roughness direction of steel counterfaces. At steady state, PEEK exhibited considerably lower wear in perpendicular versus parallel sliding. Infrared thermography showed that the temperatures produced near the wear interface for perpendicular sliding were higher than in parallel. This was hypothesized to be due to a greater extent of cyclic viscoelastic deformation of the surface during perpendicular sliding, and was confirmed by use of a thermal model and experimental observations of stress-cycled PEEK.

Session 3E • Music Row 5

Commercial Marketing Forum III

8 – 8:30 am | Vanderbilt Chemicals

New Corrosion Inhibitors and Their Application in Engine Oils

Vincent Gatto, Vanderbilt Chemicals, LLC, Bradenton, FL

Vanderbilt Chemicals, LLC provides a variety of unique corrosion inhibitors to formulators across all segments of lubrication. It is widely known, however, that effective use of any corrosion inhibitor requires a balanced formulation approach. To address some of these challenges the company is introducing a new series of corrosion inhibitors. Previously we discussed the application of these new products in industrial lubricants. In this presentation the benefits of these products for reducing copper and lead corrosion and their compatibility in engine oils will be discussed. The multi-functionality of these products can provide multiple solutions for formulations in many different applications.

8:30 – 9 am | Chevron Phillips Chemical Co.'s PAO Blending Matrix Tool: Simulations and Examples of How to Streamline Lab Blends

Ken Hope, Chevron Phillips Chemical Co., The Woodlands, TX

Synfluid® PAOs have been available for many years and bring specific property advantages that are a good fit for today's engine oil needs, now and even more so for the future. The low temperature, oxidative stability and low coefficient of friction performance properties of Synfluid® PAOs are well known. However, optimizing the many permutations for individual lubricant applications can present a laboratory challenge in time and resources. For instance, seeking low viscosity options for ULV engine oils and balancing Noack volatility and CCS viscosities can lead to a large number of laboratory blends. This presentation will focus on theoretical blends of different PAOs and explore alternatives to meet performance challenges to streamline future product development.

9 – 9:30 am | Sea-Land Chemical Company

Boot Scootin' Distribute

Jennifer Altstadt, Matthew Mapus, Sea-Land Chemical Co., Westlake, OH

Today's business climate is moving at a rapid pace with multiple ways to access information and gain knowledge about market dynamics, new technologies and the competition. In this presentation, Sea-Land will explain how they are building upon over 50 years of industry expertise, a strong ownership culture and long-standing relationships with customers and suppliers to evolve with the changing environment and create value for their business partners. Great Experience. Better Life.

9:30 – 10 am | Lockhart Chemical Company

Products, Service, Capability & Flexibility – The Keys to Longevity

Darren Mylie, Lockhart Chemical Co., Flint, MI

In a competitive marketplace where companies are tasked with cost savings, risk reduction, new product innovation and doing more with less, Lockhart Chemical plays an important role in meeting the needs of existing and future customers. Lockhart will share an overview of product offering, technical and commercial services and flexibility when meeting the customer's needs.

10 – 10:30 am | Break

10:30 – 11 am | Croda

New Products from Croda and an EcoLabel Update

Scott Davis, Croda, New Castle, DE

Croda continues to innovate and has introduced two new products. Priolube 3997 is a high viscosity, oxidatively stable ester viscosity modifier. It was designed to replace less oxidatively stable ester thickeners. It is also designed to replace bright stock where it can provide a lubricity benefit and VI increase verses formulations that use bright stock. The Perfad 3500 Series of organic friction modifiers were designed for manual transmission, 4T motorcycle engine oils. Friction modifiers have not been extensively used in wet clutch motorcycles in the past because of the negative impact that they may contribute to clutch feel. The Perfad 3500 Series are unique because they reduce steel on steel friction while maintaining clutch friction. This provides the opportunity to make a lower friction oil that provides fuel economy and emissions reduction without having a negative impact on clutch feel. An update on the recent changes to the European EcoLabel scheme will also be provided.

11 – 11:30 am | King Industries Inc.

High Temperature Performance with NA-LUBE® KR Alkylated Naphthalenes

Ross Dworet, King Industries Inc., Norwalk, CT

The global industrial fluid market continues to push toward extended life fluids that improve equipment life and production uptime to provide optimal operation efficiency. Refined base stocks and synthetics have made significant strides in satisfying industrial demands, but there are limitations to these fluids' performance. NA-LUBE® KR alkylated naphthalenes impart desirable high-performance properties to lubricants where longevity and durability matter. NA-LUBE KR alkylated naphthalenes have an intermediate aniline point, good VI, outstanding hydrolytic stability, and exceptional thermo-oxidative stability. NA-LUBE KR-019 and the food grade analogue, NA-LUBE KR-029FG, clearly demonstrate high temperature performance when formulated into lubricant systems. Through data generated by bench tests, unique in-house tests, and field cases, NA-LUBE KR delivers a clear benefit in reducing varnish formation, removing existing deposits, and improving the life of a severely stressed fluids.

11:30 am – Noon | Münzing

Next Generation 3D Siloxane Technology Based Defoamers

Justin Mykietyn, Münzing, Bloomfield, NJ

It is well known that 3D siloxane based defoamers provide the most persistent foam control in aqueous metalworking fluids. However, increasing demands on MWFs now require even more effective defoamers/antifoams. Münzing launched new lines of defoamers based on the next generation of 3D siloxane technology to meet this need. The superior defoaming and excellent persistence of the new FOAM BAN HP900 series and FOAM BAN 1800 series will be discussed.

Session 3F • Music Row 4

Metalworking Fluids III

Session Chair:
Emil Jon Schnellbacher, Lawrence Technological University, Allen Park, MI

Session Vice Chair:
Jill Myers, The Timken Co., North Canton, OH

8 – 8:30 am | Effect of Different Organic Acids in Organosilanes/Organic Acids Combo Systems as Stain/Corrosion Inhibitors in Metalworking Fluids for Application on Aluminum Alloys

Hoon Kim, Joana Costa, John Pentangelo, BASF/Chemetall, New Providence, NJ

Last year, we introduced the novel organosilane/fatty acid combo systems as new stain/corrosion inhibitors for aluminum alloy applications. The innovative inhibitor technology consists of two parts: 1.) organosilane as the head group anchoring to the metal surface, 2.) non-polar hydrocarbon chain of the fatty acid functioning as barrier to prevent corrosive chemicals from accessing the metal surface and to minimize undesirable hydrolysis of the silane functional groups. Those two parts are combined either by ionic amine/acid salt formation or covalent amide bond linkage. Along this line, we investigated the effect of various acids. Diverse organosilanes/acids combo systems were prepared using different acids and applied in metalworking fluids. The anti-corrosion/staining performance was evaluated by metal compatibility test in combination with ICP elemental analysis. From this study, we were able to confirm the excellent performance and unique versatility of the novel inhibitor systems.

8:30 – 9 am | Substitution of Zinc Stearate in Cold Extrusion Processes

Wilhelm Rehbein, LANXESS Deutschland GmbH, Mannheim, Germany

Cold extrusion is a kind of massive forming process for the mass production of hollow or solid parts in one or more stages. Zinc stearate is widely used for the lubrication of aluminium cold extrusion processes. Because it is a powder it has to be applied on the slugs by a tumbling process. This leads to a strong dust formation that can cause respiratory irritation; the thermal decomposition of Zinc stearate forms toxic and irritating vapours. The paper presents the development of a new lubricant based on renewable raw materials. This lubricant is free of zinc or other metals. Because it is a waterbased suspension, it can be applied easily and without any dust formation. Tests which were done at the Institute for Metal Forming Technology of the University of Stuttgart and at a specialised company under manufacturing conditions prove that the new lubricant is an adequate replacement for zinc stearate powder.

9 – 9:30 am | A Dynamic Industry Needs Dynamic Additives – State of the Art Wetting Agents

Kai Wirz, Evonik Nutrition & Care GmbH, Essen, Germany

Machining processes in the modern industry become faster every day. During the metalworking process, the time for the liquid to get in contact with the solid surface is very short. Because of this trend the coverage of the surface, also called wetting, must be very dynamic in order to fulfill newest technology requirements. Additionally some wetting agents also improve other parameters like swarf removal and foam knockdown. The presentation will give an insight into the mechanism and application of state of the art wetting agents and how these can help to improve the overall performance of your system.

9:30 – 10 am | High-Oil Emulsions for MWFs Based on Heavy Naphthenic Base Oils

Thomas Norrby, Linda Malm, Nynas AB, Nynashamn, Sweden

In this study, a novel range of high-oil emulsions based on high viscosity naphthenic base oils have been created, for the purpose of building a better understanding of the properties of heavy high-oil emulsions. The naphthenic base oils utilized were Nynas T 110, Nynas T 400, Nynas T 600 and a paraffinic SN 500 (Group 1). A generic non-ionic emulsifier system based on readily available sorbitan-derived emulsifiers was employed. Emulsifier blends covering a range of HLB values were utilized to prepare a number of model emulsion systems. The emulsion particle size, and the emulsion stability as a function of time, was determined by static light scattering experiments utilizing a Malvern 3000E MasterSizer equipment. Application were heavy emulsion is found are for example mineral wool insulation spinning, and in heavy metal forming operations and metal hot rolling.

10 – 10:30 am | Break

10:30 – 11 am | Foam Mechanism for Soluble Oils

Robert Golden, Pilot Chemical Co., Cincinnati, OH

Foam is an inherent property of agitated liquids, and it is of profound interest for metalworking fluids. The stability of the generated foam depends on several factors. Surfactants are a class of compounds that can stabilize foam, and the surfactants that are used to stabilize oil in water emulsions have been blamed for the stabilization of foam in the emulsions. The generally accepted model for foam formation of surfactants at the air/liquid interface is typically invoked for the foaming of soluble oils and semi-synthetics. Recent evidence calls into question this model, and a new model for foam that does not utilize surfactants at the air/liquid interface will be proposed. Understanding the mechanisms of foam stabilization can help formulators develop inherently lower foaming systems which would require less dependency on antifoams and defoamers.

11 – 11:30 am | Evaluation of Performance Properties of Slideway Lubricants

John Hogan, The Lubrizol Corp., Wickliffe, OH

Modern machine tools require slideway lubricants that minimize the potential for stick slip phenomenon during operation of the machine tool. Although there is no industry standard test to measure the frictional properties of slideway lubricants, many oil marketers rely on the Fives Cincinnati OEM approval. Fives Cincinnati relies on their internal Stick-Slip Test to demonstrate frictional performance. In this study, an adaptation of ASTM D2877-70 using the conditions of the Fives Cincinnati Stick-Slip Test is used to evaluate the frictional properties of slideway lubricants. We will present statistical analysis of our data that shows this test is suitable to differentiate frictional performance of slideway lubricants.

3F

11:30 am – Noon | Vulnerability and the Art of Metalworking Fluid Formulation

Nicole Clarkson, Soraya Krasczcyk, Clayton Cooper, ANGUS Chemical Co., Buffalo Grove, IL

The act of opening something typically creates a certain level of vulnerability. Open wounds create opportunity for infection. Open doors a chance for theft. When we apply this concept to a formulation, the potential vulnerabilities include performance, contamination, bad parts, lost business, and more. Simply said, there is potential for failure. So, why open anything? Why create a potential for failure? Because fear of failure prevents us from taking important steps forward. This presentation focuses on areas of uncertainty, of vulnerability and, most importantly, discovery. Obtaining fluid longevity when biocides are altered. Reaching corrosion control at low treat rates. Achieving staining across multiple alloys. By highlighting performance characteristics in a multitude of formulary platforms, it becomes clear that discovering something new doesn't always mean the use of a new product, but sometimes the application of a known product to create a new opportunity.

Session 3G • Music Row 3

Tribotesting I

Session Chair:
Oluwaseyi Ogunsola, Shell Oil Company, Houston, TX

Session Vice Chair:
Alex Lin, Northwestern University, Evanston, IL

8 – 8:30 am | In-Situ Measurement of Friction by Causing Nano-Scale Slip with a High-Powered Ultrasonic Wave

Rob Dwyer-Joyce, Xiangwei Li, University of Sheffield, Sheffield, United Kingdom

In this study we have investigated the use of high-powered ultrasonic waves to cause slip at an interface and so determine the friction coefficient in-situ. A high-powered shear wave when it strikes an interface can cause asperity slip. This results in non-linearity in the reflected signal that can then be used to deduce whether slip has taken place. If we know the shear stress caused by the wave and the normal pressure we can deduce the friction coefficient. Experiments were performed on a dry rough aluminium contact. Waves of increasing amplitude were incident on the interface and the non-linear reflected components recorded. Laser-vibrometry was used to estimate the deflection and shear stress induced by each wave. The most powerful waves caused deflections of 70 nm and shear stresses of 4 MPa. The experiments were conducted with a range of contact pressures. In this way we were able to build a map of when slip occurred and the local friction coefficient.

8:30 – 9 am | Development of a Test Procedure, System and Process for High Throughput Tribological Testing of Used Oil Samples as Part of a Condition Monitoring Protocol

George Plint, Phoenix Tribology Ltd., Kingsclere, Select, United Kingdom

With a used lubricant, chemical elements associated with the original additive package can still be present and detected, but we do not know which compounds they are associated with and thus whether they work as originally intended. Furthermore, we do not know whether the used lubricant contains additional compounds that inhibit the action of the original additive chemistry. It is only possible to assess the tribological response by empirical observation. It follows, that if such observations are to be integrated with an established condition monitoring process, the cost per data point for the physical test must be comparable with the cost of the analytical data. The development of a test procedure, system and process for generating friction and wear data, with a target price of not more than $20 per data point and throughput of 200 samples per day, with the potential for process automation, is discussed.

9 – 9:30 am | Florescent Nanoparticle – Assisted Probing of Fluidic Behavior on 3D Printed Surfaces

Peter Renner, Hong Liang, Wei Dai, Texas A&M University, College Station, TX

Textured surfaces have shown enormous promise in reducing friction, although the mechanisms of fluidic behavior on such surfaces have yet to be fully understood. In this research, we developed a methodology to prove fluidic behavior of water on a shark-skin-like textured surface using florescent nanodiamond particles. The surfaces were 3D printed with various morphological characteristics. Using the nanoparticles and principals of fluid dynamics, we were able to generate a viscosity map. Results reviewed that the fluid drag was reduced due to the low-velocity gradient.

9:30 – 10 am | Contamination Impact on Gas-Phase Synthesized Graphene and Graphene Platelets Effectiveness as a Lubricant Additives in Bio-Derived Oil and PAO

Gordon Krauss, Albert Dato, Harvey Mudd College, Claremont, CA, Matthew Siniawski, Loyola Marymount University, Los Angeles, CA

Suspended graphene additives (.01 and .1% by mass) are investigated as friction and wear modifiers. This work compares gas-phase synthesized graphene to graphene platelets suspended in rapeseed oil and poly alpha olefin (PAO) during pin-on-disk testing. Previous studies have found a benefit to processing of flat graphene such that it is morphologically changed into a "crumpled" shape. Gas-phase synthesized graphene is crumpled as a result of the gas synthesis process. As a result, GSG consists of folded and randomly oriented graphene structures. The wear and sliding friction of a 52100 steel ball counter-surface is measured during testing in neat rapeseed oil and PAO, in different concentrations. Significant difference is noted with respect to wear at even the low concentrations. Friction differences are not apparent over the conditions tested. The influence of water contamination on wear and friction are observed in both oils with different types of graphene (GSG and platelet).

10 – 10:30 am | Break

10:30 – 11 am | The Influence of Operating Parameters and Viscometrics in Energy Efficiency in Rolling Sliding Concentrated Contacts

Mukesh Dubey, R. Mahapatra, Ajay Harinarain, Sarita Seth, Sarita Garg, Deepak Saxena, S.S.V. Ramakumar, Indian Oil Corporation Ltd., R&D Centre, Faridabad, Haryana, India

Overall efficiency of engines is affected by the frictional losses between several components (bearings, valve train, cam followers-camshaft, piston ring liner, etc.) working under different combinations of rolling sliding and varying loads. The function of the lubricating oil used in this is to ensure proper film formation to reduce the wear and friction existing in these engines. The losses in energy due to friction between these components could be as high as 10-15%, which offers a good potential for reduction by careful optimization of the design of the oils used in these engines. This study evaluates the effect of various lubricant formulations on the frictional characteristics under different regimes of lubrication simulated in bench top tribometers. Experimental test were performed on ball on disc configuration at wide range of temperature, operating parameters in rolling /sliding concentrated contact to study the energy efficiency aspect of the different lubricants.

11 – 11:30 am | Testing the Wear Life of Sandpaper

Kenneth Budinski, Bud Labs, Rochester, NY

The original purpose of this study was to compare the useful life of a new type of sandpaper on a metal support with the traditional silicon carbide and alumina sandpapers. However, the study ended up in the development of a new test method to rank the life of fixed abrasives. he abrasive material (sandpaper, etc.) to be tested is affixed to a slowly–rotating horizontal platen and the desired rider (wood cylinder in this case) is reciprocated on the rotating platen. Rider (wood) wear volume is the test metric and it is determined from length change of the rider. These studies indicated that the feature sandpaper had lower removal rates than the competitive sandpapers. However, tests were continued to compare silicon carbide with alumina, and to rank the "sandability" of a spectrum of woods: soft pine to ebony.

11:30 am – Noon | Insoluble Residues from Thin Films of Hydraulic Fluids and Engine Oils after Prolonged Heating

Svajus Asadauskas, Dalia Brazinskiene, Asta Griguceviciene, Center for Physical Sciences and Technology, Vilnius, Lithuania

Hydraulic fluids, engine oils and many other lubricants often produce thin films, which reside on heated surfaces. Severe exposure to air, humidity, combustion gases and other aggressive factors, makes degradation proceed much faster than in bulk oils. In this study certified high quality engine, hydraulic, gear and generator lubricants were tested as 200 µm thick films for up to 3,000 hrs at 120 to 150°C. After heating, which resembled micro-oxidation, severely degraded thin films were soaked in fresh lubricants to observe whether nearly solid residues still dissolve in original oil. Results showed major differences among the same type of commercial lubricants. Such thin film methodology can predict long-term ageing tendencies for basestocks, formulated lubricants and biofuel blends, greatly reducing the need of expensive testing. The project COSMOS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 645405.

Session 3H • Music Row 2

Fluid Film Bearings III

Session Chair:
Ilmar Santos, Technical University of Denmark, Lyngby, Denmark

Session Vice Chair:
J. Bouyer, Institute Pprime, Futuroscope Chasseneuil Cedex, France

8 – 8:30 am | Dynamic Performance Analysis of Hydrostatic Oil Film Considering Oil Pad Damage Under Extreme Working Conditions

Zhifeng Liu, Yongsheng Zhao, Qiang Cheng, Congbin Yang, Institute of Advanced Manufacturing and Intelligent Technology, Beijing University of Technology, Beijing, China

Hydrostatic oil pad is an important part of heavy-duty hydrostatic turntable. Due to the influence of long-term and heavy load, hydrostatic oil pad will be damaged to a certain extent. Oil pad damage will directly affect the load-bearing safety of oil film, thus affecting the performance of turntable. In this paper, the influence of the loading position of the workpiece on the inclination of the turntable is studied when the damage degree of the oil pad is coupled with the loading force. Considering the influence of inclination and rotational speed on the stability of oil pad, the influence of the damage degree of oil pad on the fluctuation of oil film is studied. Finally, a method is proposed to find the maximum reasonable rotational speed under the condition of determining the tilt angle of the turntable, and the oil film fluctuation is controlled within the preset range.

8:30 – 9 am | TEHD Analysis of Dynamic Behavior of a Planetary Star Gearbox Journal Bearing Due to Misalignment Torque

Balint Pap, Alexis Dombek, Patrice Gedin, Ludwig Biadalla, Safran Transmission Systems, Colombes, France, Michel Fillon, Institut Pprime, Chasseneuil-du-Poitou, France

In the transmission systems of next generation civil aircraft gas turbines, to achieve a high reduction ratio in a relatively small volume planetary gearboxes may be used. In planetary gearboxes a sun gear transmits its power to the planet carrier through (usually 3-5) planet gears mounted on the fix planet carrier, which transmit then the power to the ring gear. A journal bearing is often used to support the planet gears on the shafts of the carrier. During the aircraft maneuvers (pitch, yaw and roll) a gyroscopic torque is generated by the rotating planet gear, which is balanced by the pressure of the fluid film bearing. The present work details the influence of the gyroscopic torque on the various planet gears at different positions (relative to the load direction) in the reduction gearbox. The simulations are performed under hydrodynamic (HD), elastohydrodynamic (EHD) and thermoelastohydrodynamic (TEHD) regimes.

9 – 9:30 am | Comparison of CFD-FSI and Reynolds Equation Based Approaches in the Prediction of Dynamic Coefficients of a Convergent-Divergent Slider Bearing with an Eeforming Liner

Troy Snyder, Minel Braun, University of Akron, Akron, OH

Paramount to the design of the rotordynamic systems in which elastomer-lined bearings are installed is characterization of the static load-carrying capacity and the dynamic properties of the bearings. In this paper, the convergent-divergent slider geometry is investigated as the template geometry for a single-stave within a full elastomer-lined, marine bearing. Linearized dynamic coefficients are predicted using a CFD-FSI approach with a linear elastic model for the bearing liner and compared to a Reynolds equation (hyrodynamic lubrication) based model coupled to a thin elastic liner model for the bearing deformation. A parametric study varying sliding speed, perturbation frequency, liner material, and liner thickness of the bearing is performed to reveal differences in the predicted dynamic coefficients.

9:30 – 10 am | Thermal Characteristics of a Vertical Hydrostatic Guideway System with Ballscrew Drive of Precision Milling Machines

Hua-Chih Huang, National Kaohsiung University of Science and Technology, Kaohsiung City , Taiwan, Wen-Hao Yang, Hiwin Technologies Corp., Taichung, Taiwan

This paper simulates the thermal characteristics of a vertical hydrostatic guideway using ANSYS/Fluent in precision milling machine applications by considering the oil film friction of hydrostatic bearings in operational feed speed and heat generation in ballscrew nut. A thermal characteristic experiment of this vertical guideway system at different feed speeds will be tested to verify the correctness of boundary conditions of Ansys model. Temperature rise in individual hydrostatic bearing due to different supply pressure, feed speed, and oil viscosity will also be analyzed, and the thermal displacement of the center point of worktable can be predicted in case of thermal deformation.

10 – 10:30 am | Break

3H

10:30 – 11 am | Numerical and Experimental Investigations of the Performance of Pocketed Thrust Bearings Operating in Micro-Electro-Mechanical Systems

Peng Wang, Thomas Reddyhoff, Daniele Dini, Francisco Profito, Imperial College London, London, United Kingdom

The high frictional torque and sever wear has prevented the development of Micro-electro-mechanical systems (MEMS) that include sliding and rotating parts for a long time. Micro-scale hydrodynamic bearings are potential to provide low friction and reduce wear at the small-scale contacts, but appropriate design is required to optimize its performance. In this study, a pocketed 1-mm diameter hydrodynamic parallel thrust bearing has been investigated both numerically and experimentally with concentration on factors affecting its load capacity and friction coefficient. Results from experiments on a custom-built MEMS tribometer demonstrated that the small-scale bearings can bear applied load up to 0.05 N and the measured friction coefficient is below 0.05 when lubricated with low viscosity liquids. An FVM model considering mass conservation, inertia effects of liquids and capillary pressure is developed to better understand the bearing working mechanism and optimize the bearing design.

11 – 11:30 am | Determination of Inducer Shape Influence on Acoustic Levitation Characteristics

Bartosz Bastian, Michal Wodtke, Gdansk University of Technology, Gdansk, Pomorskie, Poland

The paper presents results of theoretical research for near field acoustic levitation. The principle of the system is based on a rigid vibrating plane which under specific frequency and amplitude of vibration allows for the creation of an air squeeze film supporting a freely suspended body. CFD-based calculation method allowed for consideration of the interaction between the air film flow (described by Navier-Stokes equations) and the dynamic of the levitating object. The goal of the research was to study the effect of the levitating object shape on near-field levitation parameters. Comparison between various dimension ratio of rectangular and oval shape was investigated. The impact of dimension ratio on load carrying possibilities is presented. Results of analysis (e.g. film thickness, oscillation amplitude) allow to determine the most favourable excitation parameters for the specific shape of the levitating object

11:30 am – Noon | Multiphase Fluid-Structure Interaction (FSI) Computational Fluid Dynamics (CFD) Analysis of An Elliptical Journal Bearing with Varying Supply Rate: A Look at Starvation

Cori Watson, Minhui He, Roger Fittro, Houston Wood, University of Virginia, Charlottesville, VA, Scan DeCamillo, Kingsbury, Inc., Philadelphia, PA

Fluid film bearings are used in a wide range of rotating machinery to support a load during rotation. This study looks at starvation of fixed geometry two pad elliptic journal bearings using multiphase computational fluid dynamics (CFD) and fluid-structure interaction (FSI) techniques. The bearing is modeled in ANSYS CFX using FSI to find the loaded journal position and convection boundary conditions are used between the solid and the lubricant; deformation is ignored. The supply pressure is varied and starvation is analyzed through the pressure, thermal and oil volume fraction distributions. The results show that the shape of the starved region does not match the "straight line" assumption of many thermoelastohydrodynamic (TEHD) codes. The results also show that the elliptical bearing modeled is always somewhat starved regardless of supply pressure. Finally, the influence of starvation on minimum film thickness, peak temperature and peak temperature location are also discussed herein.

Session 3I • Cumberland 1/2

Engine & Drivetrain I

Engine Tribology, Surface Sciences

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

Session Vice Chair:
Min Zou, University of Arkansas, Fayetteville, AR

8 – 8:30 am | DD13 Liners – Batch Consistency and Scuffing Initiation

Peter Lee, Carlos Sanchez, Jose Starling, Southwest Research Institute, San Antonio, TX

The DD13 scuffing test was developed as part of the new PC-11 oil specification. It uses the Detroit Diesel 12.8L in-line 6 diesel engine running with controlled batch liners and uncoated top rings. The test operates at 1800rpm throughout the test at 50% load for 30hrs before stepping to 100% load for the remainder of the test. If the engine scuffs, it normally scuffs not too long after the higher load set point is reached. However, repeatability of the test is dependent upon the liner batch. This presentation will explore the differences found in the liner batches and these differences may be driving the test.

8:30 – 9 am | Real-Time Wear Mapping of a 2.0L Turbocharged Gasoline Direct Injection Engine

Peter Lee, Craig Wileman, Gregory Hansen, Southwest Research Institute, San Antonio, TX

A 2.0L turbocharged direct injection gasoline engine was disassembled, measured and parts irradiated to create measureable radio nuclides. The engine was then reassembled and operated through a range of test conditions in an engine test cell. As the engine was operated, the lubricant was pumped through a radio nuclide detector to measure, in real time, the wear taking place in the engine. This presentation will discuss the results obtained from this work.

9 – 9:30 am | Effect of Surface Textures on Fuel Economy

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

Micro-surface textures have been used in seals successfully since early 2000s. Application attempts to automotive engines to improve fuel economy have been attempted. Despite friction reduction demonstrated at the bench test level, engine performance data have been elusive. One of the issues is how to measure friction reduction of a single engine component in an engine test, while there are many sliding components operating at the same time. Other parameters such as temperature, engine built, duty cycle, tolerance etc all affect the final fuel economy. This study uses an disassembled engine and fabricate textures on most of the sliding surfaces. Then ran engine fuel economy test in an engine chassis dynomometer to measure fuel economy, which was measured by metered fuel pump and by tail pipe carbon analysis and balance. Results of such tests will be reported in this presentation.

9:30 – 10 am | Experimental Research on the Tribological Performance of Laser Textured Cylinder Liner

Bifeng Yin, Bo Xu, Hekun Jia, Huiqin Zhou, Xin Kuang, Jiangsu University, Zhenjiang, China

Due to the hydrodynamic effects of surface texture on improving lubrication property of sliding surfaces, it has great application potential in the Cylinder Liner-Piston Ring (CL-PR) system. In this research, the Laser Surface Texturing (LST) technology is used to process micro-dimples (diameter 50 m, deepth 8 m; area ratio 10%) on the cylinder liner surface. Then by conducting the reciprocating friction tests on a friction-

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wear tester, the instantaneous friction force of ring/liner pair is measured. The testing results indicate that laser texturing liner could reduce the friction force, especially the peak friction value around the stroke ends of CL-PR under different lubrication conditions. Compared with the honing processed liner, the average friction coefficient of the laser textured liner can be reduced effectively under hydrodynamic lubrication state, while the average friction coefficient decreasing rate narrows under mixed lubrication state.

10 – 10:30 am | Break

10:30 – 11 am | A Comparison of Tribosystems, Wear Mechanism and Lubricant Effects in Silent and Roller Timing Chains

Ramoun Mourhatch, Shelby Skelton, Seyedeh Mahboobeh Hosseini, Chevron Oronite LLC, Richmond, CA

Silent and roller timing chains are the two most common torque transfer elements between the crankshaft and the camshaft in modern IC engines. While silent chain consists of a series of link plates, connected by pivot pins, the roller chain consists of a series of connected journal bearings that actuate as they enter and leave the sprockets. Wear in both types of chains results in chain elongation and engine timing deviation. The presence of soot in modern passenger car engines due to widespread adoption of gasoline and diesel turbocharged direct injection technologies can lead to accelerated chain wear. The purpose of this study is to map the tribosystems and lubrication regimes in both types of timing chain and establish the primary wear mechanisms in each case. For that end, the authors analyzed silent and roller timing chains from controlled engine tests. The effects of material (e.g., coatings) and lubricant parameters on wear rate and mechanism were examined for each system.

11 – 11:30 am | Friction and Wear Investigations on Chain Joints of Timing Chains

Andre Becker, Sauer Bernd, Institute of Machine Elements, Gears, and Transmissions, University of Kaiserslautern, Kaiserslautern, Germany

The lifetime of timing chains is determined by the wear in the chain joints. Due to contact forces and sliding motion, the pin and the bush of the chain joints are worn out. The influences on the chain wear are highly complex, from basic aspects like the chain geometry and the lubrication up to the surface treatment. In order to investigate these influences systematically, a home-made test rig, the so-called chain joint tribometer, was developed and realized. This tool allows for friction and wear investigations on one single chain joint. Therefore, the real contact situation is reproduced using batch production components. The load curves, in particular the contact force and the relative motion, are determined from a MBS model of a real chain drive and applied to the test chain joint with highly dynamic actuators. The chain joint Tribometer is presented together with different measurement methods and results from wear and friction investigation.

11:30 am – Noon | Real-Time Measurements of Piston Ring and Liner Lubrication in a Marine Diesel Engine Using Ultrasound

Xiangwei Li, Henry Brunskill, Rob Dwyer-Joyce, Leonardo Centre for Tribology, Sheffield, United Kingdom, Matthias Stark, Winterthur Gas & Diesel, Winterthur, Switzerland

The lubricant film thickness between the piston ring and the engine liner is a critical parameter that has a significant effect on operating efficiency. Breakdown of lubrication film results in metal-metal contact and scuffing. This can result in severe damage on interior surface of liner and reduce engine efficiency. Real-time monitoring of liner lubricant film and detection of scuffing would facilitate how operating parameters affect engine performance at the critical location. A non-invasive ultrasonic measurement system has been implemented on a test engine to monitor the lubrication in-situ. Longitudinal and shear polarised sensors were mounted on the liner at Top Dead Centre. Low-frequency ultrasound was transmitted to strike the contact interface between engine liner and piston rings. Test results found the returning signals changed with engine operating conditions which suggests that lubrication characteristics can be monitored in real-time using this ultrasonic tool.

Session 3J • Cumberland 3

Nanotribology III

Session Chair:
Izabela Szlufarska, University of Wisconsin, Madison, WI

Session Vice Chair:
Philip Egberts, University of Calgary, Calgary, Alberta, Canada

8 – 8:30 am | Block Copolymer Nanoparticles Prepared via Polymerisation-Induced Self Assembly for Use as a Friction Modifier in Motor Oils

Liam Pratt, Rob Dwyer-Joyce, Steve Armes, University of Sheffield, Sheffield, United Kingdom

Poly(stearyl methacrylate)-Poly(benzyl methacrylate) (PSMA-PBzMA) diblock copolymers were synthesised via RAFT dispersion polymerisation in mineral oil by a one-pot protocol. These copolymer chains self-assemble in situ to produce sterically-stabilised spherical nanoparticles with the soluble PSMA acting as the stabiliser block and the insoluble PBzMA forming the nanoparticle cores. Stribeck curves obtained via MTM (0.5 wt%, 100°C, 10-2500 mm s-1, 35 N) show that 20-60 nm diameter nanoparticles lower the friction coefficient across all rolling speeds compared to mineral oil alone, with a 46% reduction being achieved in the boundary lubrication regime. Unlike most friction modifiers, no 'running-in' period was required. This suggests a 'nanoparticle entrapment' mechanism, rather than the thin film mechanism that characterises most friction modifiers. If this is correct, it may indicate a universal lubrication mechanism.

8:30 – 9 am | Scale Dependent Tribological Behavior of Steel on MoS_2 Co-Deposited Commercial Lubricants with Macroscopic and Nanoscale Contacts

Peter Serles, Tobin Filleter, The University of Toronto, Toronto, Ontario, Canada, Guillaume Colas, Institut FEMTO-ST, Besançon, France, Aurélien Saulot, INSA Lyon, Lyon, France

While many commercial solid lubricant coatings are able to boast superlubricious properties, the reliability and fundamental understanding of their tribological performance including wear, third-body creation, and velocity accommodation remains largely unknown. Macroscale tribometers are able to best replicate application conditions but offer a limited understanding of the evolutionary nature of the lubricant response [1]. By matching the macroscale contact conditions to the nanoscale using friction force microscopy with custom steel-beaded cantilevers, high-resolution application-specific testing has been achieved. In the present study, three commercial 1 µm thick MoS_2 co-deposited solid lubricant coatings have been tested on macroscale and nanoscale tribological testers with contact diameters of 2 mm and 200 nm, respectively. It was found that coefficient of friction does not change across scales while wear characteristics and third body circuit scale proportionally to the contact size.

9 – 9:30 am | Experimental Investigation of Friction and Wear Behavior of 52100 Steel Against Nano-Coated Mild Steel Subject to Refrigerant Lubrication

Zulfiqar Khan, Muhammad Bhutta, Bournemouth University, Bournemouth, Dorset, United Kingdom

Refrigerants have significant impact on friction and wear behaviours of interacting components in several industrial applications such as compressors. Refrigerant industry has been proactive in terms of introducing new and environmentally friendly refrigerants as a response to major environmental concerns arising from previously employed thermo-fluids. Hydrofluoroethers (HFEs) are promising environmentally friendly refrigerants with good thermodynamic properties. HFEs have zero ozone depleting potential and a lower global warming potential as compared to previous generation of refrigerants. Apart from having the knowledge of the thermodynamic properties of a thermo-fluid, it is imperative to fully understand the tribological properties of thermo-fluids as lubricants in tribo-systems within the context of sustainable development. This paper presents a study of friction and wear properties of Nano-coated interacting parts with HFEs as lubricants.

9:30 – 10 am | A Direct Experimental Link Between Atomic-Scale and Macro-Scale Friction

Nikolay Garabedian, David Burris, University of Delaware, Newark, DE

While it is well-established that fundamental atomic-scale interactions govern the friction coefficients and wear rates observed macroscopically, atomic scale and macroscale friction coefficient measurements are quantitatively disconnected for reasons that remain unclear. Macroscale friction is insensitive to external factors like environment and material, while nanoscale friction coefficients can vary from extremely large to extremely small. We propose to begin bridging this knowledge gap by bridging the length scale gap between nano and macroscale tribometry. We will describe how we modified these methods to enable friction coefficient measurements of a model system involving single-crystal MoS2 under the same conditions using instruments traditionally used to probe nanoscale and macrioscale friction. Eliminating this experimental 'dead-zone' between nanoscale and macroscale measurements will provide the means for when 'nanoscale' friction becomes 'macroscale' friction and why.

10 – 10:30 am | Break

10:30 – 11:30 am | Invited Talk: Nanotribology of Tunable Polymer Coatings

Marina Ruths, University of Massachusetts-Lowell, Lowell, MA

Structuring in polymer and polyelectrolyte films can be induced and controlled by modifying solution conditions or annealing procedures. These phenomena are of interest for controlling adhesion, friction, and lubrication of surfaces in biomedical applications. For example, changes in the solvent quality and the presence of multivalent ions in polyelectrolyte systems cause aggregation and strongly influence the normal and frictional forces between interacting layers. Some of these changes can be reversible upon changing the solution conditions and enable evaluation of the contributions to aggregation from solvent quality and electrostatic bridging of polyelectrolytes. To illustrate these phenomena, examples will be shown of structure formation observed with AFM and its effects on normal and friction forces as studied with the SFA.

11:30 am – Noon | Metallic Coating Characterization with Nanoindentation Measurements

John Despard, Matthew Brake, Rice University, Houston, TX

Nanoindentation measurements are an attractive approach for accurately characterizing the material properties of a test specimen. This is especially true for thin metallic coatings, which have become increasingly useful for electrical and structural component design in harsh and unpredictable environments. Yet, the design space of thin, metallic coatings remains largely in trial and error. The system properties of a coating and its substrate are not yet well understood. This body of work uses nanoindentation techniques to study the response of the coating/ substrate system with particular emphasis on the influence of coating thickness to system hardness and elastic modulus. These experiments are carried out on stainless steel 304 coupons coated with hard gold and electroless nickel of thicknesses ranging from 0.5µm to 80µm. Conclusions about the design specifications of these coatings for competent design and usefulness of the nanoindentation technique for study are discussed.

Session 3K • Cumberland 4

Environmentally Friendly Fluids I

Session Chair:
Brajendra Sharma, Illinois Sustainable Technology Center, Champaign, IL

Session Vice Chair:
Selim Erhan, ADM, Decatur, IL

8 – 8:30 am | Positive Effects of Mono-Unsaturation on Hydraulic Fluid Performance

Svajus Asadauskas, Linas Labanauskas, Center for Physical Sciences and Technology, Vilnius, Lithuania, Jean Couturier, Jean Dubois, Arkema, Europe, France

Basestocks from vegetable oils are vulnerable to degradation due to the abundance of double bonds. Nevertheless, mono-unsaturation might bring many positive aspects, such as high Viscosity Index, low volatility, good cold fluidity, biodegradability etc. In this study viscometric, oxidative and hydrolytic stability, vaporization, additive compatibility and other tests were carried out to compare mineral, vegetable and synthetic basestocks to systematically synthesized polyol esters and dibasic esters with or without unsaturation. Results show that highly mono-unsaturated esters, such as oleates, gondoates or erucates, approach the stability of synthetic basestocks with other properties being similar or better. Careful selection of basestocks can minimize the need for high performance additives and improve wear resistance. The project COSMOS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 645405.

8:30 – 9 am | Ecolabel 2018 and VGP2018 II – Changes and Challenges in 2019

Paula Vettel, Novvi LLC, Emeryville, CA

The EU Ecolabel specification is the premium approval to be obtained for environmentally acceptable lubricants (EAL). The EPA Vessel General Permit (VGP) 2013 requires that all ships over 79 feet use EAL lubricants in all ship-sea interfaces. EAL lubricants must meet requirements for biodegradability, non-bioaccumulation, low toxicity, and previously, renewable content for Ecolabel. Both Ecolabel and VGP have been renewed and updated in 2018. This presentation will review the updated information about these specifications and discuss the changes and challenges from the formulator's point of view.

3K

9 – 9:30 am | Soybean Oil: Lubricating Performance

Robert Brentin, Omni Tech International, Midland, MI

Soy-based lubricants is one of the oldest and newest categories. Vegetable oils were one of the first materials used to lubricate. New advances in chemical modifications and soybean agriculture are leading to more effective soy-based lubricants. Recent development of soybeans with an increased proportion of oleic acid and low content of polyunsaturated fatty acids provides an oil with higher oxidative stability. Soybean oil has high lubricity, a polar nature, high viscosity index, high flash point / low evaporation rate, and is biodegradable and non-toxic. These properties make it a favored candidate for use in passenger car motor oil, two-cycle engine oil, greases, cable lubricants, hydraulic fluids, and metalworking fluids while having an environmentally acceptable footprint. This presentation will discuss the performance factors that make soybean oil a leading lubricant material in the biobased and vegetable oil category.

9:30 – 10 am | Evaluation of Water-Soluble Polymers for Aqueous Lubricants

Erik Willett, Functional Products Inc., Macedonia, OH

Water-based lubricants reduce the need for petroleum derivatives and offer greater fire safety over hydrocarbon alternatives. The challenge with water arises from the low starting viscosity and its potential for freezing and evaporation. Six water-soluble polymer chemistries were evaluated for thickening efficiency and viscosity index improvement from ISO 22 to 680 in pure water. Evaluation was continued to screen for inherent corrosion inhibition, lubricity, water retention, and anti-freeze behavior in water. Drawbacks like haze, foaming tendency, and surface films were observed in certain chemistries which were mitigated through additives. Water soluble AW and EP additives were formulated into the polymer/water blends to identify useful additive chemistries and verify if polar polymers hinder the function of surface-active additives on metal surfaces.

10 – 10:30 am | Break

10:30 – 11 am | Performance Comparison of Hydraulic Oil Blends Made with Vegetable-Based Fluids – Evaluations of High-Oleic, Low-Oleic Vegetable Oils as well as a Mineral Oil Blend

Doug Adams, RSC Bio Solutions, Indian Trail, NC

The importance of Environmentally Acceptable Lubricants (EAL) has led to improvements in the quality of vegetable-based fluids. The base fluids used in this study are high oleic soy bean oil, low oleic soy bean oil, high oleic canola oil and a mineral oil blend. To determine the level of improvements, hydraulic fluids were made with an established additive combination in the commercially available base fluids previously described. These fully formulated hydraulic fluids will be evaluated using tests that are typically used to measure the quality of hydraulic fluids. Some of the performance characteristics of the fully formulated hydraulic fluids that will be evaluated include corrosion protection, RPVOT, Pour Point, Four Ball Wear, Water separation and air entrainment.

11 – 11:30 am | Bio-Based Base Oils for Performance Lubricants

Basudeb Saha, University of Delaware, Newark, DE

Synthesis of bio-based base oils for high performance lubricants are desirable for operation optimization, modular equipment, environmental ecosystems and future energy security. We have developed next generation enabling technology to produce bio-based base-oils from inexpensive, abundantly supplied, and sustainably sourced feedstock (non-food biomass, natural oils and/or waste cooking oils). Our tech - nology innovation, based on energy-efficient and atom-economic catalytic coupling and deoxygenation reactions, offers the flexibility to produce base-oils with tailored molecular architecture (carbon number, molecular size, branching, number of branching, and distance between branched chain) and tunable specifications for a wide range of existing high-performance applications. This presentation will illustrate the core technology innovation and specification comparison of products with those of commercial synthetic and mineral base oils.

11:30 am – Noon | Estolides – The Latest in High Viscosity Biosynthetic Base Oils

Jakob Bredsguard, Biosynthetic Technologies, Rancho Santa Margarita, CA

Estolides are an environmentally acceptable base oil that is sometimes referred to as a "biosynthetic." Over the last few years, they have gained recognition for their performance and environmental qualities, allowing lubricant companies to formulate quality products that are seen as environmentally friendly. They are synthesized from vegetable oils so they have high renewable content. They are also biodegradable and nontoxic, yet have strong performance characteristics. Recent developments in biosynthetic base oils have led to a high viscosity base oil (ISO VG 680) that is both bio-based and biodegradable. The product is based on the estolide technology giving the oil the expected high viscosity index and low volatility common to other estolide oils. The product is expected to be ideal for use in grease and gear oils, offering formulators a new quality option when developing performance and/or environmentally friendly products.

Session 3L • Cumberland 5

Lubrication Fundamentals III

Session Chair:
Jodie Nelson, American Refining Group, Inc, Bradford, PA

Session Vice Chair:
William Wyatt, Afton Chemical Corp, Richmond, VA

8 – 8:30 am | Towards a Fundamental Understanding of Organic Friction Modifier Additives

Sophie Campen, Janet Wong, Imperial College London, London, United Kingdom

Organic friction modifiers play an important role in reducing friction and wear in lubricated systems. To gain a fundamental understanding of organic friction modifier behaviour, it is necessary to investigate their friction and film-forming abilities. Organic friction modifiers adsorb onto surfaces forming self-assembled monolayers, however there is evidence that an applied shear stress can promote boundary film formation or alter the adsorbed film morphology. Here we combine friction-testing and adsorption experiments to better understand their behaviour. Quartz crystal microbalance with dissipation monitoring (QCM-D) is used to monitor organic friction modifier adsorption and atomic force microscopy (AFM) is used to probe the morphology of adsorbed and 'rubbed' friction films. Under certain conditions, friction modifiers exhibit very-low boundary friction for steel surfaces (friction coefficient < 0.02). A thin (< 2 nm) low-friction film is observed on the friction surface.

8:30 – 9 am | Research on Polyalkylene Glycols Superlubricity System

Wenrui Liu, Yuhong Liu, Tsinghua University, Beijing, China

Superlubricity with an ultralow friction coefficient is uneasy to achieve under macroscopic conditions. In this study, we broaden the scope of polyalkylene glycols (PAGs) superlubricity system with different molecular weights (MWs). Remarkably, the threshold concentration, where superior load-bearing capacity is achieved, for such superlubric behavior decreased with increasing MW. Both molecular-level

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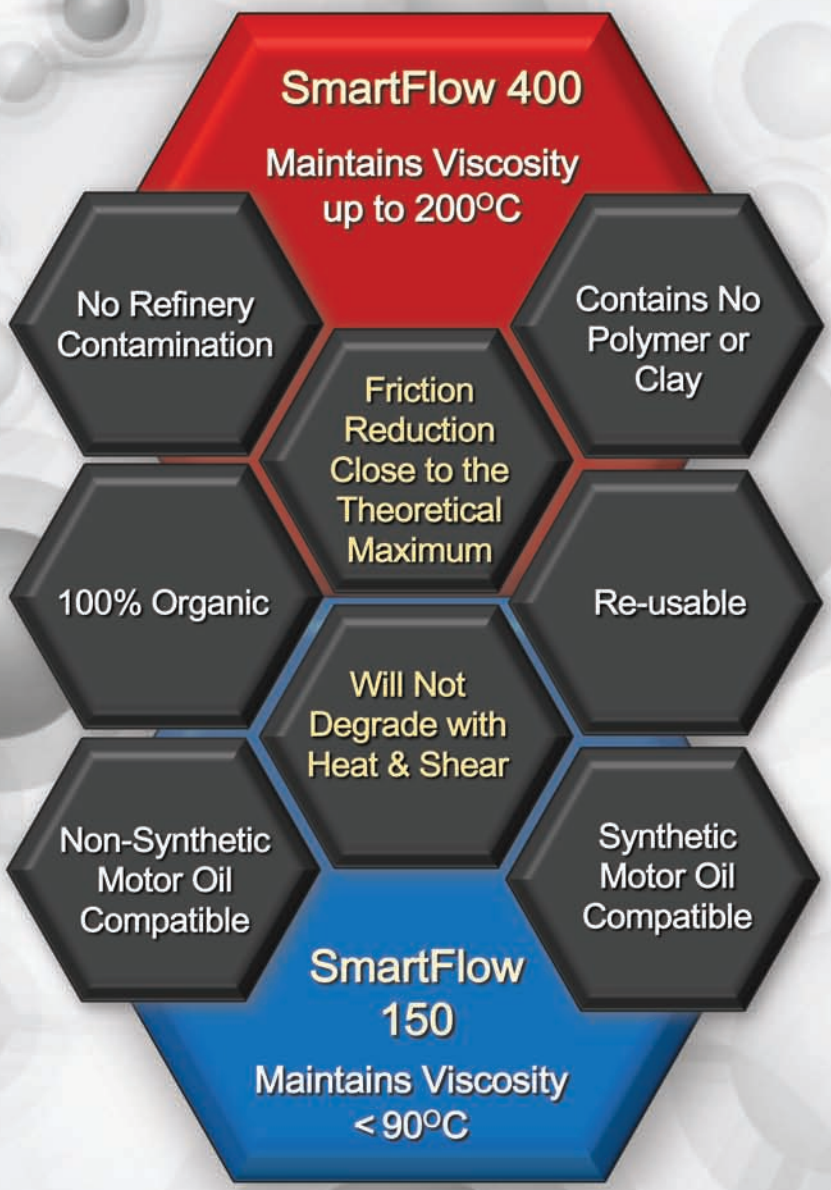

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adsorption and shear rheology of the lubricants are demonstrated to play a synergistic and complementary role in achieving superlubricity with PAG aqueous solutions. Furthermore, by introducing organic acids to such polymer aqueous solutions, the running-in time is decreased and the load-bearing capacity is significantly improved, while inorganic acids have no effects. This phenomenon is considered to be attributed to tribochemical reactions during the frictional process. This work enriches the investigation about tribological behaviours of water-based polymer lubricants at interface.

9 – 9:30 am | Influence of the Oil Additives and Their Molecular Structure on the Wetting and Friction Performance

Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Although it is obvious that wettability is an important characteristic in tribology, there is still no information on how additives and their different molecular structure change the wetting behaviour of oil, if at all. This work reports the influence of some simple organic friction modifiers like fatty acids, amides, alcohols and amines on static and dynamic wetting of oil. The influence of additive molecular structure was investigated by varying the number of additive polar head groups, chain length, polarity and saturation. The results show strong effect of all these additives properties on wetting of oil. Moreover, important effect on EHD friction is also reported and discussed.

9:30 – 10 am | Traction Curves and Rheological Properties of Some Lubricating Fluids

Robert Erck, Argonne National Laboratory, Lemont, IL

Traction curves were obtained for 20 fluids using a traction testing device which slid a disk against a ball. The traction coefficient was measured as a function of bulk fluid temperature and slide-to-roll ratio (SRR). Fluids were bio-based, PAO, mineral, polyol, polyalkylene glycol, and diester. Some fluids were fully formulated. The device used was a PCS brand "mini traction machine." At a mean speed of 3 m/s, and temperatures of 25-50 °C, full-film lubrication was attained. SRR values were + 60 to -60%. The 37 N load produced a maximum contact pressure of 1 GPa, and the conditions were such that in all cases, three regions of behavior were measured: near-linear regime for small SRR, increasing to a maximum traction coefficient max at 20 to 40% SRR, followed by a decrease in due to thermal effects in the contact area. Values of τ are correlated with regime and type of fluid and temperature.

10 – 10:30 am | Break

10:30 – 11 am | Effect of Different Running-In Stages on Fatigue Life of Mixed-Lubricated Circular Contacted Machine Elements

Hui Cao, Yonggang Meng, Tsinghua University, Beijing, China

An appropriate running-in process can prolong the life time of mechanical components. During running-in, the microstructure of contacting surfaces evolves continuously, the details of which have not been fully explored. In this study, the morphology evolution and the corresponding coefficient of friction variation of a ball-on-disc pair in sliding-to-rolling process were numerically simulated. Meanwhile, the fatigue lives of the disc with different running-in durations were calculated and compared. The results have indicated that the running-in state significantly affects the surface fatigue life while the influence on the spalling fatigue life is relatively slight. In addition, the running-in parameters were optimized for the friction pairs to be operated in different working conditions.

11 – 11:30 am | The Tribological Characteristics of Selected Base Oils under Oscillatory Sliding Conditions

Sipho Masilela, University of Pretoria, Pretoria, Gauteng, South Africa

Synthetic base oils are currently the most efficient commercially available base oils. However, their high cost creates a need for alternative cost effective base oils. This work reports on a comparative study of the effect of temperature on the tribological behaviour of five base oils using an oscillating ball-on-disc SRV4 tribometer at five different temperatures under a constant load of 150 N. The results demonstrated that in the mixed lubrication regime, the hydrocracked Group III+ base oil is a strong alternative for applications requiring PAO base oils, especially at 100 oC and 120 oC. At these two temperatures the Group III+ base oil gave the lowest values of the average coefficient of friction compared to the PAO, the mineral Group I and the hydro-processed Group III (Sample 1 and Sample 2) base oils. Both the PAO and the hydrocracked Group III+ base oils demonstrated better film stability and wear volume reduction compared to the latter, at all test temperatures.

11:30 am – Noon | The Role of Fatty Amine Chemistry in Friction Reduction

Toby Stein, Nouryon, Stenungsund, Sweden

The role of additives to enhance performance in lubricants is long established. This paper builds on one particular chemistry, that of fatty amines. We will look to discuss the history, the current role and the choices that are available. The process of evaluating fatty amines shows different levels of friction modification can be achieved and will be shown. Evaluations are carried out using MTM to try to establish structural performance relationships. A core part of the use of fatty amine chemistry is the central Nitrogen atom and the options this provides to synthetic chemists to create unique properties at a molecular level for any individual lubricant formulation or scenario. The paper will discuss how these transformations can be carried out and lessons learnt.

Session 3M • Cumberland 6

2D Materials I

Materials Tribology and Nanotribology Joint Session

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

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

8 – 8:30 am | Friction on 2D Materials: Friction Contrast between Graphene, MoS_2 and Graphene-MoS_2 Heterostructures

Mohammad Rasool Vazirisereshk, Ashlie Martini, University of California, Merced, Merced, CA, Han Ye, Mengqiang Zhao, A.T. Charlie Johnson, Robert Carpick, University of Pennsylvania, Philadelphia, PA, Zhijiang (Justin) Ye, Miami University, Oxford, OH

Two-dimensional (2D) materials, including graphene and molybdenum disulfide (MoS_2), are promising candidates for the next generation of solid lubricants in oil-free systems and as functional materials for flexible electronics. The adhesion and friction behavior of 2D materials is therefore important. To understand these properties, we characterized the nanotribological properties of graphene and MoS_2 monolayers, both transferred onto a single silicon sample, establishing three structures: graphene on silicon, MoS_2 on silicon, and a graphene on MoS_2

heterostructure on silicon. This approach enabled direct comparison between friction at different loads on these three surfaces using atomic force microscopy experiments and molecular dynamics simulations. The simulations reveal the origins of the friction contrast on graphene, MoS_2 as well as the graphene-MoS_2 heterostructure. Ultimately this investigation helps provide a comprehensive understanding of contact and sliding of 2D materials.

8:30 – 9 am | Interlayer Friction and Superlubricity in Single-Crystalline Contact Enabled by 2D Flake-Wrapped AFM Tips

Yanmin Liu, Tianbao Ma, State Key Laboratory of Tribology, Beijing, China

Interlayer friction between 2D materials and heterostructures is a promising probe of the physics in their interlayer couplings and superlubricity. We propose a TAMET method to fabricate various 2D flake-wrapped AFM tips and to directly measure the interlayer friction between 2D flakes in single crystalline contact. First, superlubricity between different 2D-flakes and layered bulk materials is achieved with the friction coefficient as low as 10-4. The rotation angle dependence of superlubricity is observed for friction between graphite layers, whereas it is not observed between graphite and h-BN because of the incommensurate contact of the mismatched lattices. Second, the interlayer lateral force map between ReS2 layers is measured with atomic resolution, showing hexagonal patterns, as further verified by theoretical simulations. The tribological system constructed here offers an experimental platform to study interlayer couplings and friction between 2D flakes and layered materials.

9 – 9:30 am | Pressure- Induced Friction Collapse of Graphite Flake Sliding on Muscovite Surfaces

Bingtong Liu, Jin Wang, Ming Ma, Tsinghua University, Beijing, China

In this paper, the dependence of friction on normal load for monocrystalline van der Waals (vdW) heterojunctions composed of microscale graphite flake and millimeter-sized mica are investigated. The experimental results show that the friction can be reduced by applying a normal load with the slope in a magnitude of -0.01 during both loading and unloading processes, which deviates from the Amonton law. The negative friction coefficient is robust at different temperatures. Mechanisms are revealed using molecular dynamics simulations. The results for normal load-induced friction collapse enriches our fundamental understanding about friction and offers a route to achieve nearly frictionless sliding interfaces.

9:30 – 10 am | Robust Microscale Superlubricity in Graphite/Hexagonal Boron Nitride Layered Heterojunctions

Yiming Song, Ming Ma, Quanshui Zheng, Tsinghua University, Beijing, China, Davide Mandelli, Oded Hod, Michael Urbakh, Tel Aviv University, Tel Aviv, Israel

Structural superlubricity is a fascinating tribological phenomenon, in which the lateral interactions between two incommensurate contacting surfaces are effectively cancelled resulting in ultralow sliding friction. Here we report the experimental realization of robust superlubricity in microscale monocrystalline heterojunctions. The results for interfaces between graphite and hexagonal boron nitride clearly demonstrate that structural superlubricity persists even when the aligned contact sustains external loads under ambient conditions. The observed frictional anisotropy in the heterojunctions is found to be orders of magnitude smaller than that measured for their homogeneous counterparts. Atomistic simulations reveal that the underlying frictional mechanisms in the two cases originate from completely different dynamical regimes. Our results are expected to be of a general nature and should be applicable to other van der Waals heterostructures.

10 – 10:30 am | Break

10:30 – 11 am | Raman Spectroscopy as an Effective Tool to Detect Interaction on 2D Material Interfaces

Xiang Zhou, Dameng Liu, Jianbin Luo, State Key Laboratory of Tribology, Beijing, China

By performing low-frequency Raman measurements and adopting a linear chain model, we obtain interlayer force constant in a new material – SnSe2. The lateral force constant is lower than many other 2D materials such as MoS_2 and black phosphorus. The same strategy is also used to study twisted MoS_2. We find that the vertical component of the force constant on twisted (incommensurate-stacking) interface decreases remarkably, and that thickness, which to some extent reflects rigidity, of the component layers may also affect the strength of interlayer interaction. The force constant we obtain is more of an intrinsic characteristic of the material than a measurement of frictional or adhesive force, but it helps deeply understand tribological phenomenon concerning interlayer interaction such as solid-state superlubriciy. Our method can act as a conventional method for measuring interaction on the interface in 2D materials, as well as their homo- or hetero-structures.

11 – 11:30 am | Friction Modulation on Graphene: Underlying Substrate, Atomic Roughness, Defects, and Beyond

Jun Liu, Chang Ye, Yalin Dong, The University of Akron, Akron, OH, Qunyang Li, Xi-qiao Feng, Tsinghua University, Beijing, China, Zengfeng Di, Chinese Academy of Sciences, Beijing, China, Wen Yue, China University of Geosciences, Beijing, China

It has been recognized that graphene offers excellent anti-friction and anti-wear properties. Being produced by exfoliated or epitaxial method, the friction behaviors of graphene are significantly influenced by the underlying substrate and structural defects in graphene that may develop during growth or processing. Using molecular dynamics simulation, we reveal that moiré pattern formed between graphene and supporting substrate modulates the lateral force, which arises from geometric undulation of graphene due to its different stacking states on the substrate. The presences of chemical adsorbents and vacancies increase friction in varying degrees. The Schwoebel barrier, the chemical reactivity, as well as the roughening induced by adsorbents contribute to the friction enhancement. We provides a friction-mechanism map that correlates frictional behavior to various atomic scale mechanisms, which is useful for understanding the nanoscale friction of graphene.

11:30 am – Noon | Eliminating Delamination of Graphite Sliding on Diamond Like Carbon

Yujie Gongyang, Tsinghua University, Beijing, China

Delamination is one of the major issues which cause the failure of two-dimensional layered-material based superlubric friction pairs. Using graphite mesas with single crystalline surfaces sliding on a diamond-like carbon film as an example, here we show experimentally that the delamination of graphite can be eliminated after proper annealing. With a combined approach of careful X-ray photoelectron spectroscopy analysis, force measurement and quantitative theoretical estimation, we find the variation in the chemical states of graphite edges and the desorption of water accounts for the absence of delamination. Our result provides a new concept for tuning the frictional properties of superlubric graphite mesas and the design of delamination-free layered-material based friction pairs.

Session 4D • Music Row 1

Wear II

Session Chair:
Chinpei Wang, Cummins, Inc., Columbus, IN

Session Vice Chair:
Gustavo Molina, Georgia Southern University, Statesboro, GA

2 – 2:30 pm | Effects of Unevenly Worn Cage Pockets on the Service Life of a Solid Lubricated Rolling Bearing

Rahul Dahiwal, Sascha Pörsch, Sauer Bernd, University of Kaiserslautern, Kaiserslautern, Rheinland Palatinate, Germany

Solid lubricated rolling bearings use a polymeric cage endowed with Molybdenum Disulfide (MoS_2) particles as a reservoir of lubricant, increasing their service life significantly. During the bearing's operation, solid lubricant from the cage is transferred onto the raceways replenishing the initial lubricant coating of the raceways. Experiments have shown that uneven wear of the individual cage pockets can occur that causes the pockets to possess different diameters. This results in an effect on the bearing's service life. To analyze the real wear process, a four-bearing-vacuum-test-rig is used. Cage pockets with intentionally enlarged pocket diameters of solid-lubricating material are considered. In order to understand the effects of enlarged pocket geometries on the bearing's dynamic, a multi-body simulation model (MBS) is utilized. Furthermore, the first outcome shows that an increase of the pocket diameter results in a decrease of the pocket wear and thus the lubrication interval.

2:30 – 3 pm | Modeling of Low Wear of Rough Disc in Sliding Contact with Flat Ring

Pawel Pawlus, Andrzej Dzierwa, Wieslaw Zelasko, Rzeszow University of Technology, Rzeszow, Poland, Rafal Reizer, University of Rzeszow, Rzeszow, Poland

The experiments were carried our using a ring-on-disc tribological tester under dry friction condition for a conformal contact at ambient temperature. The linear speed of disc was 0.27 m/s, the sliding distance was 320 m, the normal force was 210 N. Steel discs of smaller hardness (20 HRC) were put in contact with a steel ring of higher hardness (45 HRC). Disc samples were prepared using various machining processes in order to obtain various surface topographies. It was found that disc volumetric wear was proportional to standard deviation of surface roughness height. The average coefficient of friction was proportional to disc wear. In modeling of disc wear the contact of equivalent rough surface with smooth flat surface was analysed using a numerical FFT method. In each step wear was proportional to the contact pressure. High correlation was obtained between measured and simulated disc wear levels.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Impact of Wear Models on the Local Behavior of Railroad Brake Pad

Mathieu Renouf, University of Montpellier, Montpellier, France, Eric Chapteuil, Yves Berthier, INSA Lyon, Villeurbanne, France

Material used for railroad brake pad are usually composed of several constituents such as copper, graphite, etc. In view to optimize their tribological performance in terms of friction coefficient or wear rate, it is crucial to have an accurate view of their tribological behavior. Indeed, as experimental investigations are quite impossible on a real brake, numerical simulations appear as unavoidable to understand their local behavior. In this sense, a multi-physical approach based on the discrete element framework is proposed to account for, mechanical, thermal and electrical feature during the sliding of a brake pad shoe. Numerical samples derive from tomography snapshots obtained on real brake pad shoe. There are submitted to tribological solicitations and different wear models which represent different operating conditions. Their behavior is then analyzed and discussed according to the different local models used in the simulation.

4:30 – 5 pm | Surface Damage from Micro-Slip: Analytical versus F.E.M. Approach

Iyabo Lawal, Matthew Brake, Rice University, Houston, TX

The dynamic behavior at the jointed interface of structures produce complex loading that creates a unique tribosystem. A major contributor to surface damage comes from micro-slip events that can cause significant adhesive and/or abrasive wear of the interface. For mission critical sub-structures subjected to high-cycle fatigue events, this surface damage can affect structural stability and can lead to adverse dynamic performance. A comparison study of two modeling techniques for surface damage will be done to quantify the merits of each approach. The first approach uses statistical summation and contact mechanics principles. The second approach is based on a commercially available FEA tool. Both approaches will be validated with experimental data collected for 304 SS materials from sphere on flat tribology studies. The results will be used to continue development of a fretting fatigue modeling and will also help in understanding how experimental data can inform numerical models.

5 – 5:30 pm | Evolution of the Contact Interface: Towards the Introduction of a Tribological Circuit in a Multi-Scale and Multi-Physics Modeling

Vincent Magnier, Yassine Waddad, Philippe Dufrenoy, University of Lille, Villeneuve d'Ascq, France

In this paper, we propose a multi-scale and multi-physics numerical approach to the contact problem. Indeed, in a model representing a system, enrichment at the interface is proposed including roughness. At this interface, tribological evolution are integrated to model the mechanisms of wear, adhesion and trapping on the scale of roughness. This information is then reinjected into the macroscopic model leading to a large change in contact distribution over time. The strategy put in place is based on a theoretical enrichment of a finite element model allowing in addition to obtain a fast resolution. A comparison is made with a friction material having a flat surface.

5:30 – 6 pm | Wear Business Meeting

Session 4E • Music Row 5

Commercial Marketing Forum IV

2 – 3 pm | Afton Chemical Corp.

Afton Chemical's Key Driver Seminar: Pushing the Limits – The Pressures that Drive Hydraulic Fluids to New Heights

Ralf Leonhardt, Viktor Schuck, Bosch Rexroth Corp., Fountain Inn, SC, Brian Rhode, Afton Chemical Corp., Richmond, VA

The ever-increasing needs of hydraulics end-users are driving continuous improvement in hydraulic system design. Modern hydraulic systems are operating at higher temperatures, speeds, and pressures and are experiencing increased power to weight ratios. Hydraulic fluid is the lifeblood and must provide the vital elements needed to bring performance and protection to these complex systems. Please join us as we hear a leading OEM view on key drivers in hydraulic systems and fluids and how these are leading to new hydraulic fluid rating procedures.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Lanxess Germany GmbH

Additive Packages for Challenging Hydraulic Applications

Steffen Sandhoefner, Lanxess Germany GmbH, Mannheim, Germany

In addition to standard hydraulic specifications like the ASTM D 6158, high performance hydraulic fluids need to pass important OEM requirements. One example, well known since many years, is the Parker Denison HF-0 approval. Over time, the power density increased, and today, the performance requirements of modern hydraulic equipment and particularly mobile hydraulic traction drive systems often exceed the existing specification level. To close this gap, Bosch Rexroth established the RFT-APU-CL pump test with their latest revision of the RDE 90235 specification. This specification now represents the highest and most demanding challenge for fluid blenders as well as additive package suppliers. With the investment in an own RFT-APU-CL test rig LANXESS is now in the strong position to push the additive development to the new specification limits. First approvals for the premium hydraulic additive package segment are already achieved.

4:30 – 5 pm | Eastman Chemical

When and Why to Use Synergex™ Multifunctional Amine Additives for Metalworking Fluids

Caroline Johnson, Eastman Chemical Co., Kingsport, TN

5 – 5:30 pm | Evonik

DYNAVIS® Technology Propels Mine Operators into a New Era of Operating Economics – With Higher Profits and Lower Costs Performance Demonstration: Open-Cast Coal Mine Siberia, Russia

Lauren Zunner, Evonik Oil Additives, Horsham, PA

Hydraulic fluids are a critical component in the operation of mining equipment. DYNAVIS® technology ensures high efficiency and maximum performance, even under the adverse climate of Russia's largest coal-mining region. Simply changing to a DYNAVIS® formulated fluid opened up productivity gains of 8% more material moved per hour in the mine, plus a 4% reduction in fuel consumption. In this ultra-demanding environment, temperatures vary from -54° F in winter to +100° in summer and the DYNAVIS® fluid demonstrated superiority over conventional products by maintaining pump efficiency and achieving reductions in energy consumption. Sensors were installed to measure the production efficiency of one of the mine's toughest workers: a HITACHI EX1200 mining excavator. The test demonstrated a 10% rise in handling rates – a gigantic leap forward in efficiency for mine operators. DYNAVIS® technology delivers higher productivity in mining excavators, improves fuel efficiency, and boosts performance.

5:30 – 6 pm | BASF

New Non-Antagonistic Oil-Soluble Corrosion Inhibitor: IRGACOR® L 844

Alex Mannion, Meaghan McGuire, Ryan Fenton, Matthias Fies, Michael Hoey, BASF Corp., Florham Park, NJ

Corrosion inhibitors (CIs) and anti-wear (AW) additives are both chemically active and form films on metals. As such, they compete for surface access. Formulators must carefully balance the amount of each for optimal lubricant performance, thereby limiting their formulation options. One solution is to use CIs that are effective at low treat rates since there is less competition for metal surfaces. Alternatively, formulators can use CIs that are non-antagonistic with AW additives. BASF has developed IRGACOR® L 844, an oil soluble corrosion inhibitor for industrial lubricant applications that demonstrates both: non-antagonism with ashless AW additives and effectiveness at low treat rates. Industrial lubricants are required to perform in increasingly severe environments and IRGACOR® L 844 provides formulators unparalleled flexibility, particularly for long lasting ashless AW hydraulic fluids. IRGACOR L 844 is an easy to handle liquid and is not labeled as hazardous to human health.

Session 4F • Music Row 4

Metalworking Fluids IV

Session Vice Chair:
Jill Myers, The Timken Co., Nortth Canton, OH & Emil Jon Schnellbacher, Lawrence Technological University, Allen Park, MI

2 – 2:30 pm | A New Generation of Anti-Wear Solutions and Staining Inhibitors for Metalworking Fluids

Claude Hedoire, Solvay, Aubervilliers, France

Phosphate-esters are multi-functional additives providing anti-wear performance and staining inhibition. However the current generation of phosphate-esters has some limitations. They are quite foaming additives and they tend to generate soaps when hard water is used. Soaps help to control foam but leave deposits on metal surfaces and pipes that are sometimes difficult to remove. Besides they are toxic (causes serious eye damage) and eco-toxic (harmful to aquatic organisms). Solvay is actively working on developing new solutions for metal working fluids with enhanced performance and better classification. We will present a new generation composed of several new phosphate-esters providing the following benefits: anti-wear performance, staining inhibition, emulsion stability, low soap formation, foam control, low toxicity and eco-toxicity. We will also present some formulation guidelines to get the best performance balance combining these new phosphate-esters.

2:30 – 3 pm | Application of Predictive Safety Screening Tools in GHS Labeling and TSCA New Chemical Notifications: A Small Company Perspective

Pamela Spencer, ANGUS Chemical Co., Buffalo Grove, IL

Strong initiatives are underway to move from animal to non-animal test methods to evaluate and classify chemical hazards. For example, under the new Lautenberg Chemical Safety Act (LCSA), unless EPA restricts a PMN substance, it is required to make an affirmative finding that the substance is not likely to present an unreasonable risk of injury to health or the environment before non-exempt commercial manufacture can begin. In doing so, EPA must consider using non-animal test methods first to fulfill information needs. As a small company, with limited toxicology expertise, we have created a modified stage-gate process to inform early GHS classifications to guide safe handling/disposal of new chemicals while improving the successful outcome of a PMN under LCSA. The approach incorporates a well-defined, tiered use of new approach methodologies (NAMs) to provide early screening level safety information that can serve as a model for other small chemical companies.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Boundary Lubricant Additive Response Comparisons on Aluminum Alloys Using Twist Compression Tests (TCT)

Ted McClure, Sea-Land Chemical Co., Westlake, OH

The Twist Compression Test (TCT) is a bench test that creates lubricant starvation under high pressures and sliding contact. It is used to evaluate the boundary friction performance of metalworking lubricants. This

presentation is an extension of work presented at STLE in 2017 and 2018. Increasing use of aluminum alloys is one practice automotive lightweighting initiatives can be supported. In this work, TCT is used to compare additive responses on a series of aluminum alloys. Boundary lubricants evaluated include polymers, esters, phosphorus bearing additives, and combinations. The aim is to provide useful data for formulation of lubricants for severe applications with these materials.

4:30 – 5 pm | Tribological and Anti-Corrosion Property of IF–WS_2 Particle in Aqueous System

Girija Chaubey, George Diloyan, Nanotech Industrial Solutions, Avenel, NJ

Nano size inorganic fullerene like tungsten disulfide (IF-WS_2) particles are known to be high performing friction reducer, anti-wear and extreme pressure additive for lubricant applications. They are not only suitable for conventional lubrication conditions rather can be used in extremely harsh conditions such as high/low temperature and high pressure. Surface engineering of the nanoparticles using appropriate surfactants/dispersion is important for stability and performance. This work present that IF-WS_2 base nano fluid can significant improve AW/AF/EP properties of synthetic and semi-synthetic metalworking fluids. Our extended experiments further showed that particles not only improve the tribological properties and cooling efficiency rather it reduces the corrosive properties of water as well. A systematic studies on anti-corrosion performance of particles was conducted. There is an ongoing research to explore the additional properties of IF–WS_2 particle along with tribological.

5 – 5:30 pm | Surface Integrity Analysis of the Hardened Bearing Steel Ground Under Different Cooling-Lubrication and Cutting Conditions

Rosemar Da Silva, Bruno Abrão, Mayara Pereira, Raphael De Paiva, Antonio De Mello, Federal University of Uberlandia, Uberlandia, Minas Gerais, Brazil, Emmanuel Ezugwu, Air Force Institute of Technology, Kaduna, Nigeria

During grinding process, most of mechanic energy is converted into heat, which is concentrated in the grinding zone. Because of low thermal conductivity of conventional abrasive wheels and small sections of chips, the workpiece is heated to high temperatures what can cause several thermal damages, thereby, compromising component surface integrity, especially of hardened bearing steels. Thus, cutting fluid is indispensable for cooling of the workpiece, as well as the correct coolant delivery form can represent economic and environmental benefits. This present work presents a study of the cooling-lubrication technique (conventional and MQL) and cutting conditions in grinding of the hardened bearing steel. Surface integrity was evaluated in terms of surface roughness and texture of ground surfaces. Results showed that machining with the MQL technique provided the lowest roughness and more uniform texture.

5:30 – 6 pm | Tribological Approach of Grinding Stainless Steel with Semi Synthetic-Based Cutting Fluid

Rosemar Da Silva, Mayara Pereira, Bruno Abrão, Antonio De Mello, Federal University of Uberlandia, Uberlandia, Minas Gerais, Brazil, Alisson Machado, Pontifícia Universidade Católica do Paraná – PUC-PR, Curitiba, Paraná, Brazil, Rodolfo De Oliveira, Saint-Gobain do Brasil Produtos Industriais e para Construção Ltda, Sao Paulo, Sao Paulo, Brazil

Tribological analysis in grinding process is very important to understand chip formation and wear of abrasive wheel, thus to guarantee manu - facturing of components free of thermal damages and to achieve the highest machining efficiency. Since grinding requires very high energy input per unit of volume of material removal, if cutting parameters are not proper selected, workpiece will be subjected to thermal damages, what can adversely affect its functionality. In this work, quality of surfaces of a martensitic stainless steel was evaluated in terms of surface rough - ness, Ra and Rt parameters. SEM images of the ground surfaces were also obtained. Tests were carried out with white aluminum oxide wheel, two radial depth of cut values and with a semi synthetic-based coolant. Results showed that the highest roughness values as well as more concentration of adhered material and deeper grooves on the machined surfaces were found after grinding under severest cutting conditions.

Session 4G • Music Row 3

Tribotesting II

Session Chair:
Gordon Krauss, Harvey Mudd College, Claremont, CA

Session Vice Chair:
Alex Lin, Northwestern University, Evanston, IL

2 – 2:30 pm | A New High Resolution Ultra-High Vacuum Tribometer Based on a Unique 6-Axis Force Sensor

Julien Fontaine, Matthieu Guibert, Thierry Le Mogne, Jules Galipaud, CNRS/Ecole Centrale de Lyon, Ecully Cedex, France, Thibaut Durand, Sophie Pavan, Ecole Centrale de Lyon, Ecully, France

Tribometry inside an ultra-high vacuum chamber is a useful tool, not only for fundamental understanding of solid lubrication process, but also to study the effect of environment on the tribological response of materials. For instance, MoS_2 or hydrogenated amorphous carbon coatings may exhibit friction coefficients below 0.01. However, the main challenge to measure such low friction coefficients inside a vacuum chamber is to have a perfect alignment between the actual tangential and normal forces applied on the contact and the corresponding measuring sensors. In order to solve this issue, we have developed a unique six-axis force sensor, allowing the measurements of all forces and torques between the two counterfaces. This sensor not only allows more accurate measurements, but it also permits various type of experiments. We have performed friction experiments at different temperatures, as well as indentation and scratching with a diamond tip, or fracture experiments.

2:30 – 3 pm | New Developments in Non-Invasive Ultrasonic Lubricant Film Thickness, Viscosity, and Cavitation Sensors – A Review of Case Studies

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

Active ultrasonics has been used for measuring lubricated interfaces for the last 20 years. It is only recently that the technology has really developed into a robust enough tool to be used in field applications. This body of work looks at the next generation ultrasonic lubricant sensors that are being employed in the field today to perform film thickness, viscosity, and cavitation measurements in-situ none-invasively. These installations are allowing engineers to understand the interfacial lubricant conditions in real-time thus allowing them to relate these conditions to operating parameters. Numerous case studies are given including numerous combustion engine, marine, power generation and aerospace applications.

3 – 4 pm | Exhibitor Appreciation Break

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4 – 4:30 pm | Scuffing Performance of Low-Viscosity Gear Oil Containing ZrO_2 Nanocrystals

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

Low-viscosity oils can reduce viscous drag losses and improve fuel economy at low temperatures, but require long-life additive technology that will protect surfaces at high temperatures. One application where low viscosity oil can be beneficial is the lubrication of the hypoid gear used in the rear axles of vehicles. In this work, a test protocol was developed based on gear calculations and guided by the ASTM D5182 standard, to evaluate different gear oil formulations and their ability to prolong scuffing. Lab-scale tribological experiments using a commercially available gear oil formulated with ZrO_2 nanocrystals were performed using the three ring-on-roller contact configuration to simulate the most severe region of gear tooth contact.

4:30 – 5 pm | Do You Count Water and Antifoam as Containment Particles or Not?

Thomas Canty, J.M. Canty Inc., Lockport, NY

The ASTM D8072 standard classification provides users of imaging the ability to report contamination data down to 1 micron without interference of water or antifoam droplets. It also reports water as a separate ppm value in the classifications. It also allows you to use the standard ISO 4408 codes with or without counts "soft" particles-water and anti-foam. This paper will present the case of how to move forward with the correct classification of particles and water while maintaining your historical data. The paper will explain how counting soft particle in the ISO 4406 or ASTM D8072 can lead to strange non-repeatable results since the mixing effect of the sample impacts the size and count of water and antifoam particles. In addition imaging technology lends itself to lab and inline analysis since it doesn't count bubbles.

5 – 5:30 pm | Low Temperature Testing of Greases

Kartik Pondicherry, Florian Rummel, Georg Krenn, Anton Paar GmbH, Graz, Austria

The current study focusses on a newly developed setup which enables tribological testing of greases over a broad range of temperatures, including temperatures as low as – 80°C. The greases were tested with the roller bearing attachment for the MCR Tribometer, which was equipped with a convection temperature device (CTD) for temperature control. The tests include extended Stribeck curves and break-away torque measurements, with the latter in both rotational and oscillatory modes. In addition to the tribological tests, rheological investigations were also carried out on the greases to find a correlation between rheological and tribological properties, especially in the static regime and during the transition of the system into the kinetic regime. Also, tests were carried out with the ball-on-three-plates configuration to be able to characterize the effect of greases at the contact with the help of surface analysis using microscopic techniques.

5:30 – 6 pm | Tribotesting Business Meeting

Session 4H • Music Row 2

Materials Tribology III

Session Chair:
Alex Lin, Northwestern University, Evanston, IL

Session Vice Chair:
Tomas Grejtak, Lehigh University, Bethlehem, PA

2 – 2:30 pm | Synthesis of a Self-Lubricating Composite by in Situ Formation of Graphene in Alumina Matrix During Ball Milling

Ashish Kasar, Arjun Manoj, Pradeep Menezes, University of Nevada-Reno, Reno, NV

In situ formation of graphene was carried out during wet ball milling to synthesize the self-lubricating .alumina based composite. Graphite platelets were exfoliated into graphene during ball milling in a liquid medium N, N-dimethylformamide (DMF) in the presence of micron size alumina balls. The milling was optimized at 300 rpm to avoid any destruction of graphitic sheet and promote the shear force dominating mill to exfoliate graphite. After milling, the products were characterized by FTIR to confirm the graphene formation. Subsequently, further alumina was added to prepare the composite with desired composition. Four different compositions were prepared by compaction and sintering at 1200°C in vacuum. Tribological properties of the prepared composites were measured by sliding tests against alumina ball. The addition of graphene resulted in lower friction. The friction and wear mechanisms are discussed.

2:30 – 3 pm | Out of Thin Air: In-Situ Formation of Diamond-Like Nanocomposite Films

Morgan Jones, Nicolas Argibay, John Curry, Michael Dugger, Ping Lu, David Adams, Brendan Nation, Barney Doyle, Mi Pham, Adam Pimentel, Curtis Mowry, Adam Hinkle, Michael Chandross, Sandia National Laboratories, Albuquerque, NM, Tomas Babuska, Lehigh University, Bethlehem, PA

Diamond-like carbon (DLC) is a well-known family of solid lubricants used in a variety of different applications and environments. Experiments demonstrated it is possible to tribochemically form DLC films on highly wear resistant nanocrystalline Pt-Au thin films in the presence of ambient hydrocarbons. Sapphire counterfaces were run against Pt-Au films at different loads in various environments for up to 100k cycles. During sliding, it was observed that thick (50-200nm) films of hydrogenated DLC with interspersed Pt-Au nanoparticles readily formed – as confirmed by Raman, elastic recoil detection analysis (ERDA) and TEM. The inclusion of Pt-Au nanoparticles in the DLC matrix implies that these films may exhibit favorable electrical properties as a possible low friction, wear resistant sliding electrical contact. Further investigations into the tribological properties of these films are employed to better understand formation mechanisms and other aspects of this DLC nanocomposite.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Tribological Behavior of Self-Lubricating Alumina Composites with In Situ Formation of Boron Nitride and Aluminum Borate

Pradeep Menezes, Ashish Kasar, University of Nevada-Reno, Reno, NV

The formation of self-lubricating in situ phase (BN) and utilization of this phase as effective reinforcements for alumina composite is investigated. Alumina, aluminum nitride and boric acid powder were used to synthesize the composite by conventional powder metallurgy route. Based on thermodynamic calculation, boron nitride and aluminum borate were formed during sintering. Friction and wear behavior of the

composites were measured by scratch tests against alumina and steel balls. The hardness of the composites increased with increase in aluminum borate concentration while the wear volume decreased. However, friction behavior was dependent on counterpart. More specifically, lowest coefficient of friction was observed for the composites with maximum BN and minimum aluminum borate concentrations against alumina ball. For the steel ball, a complete opposite trend was observed. The mechanisms responsible for friction and wear performance are discussed.

4:30 – 5 pm | Novel Composite Lubricant for Reducing Wear and Friction Under Extreme Contact Pressure and Long Duration

Arman Ahmadi, Jialiang Tang, Vilas Pol, Farshid Sadeghi, Purdue University, West Lafayette, IN, Kuldeep Mistry, The Timken Co., North Canton, OH

This paper describes the development of a new thermally cured polymer-graphene zinc oxide-based solid lubricant that reduces friction and wear significantly during the sliding wear of bearing steel under high contact pressure and long duration. The dry solid coating was made from a mixture of graphene, zinc oxide, and a specific binder including butanone and isopropanol, and then laminated on the contact surface of 52100 steel disks. Tribological properties of the coating was examined using a ball-on-disk apparatus with the Hertzian pressure of 1 GPa and a sliding distance of 500 m. After ~3000 cycles, the 15 µm thick coating of the lubricant created a significant reduction in the steel's coefficient of friction (approximately 82%) and wear loss compared to the uncoated surfaces. Scanning electron microscopy, energy dispersive X-ray spectroscopy, X-ray diffraction, and Raman spectroscopy were conducted to determine the topography and morphology of the coating and resultant wear scars.

5 – 5:30 pm | Graphite Nanoplatelets as Reinforcement in the Self-Lubricating Nanocomposites

Emad Omrani, Pradeep Menezes, University of Nevada-Reno, Reno, NV, Pradeep Rohatgi, University of Wisconsin-Milwaukee, Milwaukee, WI

In the present work, we studied the tribological properties of graphite nanoplatelets are studied in the Al composites. The coefficient of friction decreased in Al/GNP composites at 3% wt. of GNPs. Raman analysis shows the increase in the defects in the platelets after milling and wear tests. XRD and SEM analysis reveal the presence of GNPs at the worn surface after the tribology tests. The hardness of the Al/GNPs composites increased and the wear rate decreased with the increase of the content of GNPs up to 1 wt.%. Addition of GNPs above 1 wt.% resulted in the decrease of hardness. The addition of Al2O3 further decreased the wear rate of the composites and increased their hardness. Al/GNPs/Al2O3 composites had lower wear rate and more hardness as compared to Al/GNPs composites. The hardness increased from 74.8 HRB for pure aluminum to 94 HRB for Al/1GNPs/Al2O3 composite and the wear rate decreased.

5:30 – 6 pm | Tribological Considerations of Fouling in Air-Cathode Assisted Iron-Electrocoagulation (ACAIE)

Arkadeep Kumar, Nate Hohman, Ashok Gadgil, Lawrence Berkeley National Laboratory, Berkeley, CA, Siva RS Bandaru, Mohit Nahata, University of California-Berkeley, Berkeley, CA

Air-cathode assisted iron electrocoagulation (ACAIE) can remove contaminants such as arsenic in groundwater used for drinking or produced water in oil industry. However, long-term operation is challenging due to surface fouling. We have demonstrated efficient removal of arsenic below the maximum contaminant levels (MCL) in representative electrolyte compositions in short-term experiments. We present here long-term performance of ACAIE which remains unexplored in literature. When operated continuously over 100 hours, we see a steady reduction in H2O2 production which negatively affects contaminant removal. We present the tribological aspects of surface fouling of air-cathodes, which show deposition of Fe(III)(oxyhydr)oxides along with other salts, which we hypothesize as reason for reduction in chemical reactions for H2O2 production. We analyze the surface using contact angle (hydrophobicity), SEM, Raman, XRD, and XPS to investigate the nature of chemicals species causing fouling.

Session 4I • Cumberland 1/2

Engine & Drivetrain II

Engine Oil Additives, Testing

Session Chair:
Peter Lee, Southwest Research Institute, San Antonio, TX

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

2 – 2:30 pm | Effects of Ionic Liquids on Micropitting Behavior for Rear Axle Lubrication

Sougata Roy, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN, Lake Speed Jr., Driven Racing Oil, Olive Branch, MS, Michael Viola, General Motors, Pontiac, MI

In present study, ionic liquids (ILs) additized lubricants were studied for rear axle lubrication. Screening sliding tests were first carried out on a series of lubricants without and with ILs. The ILs' lubricating performance largely depends on their chemistry and oil formulation. Based on preliminary results, specific lubricant formulations were designed for the top-performing IL and then evaluated using a 2M-cycle rolling-sliding test protocol and the performance was compared against that of baseline commercial gear oils. The lubricants with this IL showed a significant reduction in friction coefficient, micropitting severity and wear volume. Another IL caught our interest by providing the best protection of micropitting but generating abnormally high vibration. The worn surface showed a combination of smooth and rough regions instead of uniform morphology as observed in other lubricants. Tribofilms produced by both ILs were characterized to understand the influencing mechanisms.

2:30 – 3 pm | Compatibility Between Ionic Liquids and Friction Modifiers

Weimin Li, Lanzhou Institute of Chemical Physics, Chinese Academy of Science, Lanzhou, China, Chanaka Kumara, Harry M. Meyer III, Huimin Luo, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Tribological performances of engine oils are largely dominated by the friction modifier (FM) and anti-wear additives (AWs) in the formulation. While oil-soluble ionic liquids (ILs) have recently demonstrated promising AW functionality, their compatibility with FMs is little known. Here, we report the latest results for several selected ILs when used together with two commercial FMs (OFM and MoDTC). Tribological results showed either synergistic or antagonistic effects depending on the IL chemistry of AWs as well as the contact materials. Aprotic ILs seemed to degrade the FMs' lubricating performance because of competition of interactions with the contact surface. In contrast, a protic ionic liquid showed strong synergistic effect with both the OFM and MoDTC, yielding ultra-low friction coefficients of 0.02-0.04 and very low wear rates under boundary lubrication. The mechanisms will be discussed based on surface characterization and modeling results.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Alloy-Dependence of the Antagonistic Effects between Soot and ZDDP

Jun Qu, Chanaka Kumara, Harry Meyer, Oak Ridge National Laboratory, Oak Ridge, TN

While soot, when suspended in an engine oil, is known to accelerate the wear of diesel and GDCI engines, there is a lack of consensus on the wear mechanism. Some recent literature reported antagonistic effects between soot and ZDDP but others did not. Our study found that the antagonism is alloy dependent. Four alloys, 52100 bearing steel, and A2, M2, and M50 tool steels in different rubbing pairs were tested in lubricants containing carbon black (CB, used as a soot surrogate) only, ZDDP only, and CB+ZDDP. Adding the CB alone to the oil increased the wear rate for all four steel alloys as expected. However, when ZDDP was introduced to the CB-containing oil, distinct wear behavior was observed: the three tool steels surprisingly suffered wear increases by 2-5 times, while the 52100 steel experienced a significant wear reduction. The major difference in composition is the high Mo contents in the tool steels, which is hypothesized to be vulnerable to CB-catalyzed tribocorrosion by ZDDP.

4:30 – 5 pm | Impact of Amine-Based Friction Modifiers on ZDDP Tribofilms

Joanna Dawczyk, Hugh Spikes, Imperial College London, London, United Kingdom

ZDDP additives are extremely effective at reducing scuffing and wear. However they can also increase friction in both boundary and mixed lubrication conditions. One way to address this problem is by the use of friction modifier additives, and in particular organic friction modifiers. However such additives have to be selected with care since it has been shown that some can damage ZDDP tribofilms. Here we present a study of the influence of a range of alkoxylated amines on the friction and durability of ZDDP tribofilms. It is shown that this impact is strongly dependent on molecular structure of the alkoxylated amine. The origins of this are discussed.

5 – 5:30 pm | New Organic Friction Modifiers for Wet-Clutch Motorcycle Engine Oils

David Gillespie, Croda, Cowick Hall, United Kingdom

Most high-performance motorcycles use a multiplate lubricated clutch. The main reasons for the lubrication are cooling, and to protect the steel and friction plates from excessive wear. Selecting a friction modifier for use in an automatic transmission fluid is not difficult, generally compounds that; raise the friction, ensure friction increases with sliding speed, and increase the lifetime of the fluid are chosen. However, for a motorcycle the choice becomes more complex. This is because the same reservoir supplies lubricant to the engine, transmission and gears. It is often the case that if a FM reduces friction in a steel/steel contact it will also reduce friction in a steel/friction material contact to at least some extent. We show that by the correct choice of organic friction modifier (OFM) it is possible to reduce friction in steel/steel contacts whilst maintaining efficient clutch performance.

Session 4J • Cumberland 3

Nanotribology IV

Session Chair:
Marina Ruths, University of Massachusetts-Lowell, Lowell, MA

Session Vice Chair:
Zulfiqar Khan, Bournemouth University, Bournemouth, Dorset, United Kingdom

2 – 3 pm | Invited Talk: Evolution of Tribological Contacts by Multiscale Simulations

Izabela Szlufarska, Zhuohan Li, University of Wisconsin, Madison, WI, Hubin Luo, Ningo Institute of Materials Technology and Engineering, Ningbo, China

At present there is a limited understanding of how the contact interface and the contacting materials evolve during sliding. This evolution may include chemical reactions, grain growth and refinement, evolution of dislocation networks, etc. All these phenomena can contribute to friction and wear. In this talk, I will discuss results of our multiscale simulations of materials evolution in sliding contacts. First, I will focus on chemical evolution of frictional interfaces, a phenomenon referred to as chemical aging. Specifically, I will discuss the combined effects of interface chemistry and surface roughness on the origin of static friction and on velocity dependence of friction. Secondly, I will summarize our developments of multiscale models of microstructural evolution of polycrystalline metals subject to mechanical loads. I will also discuss specific predictions from our models regarding the effects of grain size on mechanical response of metal alloys.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Nanotribology of Graphene in Hexadecane

Prathima Nalam, Behnoosh Sattari Baboukani, University at Buffalo, Buffalo, NY, Zhijiang (Justin) Ye, Nethmi De Alwis, Miami University, Oxford, OH

Two-dimensional materials such as graphene are new emerging friction-reducing additives in transmission fluids and oils to enhance the service life of sliding metallic components. Here in this work, we investigate the dissipative mechanisms of single–layer graphene sheet in presence of hexadecane solution (a major component in base oil). We employ atomic force microscopy to measure interfacial friction of mechanically-exfoliated graphene on silica substrate as a function of hexadecane immersion time. We observe intercalation and diffusion of non-polar hexadecane molecules between the two hydrophobic surfaces i.e., oxidized silica and graphene. Further, a non-linear dependence, i.e. a decrease and then increase, in friction and adhesion forces was measured as a function of immersion time. The origins for this behavior is explored by studying the quality of the contact (net pinning forces) and the conformational ordering of the confined fluid.

4:30 – 5 pm | Tuning Friction at Material-Nanoparticle-Liquid Interfaces with an External Electric Field

Jacqueline Krim, Biplav Acharya, Caitlin Seed, Donald Brenner, Alex Smirnov, North Carolina State University, Raleigh, NC

We report the use of electrophoretic forces to tune friction at material-nanoparticle-liquid interfaces with static or low frequency (0.6 – 50 mHz) electric fields. Negatively charged TiO_2 or positively charged Al_2O_3 nanoparticles suspended in water were repositioned relative to a planar platinum surface of a quartz crystal microbalance, which was then used to monitor friction levels. Active electro-tunable control of friction was achieved, and investigated as a function of electric field frequency. Kinetic effects corresponding to nanoparticle repositioning at the solid interface were discovered to occur at glass-like time scales. The studies

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also reveal that nanoparticles manipulated by electric fields can act as "cantilever-free" atomic force probes capable of "tapping mode" exploration of interfacial properties and nanoscale interactions in geometries inaccessible to optical and micromechanical probes.

5 – 5:30 pm | Sliding over 10,000 Times Faster: QCM Integrated Microtribometry to Probe Friction Fundamentals via Single-Crystal MoS_2

Nikolay Garabedian, David Burris, University of Delaware, Newark, DE, Raymond Wieser, Gabriel McAndrews, Brian Borovsky, St. Olaf College, Northfield, MN

Friction is independent of sliding speed according to Coulomb's Friction Law, and yet the Prandtl-Tomlinson model with thermal activation (PTT) predicts increasing friction with increasing sliding speed. This study lays the foundation for a collaborative effort to clarify speed-dependent friction, particularly for multi-asperity tribological interactions. We integrated a traditional microtribometer with a high-speed quartz crystal microbalance (QCM) system; the quartz crystal (~ 1 m/s, 0-50 nm displacement) was placed between the tribometer's lateral piezo stage (<0.1 mm/s, 0.01-800 µm range) and the sliding interface, so that by solely turning the QCM system on or off, friction experiments were possible at either high or low speeds without breaking the contact. This hybrid approach enables simultaneous and independent frictional characterization based on beam deflections and analysis of QCM resonance curves, which provide contact area, contact pressure and static friction data.

5:30 – 6 pm | Tribofilm Growth Mechanisms of ZrO_2 Nanoparticle Additives in a Fully Formulated Low Viscosity Gear Oil

Meagan Elinski, Zachary Milne, Andrew Jackson, Robert Carpick, University of Pennsylvania, Philadelphia, PA, Lei Zheng, Robert Wiacek, Pixelligent Technologies, Baltimore, MD

Low viscosity (LV) lubricants can improve automotive efficiency by minimizing viscous losses, but the resulting thinner lubricating films risk increased boundary contact. Zirconium oxide (ZrO_2) nanoparticle (NP) additives form tribofilms that offer surface protection against boundary contact. However, how co-additives in a formulated LV gear oil impact the growth mechanisms and frictional properties of the tribofilms is unknown. To understand NP interactions with other additives, a mini-traction machine (MTM) was used to evaluate tribofilm growth and traction performance over all lubrication regimes. As well, in situ atomic force microscopy (AFM) tribofilm generation experiments helped assess NP/co-additive interactions. Cross-sectional transmission electron microscopy (TEM) characterized the structure of ZrO_2 tribofilms. We will discuss how understanding ZrO_2 NP behavior in a LV gear oil addresses improving vehicle efficiency while maintaining component durability.

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Session 4K • Cumberland 4

Environmentally Friendly Fluids II

Session Chair:
Selim Erhan, ADM, Decatur, IL

Session Vice Chair:
Doug Adams, RSC Bio Solutions, Indian Trail, NC

2 – 2:30 pm | High Viscosity Esters to Boost Lubricant Performance Profile

Matthias Hof, Emery Oleochemicals GmbH, Monheim, NRW, Germany

Today, lubricant fluids require higher performance levels and broader applicability coming from the base stock system and the additives. Trends both in industrial and automotive applications are targeted towards future solutions that fulfill not only the technical performance level but also some environmental properties. Ester chemistry has been established as a very versatile technology to supply the formulating industry with products inheriting a broad usability. These products can be used as base stocks, co-solvents and solubilizers as well as additives. This paper provides an overview of new ester technology developments with high viscosity profiles. These new esters, synthesized for a broad application profile, address one of the most demanding applications in the industry: reduction of friction combined with equipment protection. An environmental profile superior to other technologies was also achieved.

2:30 – 3 pm | A Peculiar Observation of "Gelling" in Bio-Derived Phosphonate Ester

M. Cinta Lorenzo Martin, Oyelayo Ajayi, Argonne National Laboratory, Lemont, IL, Grigor Bantchev, Girma Biresaw, Rogers Harry-O'kuru, USDA-ARS-NCAUR-BOR, Peoria, IL

Because of their excellent tribological performance and environmental benefit, bio-based lubricants are subject of studies and development, as well as commercial activities. One of the common basefluids used in lubricant formulation is phosphonate ester. Recently, we observed gelling of palm oil derived ester during multiple viscosity measurements at 100°C. This observation is assumed to be linked to the presence of residual di-butyl phosphite used in the synthesis of the ester fluid. This gelling behavior can have an impact on the tribological performance of the final lubricant. Studies are in progress to assess the effect of this phenomenon on tribological performance of the fluid. It is imperative that development of bio-based esters should be done in manner to avoid the gelling phenomenon.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | New Class of Biolubricants Based on the Unique Fatty Acid Structure of Chinese Violet Seed Oil

Diana Berman, Asghar Shirani, Kent Chapman, University of North Texas, Denton, TX, Edgar Cahoon, University of Nebraska-Lincoln, Lincoln, NE

Our search for a better friction and wear reduction solution leads us to design a new class of bio lubricants that are safer, more environmentally friendly, and cost-effective in comparison to conventional ones. Recently, we discovered a unique structure of the oil extracted from the seeds of Orychophragmus violaceus. The oil demonstrated excellent lubricative properties and thermal stability. Specifically, coefficient of friction of the sliding steel pairs lubricated by Ov oil was 3-4 times lower than the one for traditionally used castor oil. In contrast to other plant-based lubricants, performance of the Ov oil is stable in the temperature range from room temperature up to 350C. This effect is attributed to the unique structure of the unusual long chain of dihydroxy fatty acids found in the oil. These findings provide a direct pathway for designing a new class of plant-based lubricants that are more effective and environmentally friendly than widely used synthetic oils.

4:30 – 5 pm | The Issues Facing the EAL Industry: The Stability of Oil and the Eco-Friendliness

Ashok Cholli, Polnox Corp., Lowell, MA

The key issue for lubricants based on bio-oil and bio-based products is to improve their oxidative stability for greater acceptance in the market. Oxidative stability of lubricants derived from bio-resources is inferior compared to fossil fuels and presents a key issue to the industry. Existing commercial antioxidants are not effective to stabilize plant/animal-derived biolubricants. There is a real need to look for a new antioxidant technology to make biolubricants as viable alternate products in a wide range of applications helping alternate sources for oil are sustainable and cost effective. A new class of safer antioxidants possessing superior oxidative resistance has been developed by Polnox to provide extended useful life of a wide range of materials. Compared to current industry antioxidants, these novel antioxidants significantly improve material protection, due to enhanced antioxidant activity and higher thermal stability. Their effectiveness will be illustrated with examples.

5 – 5:30 pm | Environmentally Friendly Fluids Business Meeting

Session 4L • Cumberland 5

Lubrication Fundamentals IV

Session Chair:
Brendan Miller, Chevron Oronite Co. LLC, Richmond, CA

Session Vice Chair:
Jodie Nelson, American Refining Group, Inc, Bradford, PA

2 – 2:30 pm | Fatty Acid Ionic Liquids (FAILs): Anion Effect on Physicochemical, Environmental and Tribological Properties

David Blanco, Noelia Rivera, Javier Faes, Paula Oulego, Rubén González, Antolín Hernández-Battez, University of Oviedo, Gijón, Asturias, Spain

Two novel ionic liquids (ILs), methyltrioctylammonium octanoate [N1888][C8] and methyltrioctylammonium esteareate [N1888][C18], were synthesized from natural sources using a salt metathesis reaction. One commercial ionic liquid, methyltrioctylammonium bis(trifluoromethylsulfonyl)imide [N1888][NTf2], was used as comparison sample. Traction measurements (at different speeds and temperatures) and film forming tests were made in a mini traction machine. Physicochemical and environmental characterizations of the ILs were performed. The [N1888][C8] exhibited the higher viscosity values; meanwhile, the [N1888][NTf2] had the best thermal behavior. No signs of corrosion on steel were found after 30 days of exposure. Both FAILs exhibited moderate biodegradability and [N1888][NTf2] was poorly biodegradable. Vibrio fischeri bacterial toxicity results showed that both FAILs were around 5 times less toxic than [N1888][NTf2]. [N1888][C18] IL showed the best antifriction and film forming properties.

2:30 – 3 pm | Exploration of Macroscale Superlubricity Enabled by Hydrated Ions

Tianyi Han, Chenhui Zhang, Jianbin Luo, Tsinghua University, Beijing, China

Here we demonstrate that macroscale superlubricity based on hydrated alkali metal ions (Li+, Na+, K+) can be realized for the first time under high contact pressure between the Si3N4 ball and sapphire disc. The ultralow friction coefficients of 0.005 are obtained under average contact pressure up to 0.25 GPa by a universal micro tribometer after a running-in period with acid solutions. The running-in stage can not only make the worn region smoother, but can generate a silica layer easy to shear which provides excellent boundary lubrication. The results show that the contribution of fluid effect is weak, and the realization of superlubricity relies more on hydration effect. The hydration superlubricity originates because hydration shells surrounding the alkali metal ions could generate the hydration repulsive force to sustain a large normal load and have a fluid response to shear simultaneously.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Lubricating Titanium Using a Vegetable Oil Containing Ionic Liquids

Haitao Duan, Wuhan Research Institute of Materials Protection, Wuhan, Hubei, China

Here we report the results of a recent study on titanium lubrication using a vegetable oil containing various ionic liquids (ILs). An oxygen diffusion (OD) case-hardening process was applied to Ti-6Al-4V to improve its wear resistance. Test lubricants were made by mixing four different ILs at treat rates around 1 wt.% into a vegetable oil. Ball-on-flat reciprocating sliding tests were carried out using a steel ball rubbing against the OD-treated Ti flat in the IL-containing oils. The addition of the protic IL improved the frictional behavior and wear protection but the aprotic ILs seemed to degrade the lubricating performance of the vegetable oil. It was observed that the aprotic ILs accelerated the ageing process (decomposition and oxidation) of the vegetable oil to various extents because of the ILs' catalytical effects.

4:30 – 5 pm | Impacts of Glyceride and Ionic Liquid Additives on Tribological Properties of Water-Based Drilling Mud

Min Ji, Shuhai Liu, Huaping Xiao, China University of Petroleum-Beijing, Beijing, China

Water-based lubricant additive of drilling mud plays a significant role in lubrication in the drilling operation. In this study, impacts of glyceride and ionic liquid (IL) additives on properties of water-based drilling mud were evaluated using a ball-on-disk tribometer. For glyceride, the experimental results indicate that carbon chain length, level of unsaturation, and polar groups of additives are three key factors which determine friction reduction and anti-wear behaviors of the drilling mud. Under the lubrication of IL, good tribological performance and improved load capacity with increasing concentration were obtained which is related to the adsorption of the tribofilm on the contact surface.

5 – 5:30 pm | Evaluation of Greases Used in Rail Journal Bearings

Kuldeep Mistry, Daniel Blasko, Alan Buchanan, The Timken Co., North Canton, OH

Pre-greased and sealed packaged double row tapered roller bearings are used commonly as axle journal bearings on railway vehicles. They directly affect the vehicle's running stability, and the performance of both freight and passenger car journal bearings are closely monitored in the field due to ensure high reliability. The service life of journal bearings is dependent on the type of grease, and the grease requirements vary based on the geographical site location. Rail journal bearings are expected to meet many requirements such as being able to operate in wide moisture and temperature ranges, as well as to maintain mechanical stability under high vibration conditions. This presentation shares results from an investigation of rail journal bearing grease characteristics using a variety of relevant industry standardized tests.

Session 4M • Cumberland 6

2D Materials II

Materials Tribology and Nanotribology Joint Session

Session Chair:
Kathryn Hasz, University of Pennsylvania, Philadelphia, PA

Session Vice Chair:
Nicolas Argibay, Sandia National Laboratories, Albuquerque, NM

2 – 2:30 pm | Run-In Behaviors of Solid Lubricants

John Curry, Brendan Nation, Adam Hinkle, Michael Dugger, Michael Chandross, Nicolas Argibay, Sandia National Laboratories, Albuquerque, NM, Tomas Babuska, Brandon Krick, Lehigh University, Bethlehem, PA

Run-in (initial friction) of solid lubricant films is one of the more stochastic aspects of the friction behavior over the life of a test. A wealth of factors such as environment, microstructure, contact conditions and tribo-chemical interactions can all play a role in the magnitude and duration of run-in. This talk focuses on how these various factors serve to alter run-in behavior on MoS_2 and DLC films through experiments in ambient and UHV conditions with accompanying molecular dynamics simulations.

2:30 – 3 pm | Modified Molybdenum Disulfide for Improved Wear Resistance in Antifriction Coatings

Melissa Mushrush, Gary Weber, DowDupont, Auburn, MI

Antifriction coatings based on polymeric resins and solid lubricants are commonly sprayed and cured/dried as thin coatings in applications to reduce friction in metal-metal contacts. Commonly used solid lubricants such as graphite and molybdenum disulfide (MoS_2) enhance the wear resistance of such coatings, but applications continue to demand improvement. A known wear mechanism for MoS_2 is its slow oxidation; for this reason MoS_2 is the lubricant of choice for space/ vacuum applications. In order to improve its stability towards oxidation, and thus increase the wear resistance of the antifriction coatings containing it, our group has chemically modified the MoS_2. A patent application is currently in draft, and once it has published this abstract will be replaced with fuller details showing the chemistry and the resulting stability and wear test data.

3 – 4 pm | Exhibitor Appreciation Break

4 – 4:30 pm | Superlubricity at Macroscale in Oil-Free Rolling/Sliding Contacts (STLE Early Career Award Winner)

Kalyan Mutyala, Jianguo Wen, Anirudha Sumant, Argonne National Laboratory, Lemont, IL, Gary Doll, The University of Akron, Akron, OH

Green technology initiatives call for the development of advanced lubrication strategies to minimize oil usage without compromising durability and reliability of components. Recent demonstration of atomically thin two dimensional (2D) materials ability to withstand high contact pressures at the tribological interface enabling low friction and wear opened new paths for exploration. Bearings and gears are critical components of a typical mechanical system such as a wind turbine and an automotive transmission system and subject to rolling/sliding at the interface. In this study, we demonstrated macroscale superlubricity in a rolling/sliding contact for the first time using material pairs that are coated with diamond-like carbon in an oil-free contact using 2D materials combined with nanodiamond as a solid lubricant under dry nitrogen environment. We have shown that achieving superlubricity (COF 0.003) is possible through formation of carbon rich superlubric tribolayer at the interface.

4:30 – 5 pm | Simultaneous In-Situ Formation of MoS_2 and Carbon-Containing Tribofilms

Manel Rodriguez Ripoll, Sara Spiller, AC2T Research GmbH, Wiener Neustadt, Austria, Bernhard Kohlhauser, Carsten Gachot, TU Wien, Vienna, Austria

We study the in-situ formation of MoS_2 during sliding in the presence of sulphur-containing extreme pressure (EP) lubricant additives. The MoS_2-containing tribofilms are formed via a tribochemical reaction between the EP additive and molybdenum-containing substrates. The chemical composition and morphology of the tribofilms was studied using Raman spectroscopy and transmission electron microscopy. The tribochemical mechanisms that lead to the formation of MoS_2 are discussed as function of EP additive concentration, lubricant temperature and counterbody material. Under certain testing conditions, the in-situ tribochemical formation of MoS_2 is accompanied by the presence of oil derived carbon tribofilms. Further, the synergies and antagonisms of the in-situ formed MoS_2 tribofilms with anti-wear and dispersants co-additives is addressed. Special emphasis is set on highlighting the similitudes and differences with MoS_2 tribofilms derived from lubricants containing MoS_2 nanoparticles.

5 – 5:30 pm | Calculations of Energy Barriers to Sliding Friction in MoS_2 in the Presence of Water and Oxygen

Adam Hinkle, Michael Chandross, Sandia National Laboratories, Albuquerque, NM

A model for the temperature-dependence of the friction in MoS_2 has been developed which relies upon the heights of energy barriers to characterize the molecular pathways of MoS2-flake sliding. Here we present atomistic calculations that show changes to these barriers in the presence of water and oxygen, two major environmental contaminants affecting the friction.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

5:30 – 6 pm | Tribological Properties of Different Nano-Sized Layered Double Hydroxides as Oil-Based Lubricant Additives

Hongdong Wang, Jianbin Luo, Tsinghua University, Beijing, China

Layered double hydroxides (LDHs) are a class of naturally-occurring inorganic minerals which are composed of divalent and trivalent metal cations. In this study, we chose a micro-emulsification method to synthesize the LDH nanoplatelets whose size was controlled by changing the crystallization time. As lubricant additives, their tribological properties in base oil were evaluated using a ball-on-disk reciprocating tribometer under three different loads. Under contact pressures of up 2.16 GPa, not only did the friction coefficient (COF) decrease by about 10% after nano-LDHs were added, but also the wear performance improved substantially. These improvements resulted from a protective tribofilm formed on the contact interface, as revealed by detailed surface and structure analytical studies. In particular, cross-sectional TEM images revealed that the larger size nanoplatelets (NiAl-24h), rather than the smaller ones (NiAl-6h), showed the best and most stable tribological performance.

6 – 6:30 pm | Material Tribology Business Meeting

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Session 4N • Legends A

4 – 6 pm | **Discussion Roundtables**

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

A scientific brainstorming and networking event is organized on the basis of discussion roundtables (DRTs) by the STLE Rolling Element Bearing Technical Committee, together with other technical committees. This event aims to encourage open discussions between experts of different disciplines on various topics of interest. The format of the DRTs is very fruitful to facilitate a creative atmosphere on complex topics' character and to find technical impulses by brainstorming. The topics are proposed by the table hosts themselves and are based on current interests. A typical property of DRTs is the writable table cloth to inspire the discussion as well as keep notes for subsequent discussions. The benefit of DRTs goes beyond the technical impulses. During the DRTs, the hosts will guide the discussion only and not give a lecture. Active participation, including experience sharing of each participant, is one of the main features of this event, providing a unique opportunity to connect and learn.

The Influence of Electrical Current and Water Intrusion on the Failure Mode of Surface Initiated Damage (SID)

Daniel Merk, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

In the case of surface initiated damage mechanisms (SID), such as a gray staining formation, there are existing influence factors which are known and described. There is, for instance, known a high influence by the particular bearing steel and heat treatment, or the surface quality, like the roughness. From different tests, there was observed the electrical current and/or the water intrusion as further potential influence factors on SID which are not described precisely yet. Are there known particular thresholds which are already defined in the view of their SID – risk?

How Big is the (Tribo-)Mechanical versus Chemical Influence on Bearing Steels (In the Sub-Surface) with Respect to Overall Performance?

Kenred Stadler, SKF GmbH, Schweinfurt, Germany

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.

Some authors suggest that certain oils will lead to hydrogen ingress and subsequent weakening of the bearing steel – real chemical influence due to certain additives. Others suggest that specific additives and/or reaction layer could induce high surface shear stresses promoting surface micro-cracks – (tribo-)mechanics, e.g. due to difference in friction as function of lubricant.

How to Eliminate the Root Cause of Wear as well as the Boundary Lubrication Regime

Kenneth K. Chao, Deere & Co., Cedar Falls, IA

Wear can be generated by different tribo-mechanisms. Is debris particulate contamination in liquid lubricant always bad?

Fluid Characterization Beyond Viscosity Measurement in EHD

Manfred Jungk, MJ-Tribology, Geisenheim, Germany

The pressure viscosity coefficient of a fluid in the EHD contact is either determined by film thickness measurements and subsequent calculation or by measuring viscosity pressure curves semi-statically. Several approaches were made to predict the viscosity based on its molecular structure. Monomeric friction, radius of gyration and free volume are some of the parameters that were looked at. Participants can brainstorm on other model parameters or experimental ways to determine the state of the fluid in the EHD contact.

How Can We Make Tribology Attractive and of High Quality in Terms of Content, Especially in Teaching?

Sven Wirsching and Sebastian Schwarz, University Erlangen, Erlangen, Germany

What are concrete measures to increase the attractivity of engineering studies, especially tribology, for young people and university students? The statistics published by the German Federal Statistical Office in 2018 show a decline in the number of first-year students. This trend will become even more pronounced in the upcoming years and is particularly noticeable in the technical field. This can be explained, among other things, by demographic change and contributes to the fight for talents. In order to maintain innovative strength, it is becoming increasingly important to generate highly qualified workers and inspire them to participate in STEM education. For instance, this can be achieved through interesting and motivating teaching.

Exhibitor Appreciation Hour and Evonik Raffle

Two hours of dedicated exhibit time will occur at this year's trade show: Monday, May 20 and Tuesday, May 21 from 3-4 pm in the Omni Nashville Hotel – Broadway Ballroom, with Evonik raffle at 3:30 pm. All other annual meeting activities will be closed during this time, and refreshments will be served! Come view the industry's newest products and technologies from more than 120 companies.