CONFERENCE PROGRAM

stle

Society of Tribologists and Lubrication Engineers

November 12-15, 2023

STLE Tribology Frontiers Conference

November 14-15, 2023

STLE Tribology & Lubrication for E-Mobility Conference

ROCK & ROLL HALL OF FAME/DOWNTOWN CLEVELAND, OHIO (USA)

A Co-Branded Event

November 12-15, 2023

Cleveland Marriott Downtown at Key Tower | Cleveland, Ohio (USA)

Technical Education. Career Development. International Networking.

Log on to **www.stle.org/annualmeeting** for registration and hotel information.

78th STLE Annual Meeting & Exhibition

Minneapolis Convention Center
Minneapolis, Minnesota (USA)

MINNEAPOLIS

78th STLE ANNUAL MEETING & EXHIBITION | **MAY 19-23, 2024**

Whether you work in the field or lab–in industry, academia or government–STLE's Annual Meeting has programming designed specifically for you. Please join your peers from around the globe for five unique days of technical training and industry education that could change your career.

Program Highlights:

- 500 Technical Presentations and Posters
- 13 Lubrication-Specific Education Courses
- Sustainable Power Generation Track including Fossil Fuels, Hydropower, Nuclear, Solar and Wind
- Discussion Round Tables – An Idea Exchange Event
- Electric Vehicles Track and Course
- Trade Show
- Commercial Marketing Forum
- Business Networking

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• connect • learn • achieve

Society of Tribologists and Lubrication Engineers
840 Busse Highway, Park Ridge, Illinois 60068 (USA)
P: (847) 825-5536 | F: (847) 825-1456 | www.stle.org | information@stle.org
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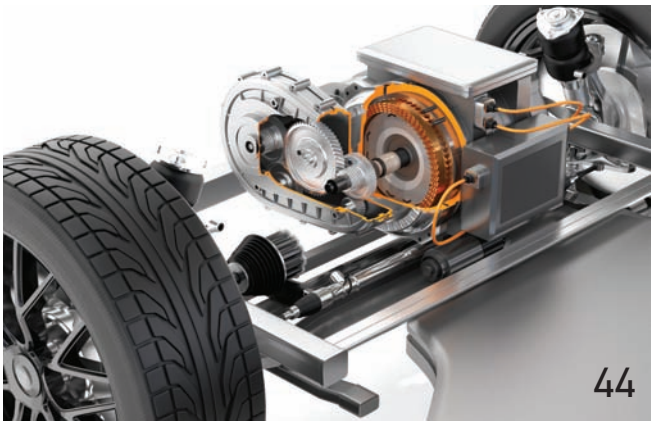

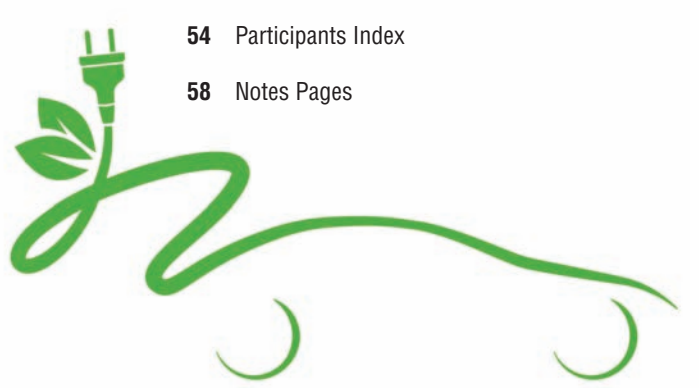

The Society of Tribologists and Lubrication Engineers (STLE) is the premier technical society serving the needs of more than 15,000 industry professionals and 200 organizations that comprise the tribology and lubrication engineering business sector. STLE offers its members industry-specific education and training, professional resources, technical information, certification programs and career development. STLE is an international organization headquartered at 840 Busse Highway, Park Ridge, Illinois (USA) 60068-2376. Contact us at (847) 825-5536, **information@stle.org, www.stle.org**.

STLE co-branded event provides the latest tribology and lubrication engineering field science

Dear Conference Attendees,

Welcome to Cleveland and thank you for participating in STLE's co-branded event – 2023 **Tribology Frontiers Conference (TFC)** and **Tribology & Lubrication for E-Mobility Conference.** I am very thrilled about this experience and am so pleased that you can join us.

During this four-day joint event, STLE is convening an international community of tribology's top minds from industry, academia and government to present the latest research in the field, as well as technical experts from leading companies and organizations with an interest in e-mobility to discuss state-of-the-art electric vehicle technologies and lubrication developments – all in one location.

I'd like to congratulate members of the joint conference planning committees (see pg. 4) for organizing an exciting program agenda. Both conferences will include more than 100 presentations covering various technical topics, including biotribology, fluid lubrication, tribochemistry, materials tribology, electrification, EV hardware, grease, thermal management, etc. The event will feature panel discussions, spotlight presentations, poster sessions, the popular "Beyond the Cutting Edge" Plenary Symposium (organized by the editors of Tribology Letters), and networking opportunities.

Four plenary speakers will address key topics at the forefront of the tribology and lubrication field, including tribological behavior of adsorbed polymer surfaces, electrification, sustainability, supply chain, energy efficient bearings, and electric vehicle driveline fluids.

Special thanks to our presenters, corporate sponsors, exhibitors and STLE staff for the great work in organizing this event. We couldn't have done it without all your efforts working together to serve our global technical community.

Looking ahead, we hope to see many of you at the 2024 STLE Annual Meeting & Exhibition, May 19-23, at the Minneapolis Convention Center in Minneapolis, MN. Details on the technical program and registration information will be available in December. Additionally, exhibit booth space is now open for companies looking to secure the best location possible in Minneapolis to enhance their visibility to key industry stakeholders.

Visit **www.stle.org/annualmeeting** for more information.

Have an enjoyable and productive conference!

Sincerely,

Hong

Hong Liang Ph.D.
Texas A&M University
2023-2024 STLE President

Registration Information

Registration is in the Foyer of the Cleveland Marriott Hotel.

Hours:

- **Sunday, November 12, 2023**
  12:00 pm – 6:00 pm
- **Monday, November 13, 2023**
  6:30 am – 6:00 pm
- **Tuesday, November 14, 2023**
  6:30 am – 6:00 pm
- **Wednesday, November 15, 2023**
  6:30 am – 12:00 pm

Attendance at all TFC & E-Mobility Conference paper presentations, networking sessions and social events is open to anyone who is registered for either or both conferences. See condensed schdedule (pgs. 8-9 & 40-41) for time and location of individual technical and plenary sessions.

Exhibits & Posters (Foyer)

Hours:

- **Monday, November 13, 2023**
  9:00 am – 9:20 am; 3:40 pm – 4:20 pm; 6:00 pm – 7:30 pm
- **Tuesday, November 14, 2023**
  9:00 am – 9:30 am; 10:40 am – 11:00 am; 2:00 pm – 2:30 pm; 3:40 pm – 4:20 pm
- **Wednesday, November 15, 2023**
  9:20 am – 9:40 am; 2:20 pm – 3:00 pm (Posters only)

Badge Policy

All attendees will receive a color-coded badge for the designated conference(s) registered and materials. Badges must be always worn and is required for admittance to TFC & E-Mobility activities. Swapping of badges is prohibited and may result in revocation of the badge.

Cellular Phone Policy

To not disturb speakers or attendees, please keep cellular phones on vibrate or leave the room to talk.

Dress Code

Business casual dress is appropriate for STLE conferences. Technical session speakers often choose attire that is more formal on the day of their presentations.

Recording Policy

Audio or video recording is not permitted in any of the technical or panel sessions. No video of any kind is permitted and may result in removal from the room.

Harassment Policy

STLE is committed to providing an atmosphere that encourages the free expression and exchange of scientific ideas. As part of that commitment, STLE is dedicated to promoting a safe and welcoming environment for all participants attending the TFC & E-Mobility joint event. All participants are expected to abide by this policy in all venues at the conference, including ancillary events and official and unofficial social gatherings. Harassment of any kind is strictly prohibited, and the Society will not tolerate acts in violation of this policy. Any individual who believes that he or she has been the subject of, or has witnessed, harassment should immediately report the incident to STLE staff. All reports are confidential. A copy of the full policy is available at **www.stle.org.**

Statement of Diversity and Inclusion

STLE is dedicated to the science and engineering of friction, lubrication, and wear, with a goal of perfecting motion in machines and nature. Our mission is to foster innovation, improve the performance of equipment and products, conserve resources, and protect the environment. These goals benefit the well – being of humanity and improve our stewardship of the planet and environment. The Society welcomes and encourages participation by all individuals regardless of age, culture, ethnicity, gender identity or expression, national origin, physical or mental difference, politics, race, religion, sex, sexual orientation, socio-economic status, or subculture. We strive to cultivate a society built on mentorship, encouragement, tolerance and mutual respect, thereby engendering a welcoming environment for all.

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Future Industry Meeting Dates:

- **78th STLE Annual Meeting & Exhibition**
  Minneapolis Convention Center
  May 19 – 23, 2024
  Minneapolis, Minnesota (USA)
- **2024 STLE Tribology & Lubrication for E-Mobility Conference**
  Detroit Marriott at Renaissance Center
  October 23 – 25, 2024
  Detroit, Michigan (USA)
- **79th STLE Annual Meeting & Exhibition**
  Hyatt Regency Hotel
  May 18 – 22, 2025
  Atlanta, Georgia (USA)
- **80th STLE Annual Meeting & Exhibition**
  Hyatt Regency New Orleans
  May 17 – 21, 2026
  New Orleans, Louisiana (USA)

2023 Conference Planning Committees

STLE wishes to thank this year's Tribology Frontiers and Tribology & Lubrication for E-Mobility Conference Planning Committees for their support and organization of the 2023 joint technical program.

STLE Tribology Frontiers Conference

Dr. Bart Raeymaekers (Chair)
Virginia Tech

Dr. Philip Egberts
University of Calgary

Dr. Benjamin Gould
The Chemours Company

Dr. Tevis Jacobs
University of Pittsburgh

Dr. Brandon Krick
Florida State University

Dr. Laura Peña-Parás
Universidad De Monterrey

Dr. Angela Pitenis
University of California, Santa Barbara

Dr. Wilfred T. Tysoe
University of Wisconsin-Milwaukee

Awards will be presented during Monday evening's Networking Reception.

STLE Tribology & Lubrication for E-Mobility Conference

Dr. Peter Lee (Chair)
Southwest Research Institute

Dr. William Anderson
Afton Chemical Corporation

Dr. Neil Canter
Chemical Solutions

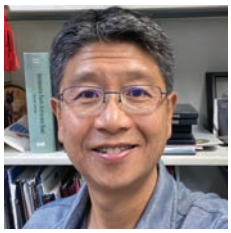
Dr. Hyeok Hahn
Chevron

Dr. Matthias Hof
Emery Oleochemicals GmbH

Dr. Ken Hope
Chevron Phillips Chemical Company

Dr. Hong Liang
Texas A&M University

Dr. Babak Lotfi
ExxonMobil Technology & Engineering Co.



Dr. Jun Qu
Oak Ridge National Laboratory

Dr. Harpal Singh
Solar Turbines

Dr. Dairene Uy
Shell Global Solutions (US) Inc.

2023-2024 STLE Board of Directors

Dr. Hong Liang (President), Texas A&M University
Jack Mckenna (Vice President), Sea-Land Chemical Company
Kevin Delaney (Secretary), Vanderbilt Chemicals, LLC
Stefan Bots (Treasurer), Lubeserv
Dr. Ryan Evans (Immediate Past President), The Timken Company
Dr. William Anderson, Afton Chemical Corporation
Dr. Nicolas Argibay, DOE Ames Laboratory
Dr. Vasu Bala, Tiarco LLC
Dr. John Bomidi, Baker Hughes
Dr. Aaron Greco, Argonne National Laboratory
Dr. Hannes Grillenberger, Schaeffler Technologies AG & Co. KG
Elaine A. Hepley, POLARIS Laboratories LLC
Dr. Peter Lee, Southwest Research Institute
Khalid Malik, Ontario Power Generation
Mandi McElwain, Univar Solutions
Dr. Kuldeep Kishore Mistry, Chevron Lubricants
Ramoun Mourhatch, Chevron Oronite, LLC
Jason Papacek, Calumet Specialty Products Partners, L.P.
Dr. Angela Pitenis, University of California, Santa Barbara
Dr. Farrukh Qureshi, The Lubrizol Corporation
Douglas Sackett, TotalEnergies USA, Inc.
Dr. Rajesh J. Shah, Koehler Instrument Company, Inc.
Dr. Dairene Uy, Shell Global Solutions (US) Inc.
Edward P. Salek, CAE, Outgoing Executive Director, STLE
Rebecca Lintow, CAE, Executive Director, STLE

2023 ASME Tribology Division Awards: **Monday, November 13, 6:00 pm – 7:30 pm** (Foyer)

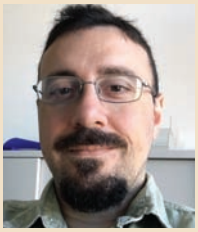
STLE would like to congratulate this year's ASME Tribology Division Award recipients for their outstanding technical achievements in the field of tribology research.

ASME Mayo D. Hersey Award

Professor Luis San Andrès, Ph.D.
Texas A&M University (Retired), USA

The Mayo D. Hersey Award is bestowed on an individual in recognition of distinguished and continued contributions over a substantial period of time to the advancement of the science and engineering of tribology.

ASME Burt L. Newkirk Award



Professor Melih Eriten, Ph.D.
University of Wisconsin-Madison, USA

The Burt L. Newkirk Award is given to an individual who has made notable contributions to the field of tribology in research or development as evidenced by important tribology publications.

Keynote Speakers

STLE is honored to have four world-renowned keynote speakers for the joint TFC-E-Mobility Conference. Please make time in your conference itinerary to hear their presentations

Monday, November 13, 2023

8:00 am – 9:00 am (Plenary Session)
Juliette Cayer-Barrioz
(Ecole Centrale de Lyon)
Surfaces in Lubrication: A Multiscale Analysis, p. 12

1:00 pm – 2:00 pm (Plenary Session)
Neil Canter
(Chemical Solutions): **STLE Trends Report: Opportunities in the Future,** p. 18

Tuesday, November 14, 2023

8:00 am – 9:00 am (Joint Plenary Session)
Troy Muransky
(American Axle & Manufacturing):
Challenges of Selecting the Correct Electric Vehicle Driveline Fluid, p. 26

1:00 pm – 2:00 pm (Plenary Session)
Michael Kotzalas
(The Timken Company): **Development of Power Dense and Energy Efficient Bearings to Address the Needs of Modern Machinery,** p. 31

Sunday, November 12, 2023

Meet and Greet Reception
6:00 pm – 7:00 pm (Foyer)

Monday, November 13, 2023

Speakers Breakfast
7:00 am – 7:45 am (Foyer)

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Plenary Session
8:00 am – 9:00 am (Salon D)

Networking/Refreshment Break (Exhibits & Posters)
9:00 am – 9:20 am (Foyer)

Plenary Session
1:00 pm – 2:00 pm (Salon D)

Networking/Refreshment Break (Exhibits & Posters)
3:40 pm – 4:20 pm (Foyer)

Poster Session
6:00 pm – 7:30 pm (Foyer)

Networking Reception & Award Presentations
6:00 pm – 7:30 pm (Foyer)

Tuesday, November 14, 2023

Speakers Breakfast
7:00 am – 7:45 am (Erie/Superior)

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Joint Plenary Session
8:00 am – 9:00 am (Salon EFGH)

Networking/Refreshment Break (Exhibits & Posters)
9:00 am – 9:30 am & 10:40 am – 11:00 am (Foyer)

Plenary Session
1:00 pm – 2:00 pm (Salon D)

Networking/Refreshment Break (Exhibits & Posters)
2:30 pm – 3:00 pm & 3:40 pm – 4:20 pm (Foyer)

Wednesday, November 15, 2023

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

"Beyond the Cutting Edge" Plenary Symposium
8:00 am – 11:30 am (Erie/Superior)

Networking/Refreshment Break (Posters only)
9:20 am – 9:40 am & 2:20 pm – 3:00 pm (Foyer)

Networking/Refreshment Breaks

All Days: Scheduled daily in the mornings and afternoons. Be sure to check the condensed schedule (pgs. 8-9 & 40-41) for specific break times. In addition to networking with your peers, be sure to visit with exhibiting companies and view the research posters in the Foyer.

TFC Spotlight Presentations

Spotlight presentations are a special category of talks being presented during the TFC featuring comprehensive longer (40-minute) presentations that have been chosen with notable principal investigators (PIs) and researchers showcasing their most compelling tribology research to a broader audience.

Panel Discussions

Q&A opportunities with top industry leaders discussing the latest topics and trends in the field, as well as exchange ideas and engage with the conference content with your peers. Featured Sessions:

Tribology & Lubrication for E-Mobility Conference

- **Esters: Tuesday, November 14**
  1:30 pm – 2:30 pm (Salon EFGH)
- **Materials Compatibility: Wednesday, November 15**
  9:40 am – 11:40 am (Salon EFGH)

2023 Conference Sponsors & Exhibitors

STLE wishes to thank the following sponsors and exhibitors for their generous support of the 2023 Tribology Frontiers Conference and Tribology & Lubrication for E-Mobility Conference.

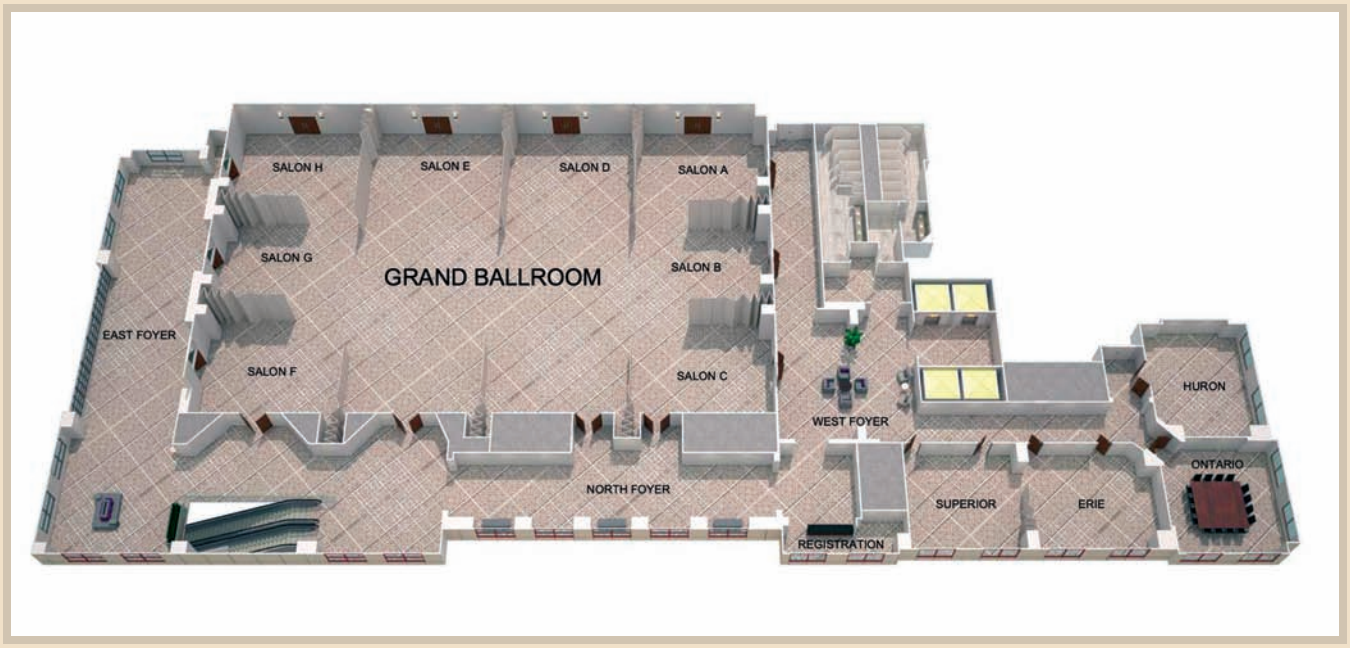
Trailblazer Sponsors:

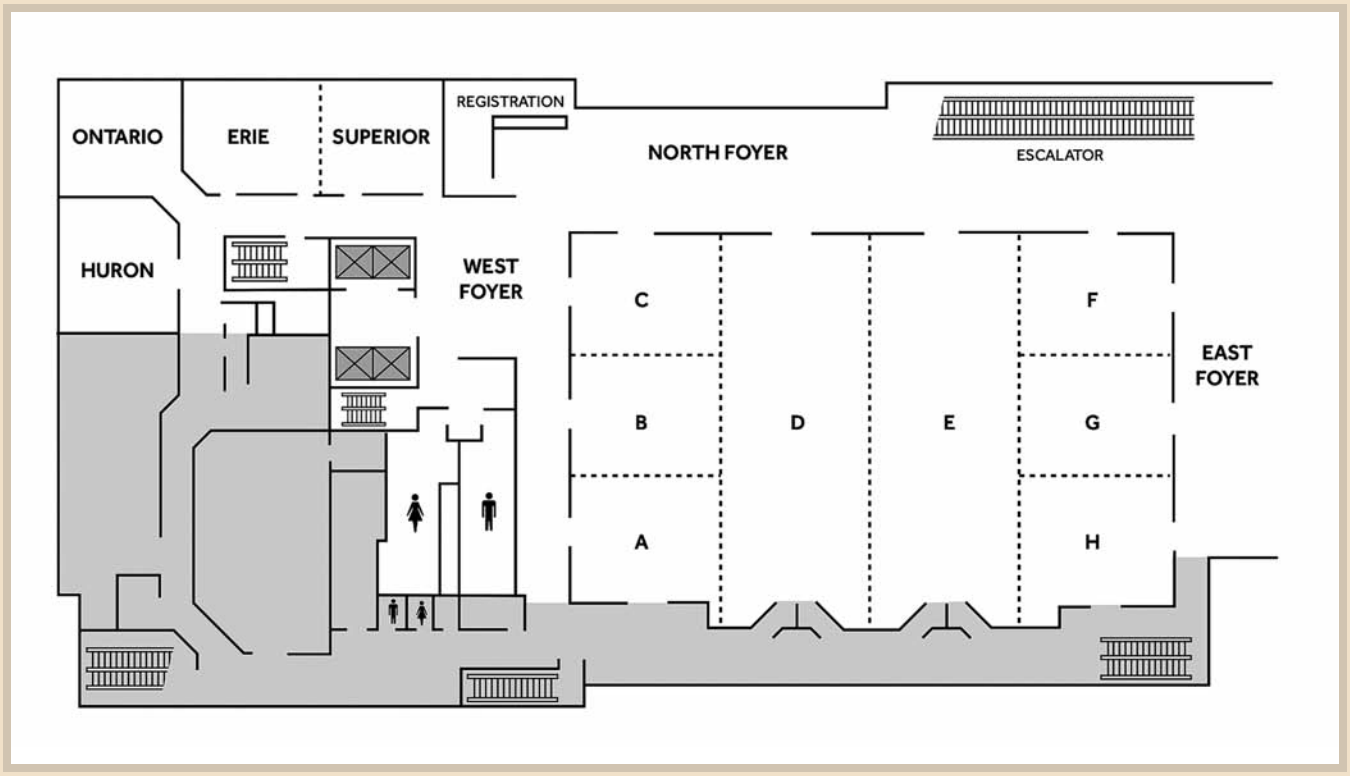
Pioneer Sponsors:

Exhibitors*

Eurofins TestOil • Rtec Instruments

**Exhibits are located in the Foyer of the Cleveland Marriott Hotel.*





Exhibits & Posters Hours

- **Monday, November 13, 2023**
  9:00 am – 9:20 am; 3:40 pm – 4:20 pm; 6:00 pm – 7:30 pm
- **Tuesday, November 14, 2023**
  9:00 am – 9:30 am; 10:40 am – 11:00 am; 2:00 pm – 2:30 pm; 3:40 pm – 4:20 pm
- **Wednesday, November 15, 2023**
  9:20 am – 9:40 am; 2:20 pm – 3:00 pm (Posters only)

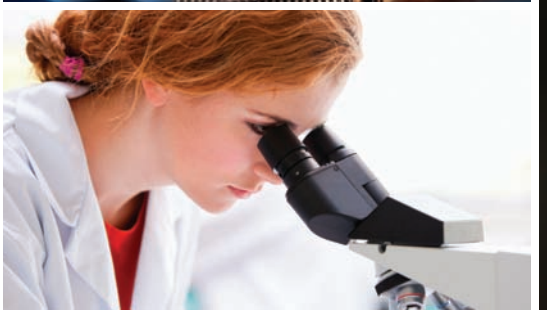
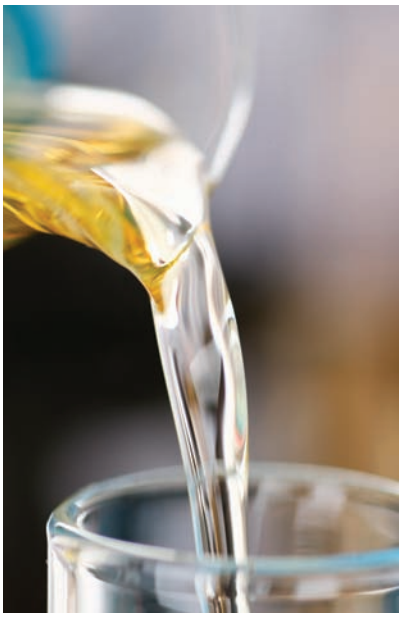
STLE Tribology Frontiers Conference

Program Schedule-at-a-Glance

As of October 30, 2023 – Subject to Change. **All times represent US Eastern Time.**

All TFC conference events are to be held in the Cleveland Marriott Downtown at Key Tower.



Sunday, November 12, 2023

Meet-in-Greet Reception
6:00 pm – 7:00 pm (Foyer)

Monday, November 13, 2023

Speakers Breakfast
7:00 am – 7:45 am (Erie/Superior)

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Plenary Session
8:00 am – 9:00 am (Salon D)

Keynote Presentation: Surfaces in Lubrication – A Multiscale Analysis, Juliette Cayer-Barrioz, CNRS Research Director, STMS/LTDS, Ecole Centrale de Lyon (France)

Networking/Refreshment Break (Exhibits & Posters)
9:00 am – 9:20 am (Foyer)

Technical Sessions – 9:20 am – 11:40 am

- 1A – Materials Tribology I (Salon A)
- 1B – Lubricants I (Salon B)
- 1C – Tribochemistry I (Salon C)
- 1D – Surfaces & Interfaces I (Salon E)

Lunch on Your Own
11:40 am – 1:00 pm

Plenary Session
1:00 pm – 2:00 pm (Salon D)

Keynote Presentation: STLE Trends Report – Opportunities in the Future, Neil Canter, President, Chemical Solutions (USA)

Technical Sessions – 2:00 pm – 3:40 pm

- 2A – Materials Tribology II (Salon A)
- 2B – Lubricants II (Salon B)
- 2C – Tribochemistry II (Salon C)
- 3D – Surfaces & Interfaces II (Salon E)

Networking/Refreshment Break (Exhibits & Posters)
3:40 pm – 4:20 pm (Foyer)

Technical Sessions/continued – 4:20 pm – 5:20 pm

- 2A – Materials Tribology II (Salon A)
- 2B – Lubricants II (Salon B)
- 2C – Tribochemistry II (Salon C)
- 3D – Surfaces & Interfaces II (Salon E)

Poster Session
6:00 pm – 7:30 pm (Foyer)

Networking Reception & Award Presentations
6:00 pm – 7:30 pm (Foyer)

Tuesday, November 14, 2023

Speakers Breakfast
7:00 am – 7:45 am (Erie/Superior)

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Joint Plenary Session
8:00 am – 9:00 am (Salon EFGH)

Keynote Presentation: Challenges of Selecting the Correct Electric Vehicle Driveline Fluid, Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

Networking/Refreshment Break (Exhibits & Posters)
9:00 am – 9:20 am (Foyer)

Technical Sessions – 9:20 am – 11:20 am

- 3A – Biotribology I (Salon A)
- 3B – Lubricants III (Salon B)
- 3C – Fluid Lubrication I (Salon C)
- 3D – Surfaces & Interfaces III (Salon E)

Lunch on Your Own
11:20 am – 1:00 pm

Plenary Session
1:00 pm – 2:00 pm (Salon D)

Keynote Presentation: Development of Power Dense and Energy Efficient Bearings to Address the Needs of Modern Machinery, Michael Kotzalas, Director of Global Customer Engineering, The Timken Company (USA)

Technical Sessions – 2:00 pm – 3:40 pm

- 4A – Energy/Environment/Manufacturing I (Salon A)
- 4B – Materials Tribology III (Salon B)
- 4D – Machine Elements & Systems I (Salon D)

Networking/Refreshment Break (Exhibits & Posters)
3:40 pm – 4:00 pm (Foyer)

Technical Sessions/continued – 4:00 pm – 4:40 pm

- 4A – Energy/Environment/Manufacturing I (Salon A)
- 4B – Materials Tribology III (Salon B)
- 4D – Machine Elements & Systems I (Salon D)

Wednesday, November 15, 2023

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

"Beyond the Cutting Edge" Plenary Symposium
8:00 am – 11:30 am

- 5D – Highlights from Tribology Letters (Salon D)

TFC Spotlight Presentations

A special category of talks being presented during the TFC featuring comprehensive longer (40-minute) presentations that have been chosen with notable principal investigators (PIs) and researchers showcasing their most compelling tribology research to a broader audience.

Monday, November 13

- Self-Assembly and Chemistry of Molecules in Oil Environment, pg. 14
- Interplay of Mechanics and Chemistry Governs Wear of Diamond-Like Carbon Coatings Interacting with ZDDP-Additivated Lubricants, pg. 15
- New Contact Temperature Model for Polymer Contacts, Considering Tribo-System Geometry: A Step Toward Generalization, pg. 18
- Effect of Counterbody Material on Tribofilm Formation of PTFE-Chromium Composites, pg. 19
- CNTs to Enhance Heat Transfer of EV Fluids, pg. 20
- A New Friction Modifier Mechanism Based on Pressure-Induced Hydrogen Bonding, pg. 21
- Understanding the Effect of Forces on Tribochemical Reaction Rates, pg. 21

Tuesday, November 14

- Slippery pHysics, pg. 26
- The Slippery Slope: Temperature, Pressure and Speed Dependent Friction Modifier Performance in a Wet Clutch, pg. 28
- In Situ Investigations into the Adhesion and Compression of Catalyst-Relevant Metal Nanoparticles, pg. 31

AM | **TFC TECHNICAL SESSIONS TIME GRID** | Monday, November 13

Plenary Session – Salon D

KEYNOTE PRESENTATION

8 – 9 am Surfaces in Lubrication – A Multiscale Analysis, p. 12

Juliette Cayer-Barrioz, CNRS Research Director, STMS/LTDS, Ecole Centrale de Lyon (USA)

9 – 9:20 am **Networking Break – Exhibits & Posters** (Foyer)

	Session 1A Materials Tribology I	Session 1B Lubricants I	Session 1C Tribochemistry I	Session 1D Surfaces & Interfaces I
Location	**Salon A**	**Salon B**	**Salon C**	**Salon E**
TIME **9:20 am**		**SPOTLIGHT PRESENTATION** Self-Assembly and Chemistry of Molecules in Oil Environment, H. Washizu, p. 14	**SPOTLIGHT PRESENTATION** Interplay of Mechanics and Chemistry Governs Wear of Diamond-Like Carbon Coatings Interacting with ZDDP-Additivated Lubricants, M. Moseler, p. 15	Surface Characterization as Inputs for FEM Multi-Scale Model Development, I. Lawal, p. 16
9: 40 am	High Shear Stress and Highly Durable Electroadhesive Clutch for Soft Robotics and Haptics, C. Choi, p. 13			Residual Stress Behavior in Contacting Rough Surfaces, S. Elsheltat, p. 16
10 am	Developing Process-Structure-Property Relationships for Ultra-low Wear Plasma-Enhanced ALD Ternary Nitride Films, K. Van Meter, p. 13	A Comprehensive Evaluation of Sustainable Raw Materials in Lubricant Production, M. Miller, p. 14	Encapsulated Ionic Liquids as Lubricant Additives, J. Yan, p. 15	Surface Topography as a Material Parameter, T. Jacobs, p. 17
10:20 am	Exploring Effectiveness of Vibro-Acoustic Damping in Elastic Structures with Frictional Contacts, I. Lawal, p. 13	Experimental Investigation of the Tribological Performance and Usability of Waste Tire Pyrolysis Oil in Engine Oils, A. Alazemi, p. 14	Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM, K. Cogen, p. 15	Effects of Tip Geometry on Developing Young's Modulus Maps in Atomic Force Microscopy, L. Kirsch, p. 17
10:40 am	How Surfaces Affect the Shape, Elastic Response, and Deformation Behavior of Small Metal Nanoparticles, T. Jacobs, p. 13	Augmenting the Performance of Eco-Friendly Greases Using Synergistic Natural Resources, A. Saxena, p. 14	Wear and Degradation Behavior in Nitrided Steel Investigated by Reactive Molecular Dynamics Simulations, M. Yokoi, p. 16	Understanding Small-Scale Topography Using Scanning Electron Microscopy, V. Chadha, p. 17
11 am		Investigation of Tribological and Vibration Performance of Vegetable Oil-Based Eco-Friendly Greases on Rolling Bearing, A. Saxena, p. 15	Simulation Study of DLC-Zirconia Sliding Under Alcohol Gas Environment, R. Okamoto, p. 16	The infamous Fuorinated Carbon Materials in Tribology – A Journey to the Atomic-Scale Origins of Their Unique Properties, G. Moras, p. 17

PM | **TFC TECHNICAL SESSIONS TIME GRID** | Monday, November 13

Plenary Session – Salon D

KEYNOTE PRESENTATION

1 – 2 pm STLE Trends Report: Opportunities in the Future, p. 18
Neil Canter, President, Chemical Solutions (USA)

3:40 – 4:20 pm **Networking Break – Exhibits & Posters** (Foyer)

	Session 2A Materials Tribology II	Session 2B Lubricants II	Session 2C Tribochemistry II	Session 2D Surfaces & Interfaces II
Location	**Salon A**	**Salon B**	**Salon C**	**Salon E**
TIME				
2 pm	**SPOTLIGHT PRESENTATION** New Contact Temperature Model for Polymer Contacts, Considering Tribo-System Geometry: A Step Toward Generalization, M. Kalin, p. 18	**SPOTLIGHT PRESENTATION** CNTs to Enhance Heat Transfer of EV Fluids, J. Qu, p. 20	**SPOTLIGHT PRESENTATION** A New Friction Modifier Mechanism Based on Pressure-Induced Hydrogen Bonding, T. Reddyhoff, p. 21	Analytical Friction Models for Molecular Adsorbates, W. Tysoe, p. 22
2:20 pm				Effects of Hot Switching on Contact Reliability of Pt-Coated Microswitches at Low Contact Voltages, D. Kumar, p. 23
2:40 pm	Laser Surface Texturing of Stainless Steel Substrate for Improving the Wear Life of PDA/PTFE Coatings, F. Soltani-Kordshuli, p. 18	The Study of the Effect of Water on Engine Oil Rheology and Antiwear Performance in HEVs (Hybrid Electric Vehicles) Application, D. Uy, p. 20	**SPOTLIGHT PRESENTATION** Understanding the Effect of Forces on Tribochemical Reaction Rates, W. Tysoe, p. 21	UHMWPE Polymer Composite and Hybrid Composite Coatings for Tribological Applications, A. Samad Mohammed, p. 23
3 pm	**SPOTLIGHT PRESENTATION** Effect of Counterbody Material on Tribofilm Formation of PTFE-Chromium Composites, M. Sidebottom, p. 19			Friction in Adhesive Contacts Between Hard Indenters and Soft Elastomers: Experiments and Simulations, I. Lyashenko, p. 23
3:20 pm		Tribological Properties of Nano Al2O3 Gear Oil From Lube Oil Blending Plant Effluent Oil for Automotive Gearbox, K. Usman, p. 20	Description of High Through - put Elemental Analysis in Oil Samples Utilizing ICP-OES and Automation to Overcome Common Issues in Measure - ment, C. Conklin, p. 21	**Break**
3:40 pm	**Break**	**Break**	**Break**	
4 pm				
4:20 pm	Self-Lubricating Polyimide for EV Wear and Friction Applications, H. Lee, p. 19	The Effect of Rheological Feature of Graphene Oxide-Involved Emulsion on its Corresponding Lubricity Performance, H. Ou, p. 20	Exploring the Role of Metal - working Fluids in Tribo-chemistry: Enhancing Per - formance and Efficiency on the Surface Level, Je. Ziobro, p. 22	
4:40 pm	Relative Scuffing Resistance of Aerospace Bearing Materials and Lubricants, C. Hager, Jr., p. 19		Surface-Protective Tribofilms via Tribocatalysis and Surface-Active Precursors, Q. Jane Wang, p. 22	
5 pm	Improving Tribological Properties of Low-Cost Carbon Steels via Chromizing, T. Grejtak, p. 19		Minimizing Engine Wear in the Sequence IVA Through Tribofilm Formation, D. Williams, p. 22	

Plenary Session
8:00 am – 9:00 am (Salon D)
Monday, November 13, 2023

KEYNOTE PRESENTATION

Surfaces in Lubrication – A Multiscale Analysis

Juliette Cayer-Barrioz, CNRS Research Director, STMS/LTDS, Ecole Centrale de Lyon (France)

Reducing friction dissipations is a promising way to contribute to the global welfare. To do so, the first approach is to use low-viscosity fluids – leading to thinner and thinner films – and the second is to modify the surfaces in contact. We illustrate here the combined approach consisting in investigating the surface effects on friction in contacts lubricated with low-viscosity fluids over all the lubrication regimes. We first present the IMOTEP research platform that allows us to carry out a multiscale analysis of lubricated contacts from full-film lubrication regimes to boundary friction regimes. Covering 11 decades of sliding velocities and contact pressure from 10-10 to 10 m/s and up to few GPa [1-4], it combines simultaneous measurements of contact forces with film thickness distribution for controlled contact kinematics. Surface modification is addressed in terms of topography as well as physico-chemistry.

The first part of this keynote presentation shows how surface roughness bridges the friction scale gap from molecular to multi-asperity contacts. For a simple frictional system exclusively undergoing structural aging, we explained how the macroscopic friction response resulted from the interplay between the contact roughness via the formation of contact junctions, and the molecular motion within adsorbed monolayers on the surface, through coupled experimental and computational approaches with a unified theoretical model [5]. We were able to provide insights on the friction force decay, after the stiction peak, at the onset of sliding to a steady-state value over a few nanometers of sliding distance. The evolution of number of cross-surface attractive physical links, within contact junctions, was correlated to this memory distance.

The second part deals with the tribological behavior of adsorbed polymer layers on surfaces over all the lubrication regimes. The interactions between the metallic surface and the polymer additive induced the formation of a nanometer thick boundary layer, highly elastic with a shear elastic modulus of 90 MPa under a 50 MPa contact pressure [6]. Interferogram analysis showed that patches of adsorbed film well covered the surface at low velocity. At high velocity, the film thickness followed the elastohydrodynamic prediction. The existence of this boundary film resulted in friction reduction, shifting the mixed/EHL regime transition towards lower velocities. In hydrodynamic lubrication regime, two regimes – thermal versus non-thermal – competed depending on the kinematics. The role of non-Newtonian fluid rheology under high shear was also investigated [7].

References:

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[3] Bonaventure, J. et al. (2016), Transition Between Mixed Lubrication and Elastohydrodynamic Lubrication with Randomly Rough Surfaces, Tribology Letters, 64(3), p. 44.

[4] Barazzutti, C. et al. (2023), Thin Films in Hydrodynamic Lubrication Regime: the Osiris Friction Set-up, Rev Sci Instrum, 94, 065103.

[5] Frérot, L. et al. (2023), From Molecular to Multiasperity Contacts: How Roughness Bridges the Friction Scale Gap, ACS Nano, 17, pp. 2205–2211.

[6] Abouhadid, F., PhD thesis 2021LYSEC48, Ecole centrale de Lyon, 2021.

[7] Barazzutti, C., PhD thesis 2023ECDL0002, Ecole centrale de Lyon, 2023.

Juliette Cayer-Barrioz graduated with degrees in physics and mechanical engineering from the University of Grenoble in 1998 and Ecole Centrale de Lyon (ECL) in 2000, respectively, before obtaining her Ph.D. in materials science from ECL in 2003 and her Habilitation in Mechanics in 2011. Since 2005, she has been associated with the CNRS. Her research activities at the Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) in Ecole Centrale de Lyon focus on surface phenomena and dynamics of confined lubricated interfaces. Her multidisciplinary approach – based on unique experimental devices developed at the LTDS – combines physics, interfacial chemistry and mechanics, rheology and friction. After an eight-year contribution to the Laboratoire d'Excellence Manutech-Sise, she is now a member of the French National Committee of the CNRS in mechanics and serves as one of four editors of the STLE-affiliated Tribology Letters journal. Her teaching activities at ECL, and beyond, address the physics and chemistry of interfaces and the rheology of complex media.

Monday, November 13, 2023

Session 1A (Salon A)

Materials Tribology I

Session Chair: Kylie Van Meter, Florida State University, Tallahassee, FL

Session starts at 9:40 am

9:40 am – 10:00 am

3930958: High Shear Stress and Highly Durable Electroadhesive Clutch for Soft Robotics and Haptics

Changhyun Choi, M. Cynthia Hipwell, Aditya Kuchibhotla, Texas A&M University, College Station, TX

In this work, we demonstrate an electro-adhesive clutch that has high electro-adhesive shear stress and high durability. Current research on electro-adhesive clutch has been focused on only using a high dielectric constant to improve the electrostatic force in a parallel plate configuration. Since the change in the friction force is an electromechanical response, mechanical properties such as elastic modulus and yield strength should be taken into account as well as crack propagation at the interface. We also found that the current high dielectric constant materials have a durability issue. Using a high dielectric constant film that has a high dielectric constant and wear resistance and a structural design that minimizes the wear issue, we achieved high electro-adhesive shear stress and high durability, which can be reliably used in soft robotics and haptic applications. This work will enable miniaturized robots and haptic devices as it can generate the same required force on a smaller area.

10:00 am – 10:20 am

3953878: Developing Process-Structure-Property Relationships for Ultra-low Wear Plasma-Enhanced ALD Ternary Nitride Films

Kylie Van Meter, Thomas Lockhart, Brandon Krick, Florida State University, Tallahassee, FL; Md. Chowdhury, Nicholas Strandwitz, Lehigh University, Bethlehem, PA; Mark Sowa, Veeco ALD, Waltham, MA; Alexander Kozen, University of Maryland, College Park, MD; Tomas Babuska, Sandia National Laboratories, Albuquerque, NM; Tomas Grejtak, Oak Ridge National Laboratory, Oak Ridge, TN

Metal nitride coatings are frequently used in tribological applications due to their high wear resistance and friction-reducing properties. Compared to traditional TiN films, multi-metal nitrides such as TiVN are found to have lower wear and friction and have higher oxidation resistance. Plasma-enhanced atomic layer deposition (PEALD) techniques enable atomic level thickness and composition control, allowing for the growth of thin (~100nm), conformal, conductive films at low deposition temperatures, where conventional CVD techniques are limited. These capabilities make PEALD nitride films candidates for microelectronics and MEMS/NEMS. Recently, PEALD ternary nitrides have achieved ultra-low wear rates (K < 10-7 mm3/Nm). However, there lacks a fundamental understanding of the process-structure-property relationships in PEALD films. This work investigates the effects of deposition parameters, linking film structure, physical, mechanical, and chemical properties to tribological behavior.

10:20 am – 10:40 am

3931666: Exploring Effectiveness of Vibro-Acoustic Damping in Elastic Structures with Frictional Contacts

Iyabo Lawal, Michael Haberman, Janghoon Kang, The University of Texas at Austin, Austin, TX

Reducing vibro-acoustic energy in structures can provide vibration isolation and mitigate noise in building spaces. Building materials with Constrained Layer Damping (CLD) have been used to dissipate vibro-acoustic energy in structures, improving vibration isolation and reducing noise transmission. The material assembly in CLD typically has a viscous “constrained layer” that allows for viscous dissipation. However, the use of friction within a material assembly has not been widely used to achieve the same effect. In this work, the effectiveness of using micro-friction events at the contact interface of material layers to provide friction driven dissipation is explored. Acoustic metrics: Transmission Loss (TL) and acoustic impedance that quantify the effectiveness of vibro-acoustic energy dissipation, will be generated for the traditional CLD assembly as well as for the friction driven dissipation material assembly. In addition to analytical solutions, a set of experiments have been conducted that quantify the acoustic absorption of different material assemblies within a range of frequencies as it responds to a plane pressure wave within an impedance tube.

10:40 am – 11:00 am

3964052: How Surfaces Affect the Shape, Elastic Response, and Deformation Behavior of Small Metal Nanoparticles

Tevis Jacobs, Ruikang Ding, Soodabeh Azadehranjbar, University of Pittsburgh, Pittsburgh, PA; Ingrid Padilla Espinosa, Ashlie Martini, University of California, Merced, Merced, CA

In this talk, we will discuss three years of published and unpublished work using in situ TEM compression testing to understand how a nanoparticle’s “bulk” behavior is controlled by its surface. First, we will discuss the size-dependent shape of single-digit-nm platinum nanoparticles, and how surface energy controls the distributions of shapes that are observed. Second, when those particles of various shapes are compressed, we show how to understand their size-dependent stiffness. We use atomistic simulations and in situ compression testing to show to disentangle geometric effects such as spatial variations in stress from surface effects, where the undercoordinated surface atoms have meaningfully different bond stiffnesses. Finally, in the permanent-deformation regime, we show how the surface weakens the nanoparticle. Moving beyond the traditional Coble-creep-like model, we reveal how mechanical deformation of small particles is governed by a competition between surface nucleation of dislocations and surface-mediated shape change.

Session 1B (Salon B)

Lubricants I

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

SPOTLIGHT PRESENTATION

9:20 am – 10:00 am

3950002:Self-Assembly and Chemistry of Molecules in Oil Environment

Hitoshi Washizu, Kyosuke Kawakita, Tomoya Hasegawa, Riku Araki, Tomohito Horio, Takehiro Kobayashi, Ryuichi Okamoto, Kosar Khajeh, University of Hyogo, Kobe, Japan; Yoshiki Ishii, Kitasato University, Sagamihara, Japan; Natsuko Sugimura, National Institute of Technology, Kagoshima College, Kirishima, Japan

Self-assembly of solute molecules in oil solvent is important since many of the lubricants are used in this condition. Molecular simulation is useful to treat this phenomena and recently we applied to self-assembled systems such as liquid crystals and polymer solution. Here, we report our recent research on molecular simulations of additives and thickener in oil environment with and without metal surfaces. Although carbonate oiliness additives adsorb physically on the charged metal surface relatively quickly, extreme pressure additives such as organophosphate make aggregation structure in oil and do not easily adsorb on the surface. The dependence of the molecular structure to the stability is simulated. After adsorption to the surface, the pathway of charge transfer on the surface is different on the nascent surface and oxidized surface. In order to understand the grease, formation and breakage dynamics of self-organized structure of reverse-micelle under shear is analyzed using dissipative particle dynamics, and the dynamics is related to the experimentally found dynamics of grease thickener. The simulation method is further extended to treat wider time and space dynamics, such as multi-physics approach of coarse-grained molecules coupled with fluid dynamics, or molecular dynamics using AI-based potential to treat huge chemical reactions. These new approaches reveal the tribochemistry of lubricants on the surface from molecular levels.

10:00 am – 10:20 am

3729988: A Comprehensive Evaluation of Sustainable Raw Materials in Lubricant Production

Mark Miller, Ramapo College of NJ, Ramapo, NJ

The market demand for sustainable lubricants, bio-based base oil and green additives is growing, but what makes these products truly sustainable? The terminology in the sustainability landscape is confusing. This presentation will clarify key terms such as biobased, biodegradable, decarbonization, carbon footprint, bio-content, etc. We will also address the latest regulatory requirements and key performance issues. From this presentation, attendees will learn about the key terms prevalent in the lubricant industry today, and what key pitfalls to look out for in developing a sustainable grease offering. As many grease manufacturers adopt strategies toward sustainable products and carbon negative footprint goals, the definitions become more important. We will distinguish facts from fiction when it comes to sustainability and discuss the advantages and disadvantages of said strategies. In addition, we will cover the importance of a Life Cycle Assessment and all that assessment encompasses and how to effectively dissect the important elements of a Life Cycle Assessment.

10:20 am – 10:40 am

3759364: Experimental Investigation of the Tribological Performance and Usability of Waste Tire Pyrolysis Oil in Engine Oils

Abdullah Alazemi, Kuwait University, Safat, Kuwait

More than one billion rubber tires are annually disposed of around the world as a major part of the solid waste stream, which presents an enormous environmental risk. Therefore, there is an urgent need to recycle and take advantage of waste rubber tire materials, more commonly referred to as end-of-life tires. In the current investigation, materials extracted from recycled used tires will be studied as potential additives to conventional engine oil. Pyrolysis oil or carbon black materials derived from waste tires will be mixed in different concentrations with engine oil to obtain a lubricant mixture. Structural and chemical analyses of those tire-recycled materials will be conducted via scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Furthermore, rheological studies will be conducted to explore the effect of recycled materials on the rheological properties of the engine oil at different temperatures and shear rates. Finally, a tribometer will be utilized to perform tribological studies of the lubricant mixture to assess the effect of tire-recycled materials on the tribological performance of engine oils.

10:40 am – 11:00 am

3756294: Augmenting the Performance of Eco-Friendly Greases Using Synergistic Natural Resources

Ankit Saxena, Deepak Kumar, Naresh Tandon, Indian Institute of Technology Delhi (IITD), Delhi, India

The grease industry extensively uses non-renewable, non-biodegradable, and toxic entities as ingredients that satisfy the performance goals and jeopardize the environment simultaneously. Several environmentally benign ingredients have been tried to formulate eco-friendly greases; however, a potential alternative is not yet reached. The present study explores, for the very first time, an effort to enhance the performance of eco-friendly greases (based on vegetable oil and organoclay) using biopolymers as additives. Two different series of greases containing 0-10 %w/w of two biopolymers (B1 and B2) are developed and evaluated for antiwear (AW), and extreme-pressure (EP) tests, as per ASTM standards. B1-based greases displayed superior AW (upto ≈ 22% enhancement), frictional (up to ≈ 42% enhancement), and EP response (up to ≈ 60% enhancement). Whereas B2-based greases displayed superior EP characteristics (up to ≈ 60% enhancement), however, inferior AW response. The formation of an in-situ polymer-layered silicate nanocomposite film at the interface is attributed to the superior EP properties. The contradictory AW behavior of biopolymers is attributed to their distinct interfacial interaction tendencies (synergistic or antagonistic) with organoclay.

11:00 am – 11:20 am

3756297: Investigation of Tribological and Vibration Performance of Vegetable Oil-Based Eco-Friendly Greases on Rolling Bearing

Ankit Saxena, Deepak Kumar, Naresh Tandon, Indian Institute of Technology Delhi (IITD), Delhi, India

Conventional greases are saturated with environmentally harmful (or unacceptable) ingredients for the sake of performance. Several eco-friendly alternatives to such harmful greases have been developed; however, a potential solution is not yet reached. The present study explores, for the very first time, eco-friendly greases with enhanced tribology and vibration performance. A series of greases is developed using vegetable oil as base oil, organoclay as a thickener, and several naturally occurring additives. The greases are evaluated for antiwear (AW), and extreme-pressure (EP) tests, as per ASTM standards against a conventional commercial grease as a benchmark. Vibration and shock pulse measurements are also acquired to assess the actual dynamic performance of greases on a rolling bearing. Superior EP (up to ≈ 60% improvement) and frictional (up to ≈ 22% improvement) responses are observed for formulated greases compared to the commercial grease. Greases further display comparable AW and vibration performance to commercial grease.

Session 1C (Salon C)

Tribochemistry I

Session Chair: Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

SPOTLIGHT PRESENTATION

9:20 am – 10:00 am

3959444: Interplay of Mechanics and Chemistry Governs Wear of Diamond-Like Carbon Coatings Interacting with ZDDP-Additivated Lubricants

Michael Moseler, Fraunhofer IWM, Freiburg, Germany

Friction and wear reduction by diamond-like carbon (DLC) in automotive applications can be affected by zinc-dialkyldithiophos - phate (ZDDP), which is widely used in engine oils. Our experiments show that DLC's tribological behavior in ZDDP-additivated oils can be optimized by tailoring its stiffness, surface nano-topograph and hydrogen content. An optimal combination of ultra-low friction and negligible wear is achieved using hydrogen-free tetrahedral amorphous carbon (ta-C) with moderate hardness. Softer coatings exhibit similarly low wear and thin ZDDP-derived patchy tribofilms but higher friction. Conversely, harder ta-Cs undergo severe wear and sub-surface sulphur contamination. Contact-mechanics and quantum-chemical simulations reveal that shear combined with the high local contact pressure caused by the contact stiffness and average surface slope of hard ta-Cs favour ZDDP fragmentation and sulphur release. In absence of hydrogen, this is followed by local surface cold welding and sub-surface mechanical mixing of sulphur resulting in a decrease of yield stress and wear.

10:00 am – 10:20 am

3920625: Encapsulated Ionic Liquids as Lubricant Additives

Jieming Yan, Filippo Mangolini, Kenechukwu Moneke, The University of Texas at Austin, Austin, TX

Ionic liquids (ILs) have been extensively studied for their potential use for lubrication due to their unique physiochemical properties and good tribological performance. However, the limited solubility of ILs in hydrocarbon fluids and the high corrosivity of halogenated ILs limits their adoption as lubricant additives. Here, we encapsulate ILs in polymer shells to overcome these challenges. Two classes of ILs were selected for the study, namely a commercially available, halogenated IL and a halogen-free, boron-containing IL. The outcomes of macroscale steel-versus-steel tribological testing, together with the results of X-ray photoelectron spectroscopy measurements, indicate that polymer-encapsulated IL additives in synthetic oils release the IL at the sliding interface, following the mechanical rupture of the polymer shell at the contact inlet, reducing friction and wear with negligible surface corrosion. These novel additives will greatly facilitate the introduction of ILs into conventional lubricant formulations.

10:20 am – 10:40 am

3962974: Understanding the In-Situ Formation and Evolution of Phosphorus Antiwear Tribofilms with FFM and NanoIR-AFM

Kerry Cogen, Infineum USA L.P., Linden, NJ; Matthew Flynn-Hepford, Arya Ahmadi, Mahshid Ahmadi, Olga S. Ovchinnikova, University of Tennessee, Knoxville, Knoxville, TN

In electrified vehicle (EV) systems, the lubricating fluids deliver the chemistry needed to form the antiwear tribofilms in rolling/sliding contacting surfaces and serve to control friction and protect surfaces from wear and fatigue. Understanding the mechanism of antiwear film formation and how to tune surface chemistry to control functionality is essential for development of next generation of driveline fluids. In this work, we utilize a unique multimodal AFM methodology to understand initial film formation from different phosphorus-containing lubricants in-situ. We combine Friction Force Microscopy (FFM) to capture the spatial details of friction over the surface as the tribofilm forms and evolves and Nano Infrared Spectroscopy AFM (NanoIR-AFM) to understand the chemistry of the film. We investigate the different rates of film formation for different phosphorus-containing additives on steel surfaces under different load conditions and how other components typically found in EV fluids can impact that formation.

(Session 1C continued)

10:40 am – 11:00 am

3908910: Wear and Degradation Behavior in Nitrided Steel Investigated by Reactive Molecular Dynamics Simulations

Mizuho Yokoi, Masayuki Kawaura, Yuta Asano, Yusuke Ootani, Nobuki Ozawa, Momoji Kubo, Tohoku University, Sendai, Miyagi, Japan

The development of wear-resistant materials is important because wear can cause serious accidents. Nitriding is a surface treatment that improves wear resistance by forming a hard iron nitride layer on the surface. However, it has been reported that N atoms in the iron nitride surface released by mechanical and chemical effect during sliding, which causes degradation. In this study, we analyzed tribochemical reactions to clarify the degradation process of iron nitride by using reactive molecular dynamics sliding simulations for the friction interface in water environment. The water reacted with the iron nitride, forming Fe-O-Fe structures. Then, N atoms in iron nitride surface formed NH3 molecules. We concluded that the tribochemical reaction caused the degradation of iron nitride due to the formation of Fe oxide film on the surface and releasing NH3 molecules. The influence of structural changes of the iron nitride on the degradation process will be reported in this presentation.

11:00 am – 11:20 am

3963120: Simulation Study of DLC-Zirconia Sliding Under Alcohol Gas Environment

Ryuichi Okamoto, Hirotoshi Akiyama, Rio Nakae, Hitoshi Washizu, University of Hyogo, Kobe, Japan

Diamond-like carbon (DLC) has extensively been studied because of its tribological properties. Depending on the environment and the counter surface, the friction coefficient can drop down to less than 10-3. In particular, using yttria-doped stabilized zirconia (YSZ) as a counter-surface, it was found that the friction coefficient goes down to order 10-4 under the environment of alcohol, hydrogen and water gases (friction fade-out, FFO). The experiments suggest that the ultra-low friction can be attributed to the hydrocarbon tribofilm of thickness 100-150 nm formed on the YSZ surface in the running-in stage. To understand the early-stage chemical reactions, we perform molecular dynamics simulation using reactive force field (ReaxFF), which allows chemical reactions and varying atomic charges. In the simulation box, we place hydrogen-containing DLC film and zirconia film, between which the ethanol, water gases, and hydrogen gas (or radicals) are distributed. We then perform sliding simulation with speed 100m/s under a load pressure 1GPa. On the YSZ surface, we found that the sliding induces dehydrogenation reaction of the ethanol. Further, the sliding and the catalytic nature of the zirconia induce polymerization of ethanol molecules. These reactions may be a precursor of the tribofilm formation observed in the experiments. In this talk, we also discuss the energetics of these reactions using the potential of mean force between the chemical components.

Session 1D (Salon E)

Surfaces and Interfaces I

(Including Nanotribology)

Session Chair: Deepak Kumar, Carnegie Mellon University, Pittsburgh, PA

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

9:20 am – 9:40 am

3762022: Surface Characterization as Inputs for FEM Multi-Scale Model Development

Iyabo Lawal, The University of Texas at Austin, Austin, TX; Matthew Brake, Rice University, Houston, TX

In tribology experiments, the evolution of the wear track under fretting fatigue is a multi-physics problem involving friction, heat transfer, material phase change and local plastic deformation at different scales. It is a complex problem that is not well understood. As a first approach, an FEM model has been developed to model fretting fatigue using a non-smooth constitutive friction model that accounts for asperity level friction as well as meso-scale friction. By observing wear scar evolution from confocal micro-scope as well as SEM images, a better understanding of how to incorporate multi-scale friction into FEM models can be developed.

9:40 am – 10:00 am

3736221: Residual Stress Behavior in Contacting Rough Surfaces

Salem Elsheltat, Alastair Clarke, William Britton, HP Evans, Cardiff University, Cardiff, United Kingdom; Alexander Lunt, University of Bath, Bath, United Kingdom

This paper examines the way in which the running-in process modifies the as-manufactured surface roughness of hardened and ground steel disks, used to model gear tooth contact conditions in a disk machine experiment, and investigates the association between asperity shape changes due to plastic deformation and the asperity-scale residual stress generated in the material. Areas of high tensile residual stress at the surface are of interest as a potential precursor of surface micropitting damage in subsequent running. The shape changes of prominent asperities were measured using in-situ profilometry, and a novel depth-profiling residual stress measurement technique using FIB milling and digital image correlation enabled measurement of the near-surface residual stresses in the asperities, up to a depth of 4 microns. Comparisons were made with residual stresses predicted by ANSYS FEA elastic/plastic contact analyses, and residual stress fields could then be associated with the degree of asperity modification observed.

10:00 am – 10:20 am

3964051: Surface Topography as a Material Parameter

Tevis Jacobs, Lars Pastewka, Surface Design, Pittsburgh, PA

Surface topography controls the performance and reliability of surfaces in applications from automotive and aerospace to medical devices and consumer electronics. Yet too often our strategies to find the optimal surface finish rely on trial-and-error testing. While great strides have been made in the theory and simulation of roughness-dependent surface performance, it remains difficult to translate this into the design and control of real-world devices. First, we will discuss a recent special issue of MRS Bulletin entitled "The Materials Science and Mechanics of Rough Surfaces," in which 17 authors from around the world reviewed the cutting-edge science of surface engineering. Second, will be discussion of recent efforts in our group to rationally control the adhesion of technology-relevant coatings. Specifically, we will discuss the use of polycrystalline diamond and other hard-carbon coatings, and also the use of nanoscale patterning to modify the adhesion of silicon computer chips.

10:20 am – 10:40 am

3929643: Effects of Tip Geometry on Developing Young's Modulus Maps in Atomic Force Microscopy

Logan Kirsch, Gregory Rodin, Filippo Mangolini, Nicolas Molina Vergara, The University of Texas at Austin, Austin, TX

Atomic Force Microscopy (AFM) is commonly used to assess elastic properties at the nanoscale, but accurately calculating quantitative values for Young's modulus from load-displacement data remains a significant challenge. One major source of error lies in assuming a constant spherical or conical geometry, which fails to accurately capture AFM tip geometry. Moreover, the tip can undergo drastic geometry changes during the tens of thousands of indentations required for a typical AFM Young's modulus map. We aim to address these issues by considering different indenter tip geometries and their evolution due to tip wear. We first develop analytical procedures to dynamically calculate Young's modulus and current tip geometry from load-indentation data for various indenter tip geometries. We then assess the accuracy of these different procedures by using them with experimental load-displacement data from samples with well characterized elastic properties over the lifetime of an indenter tip.

10:40 am – 11:00 am

3930100: Understanding Small-Scale Topography Using Scanning Electron Microscopy

Vimanyu Chadha, Ruikang Ding, Kurt Beschorner, Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

Roughness-dependent surface properties cannot be understood nor predicted without a comprehensive description of surface topography, which includes many different length scales, including down to nanometer sizes. Recent work has established comprehensive topography characterization using transmission electron microscopy (TEM), but this is time-consuming, labor-intensive, and not widely available. To address these limitations in TEM, we evaluated the potential of scanning electron microscopy (SEM) to characterize comprehensive topography. We describe a straightforward approach for sample preparation, measurement, and analysis, which goes from bulk sample to spectral characterization. We use this approach to measure the topography of ultrananocrystalline diamond and compare the accuracy of SEM-measured topography against prior TEM-based measurements. We use a statistical comparison of power spectral densities (PSDs) to show that, despite a loss of smallest-scale information, the results are similarly accurate across the range of 7.5 μm to 75 nm. This investigation demonstrates a simple and widely accessible path to advanced topography characterization and analysis. Finally, we apply this technique to characterize flooring surfaces in the context of research on slip-and-fall accidents.

11:00 am – 11:20 am

3959395: The infamous Fuorinated Carbon Materials in Tribology – A Journey to the Atomic-Scale Origins of Their Unique Properties

Gianpietro Moras, Thomas Reichenbach, Leonhard Mayrhofer, Michael Moseler, Fraunhofer IWM, Freiburg, Germany; Takuya Kuwahara, Osaka City University, Osaka, Japan

The unique properties of per- and polyfluoroalkylic substances (PFASs) in terms of hydrophobicity, anti-adhesion, chemical stability and low friction make them popular materials also in tribology. However, their high chemical stability poses serious problems owing to their accumulation in the environment and in biological systems, and regulations in this area aim to their replacement. This step is not trivial but understanding the mechanisms behind their performance may help. Here, we summarize our atomistic modelling studies on the chemical and physical origin of some of the properties of PFAS that are relevant in a tribological context. We start by discussing how PFAS can be simultaneously polar and hydrophobic. Next, we investigate why and when fluorinated carbon interfaces exhibit lower friction than their hydrogenated analogs. Finally, we discuss the mechanism of film transfer and solid lubrication in PTFE-lubricated steel contacts.

Plenary Session
1:00 pm – 2:00 pm (Salon D)
Monday, November 13, 2023

KEYNOTE PRESENTATION

STLE Trends Report: Opportunities in the Future

Neil Canter, President, Chemical Solutions (USA)

This presentation focuses on the recent release of STLE's 2023 Report on Emerging Issues and Trends in Tribology and Lubrication Engineering and discusses key trends that are and will be impacting the tribology and lubrication field including supply chain, sustainability, electrification, manufacturing, medical/health and government regulations. These issues portend a future that will be full of opportunities, particularly for those individuals just entering the field. Sustainability will be prominently discussed in this presentation because it is impacting how end-users of lubricants are operating. Electrification is a term that defines the move towards decarbonization – encompassing applications beyond just electric vehicles. Manufacturing focuses on the benefits tribology can provide through efficiency improvements that reduce emissions and boost sustainability. Medical/health includes ways tribology is in use to help improve the way patients deal with health issues. Government regulations continues to be an important factor in determining what lubricants can be used and how they should be used. The case will be made that the future for tribology is bright and demand will increase for tribologists because of the growing need to improve productivity and efficiency through reducing emissions and saving energy.

Dr. Neil Canter is an STLE Fellow and an STLE Certified Metalworking Fluids Specialist (CMFS)™, with more than 35 years of experience working in the lubricants industry. He received his doctorate in chemistry from the University of Michigan in 1983 and his bachelor's of science in chemistry from Brown University in 1978. Canter runs his own consulting company, Chemical Solutions, specializing in commercial development, marketing, product development and regulatory support for the lubricants industry. Canter is a member of STLE, the American Chemical Society (ACS), and the Society of Automotive Engineers (SAE). He is a contributing editor responsible for writing the monthly Tech Beat column in STLE's TLT magazine. He is also a member of STLE's Metalworking Fluid Education & Training Committee, STLE Education Committee, and the program chair for the STLE Philadelphia Section. Besides providing technical and commercial support, he is also the host of STLE's podcast series: "Perfecting Motion: Tribology and the Quest for Sustainability."

Session 2A (Salon A)

Materials Tribology II

Session Chair: Mark Sidebottom, Miami University, Oxford, OH

SPOTLIGHT PRESENTATION

2:00 pm – 2:40 pm

3952065: New Contact Temperature Model for Polymer Contacts, Considering Tribo-System Geometry: A Step Toward Generalization

Mitjan Kalin, University of Ljubljana, Ljubljana, Slovenia

Contact temperatures are clearly an important contact parameter in tribology design. However, we still lack a generally accepted and broadly used model, allowing for easy and fast estimation of the contact temperature. This is true for steels and various other metals, and so much more for polymers. Namely, polymers are significantly more sensitive to contact temperatures due to their poor mechanical and thermal properties. Therefore, the inaccuracy in predicting the contact temperatures in polymer contacts may result in notable variation of expected surface conditions and detrimental tribological behavior. In this work, we present a ready-to-use temperature model for poylmer/steel contact, preferentially designed for pin-on-disc studies, which also considers tribo-system geometry (volume, surface). Moreover, a further development of a more generalized model for various tribological systems and their geometries is presented and discussed, as well as the effect of different contact material properties.

2:40 pm – 3:00 pm

3750598: Laser Surface Texturing of Stainless Steel Substrate for Improving the Wear Life of PDA/PTFE Coatings

Firuze Soltani-Kordshuli, Nathaniel Harris, Min Zou, University of Arkansas, Fayetteville, AR

Stainless steel substrates were laser textured, according to two texture designs using four laser powers. Polydopamine/poly-tetrafluoroethylene (PTFE) thin coatings were then deposited on smooth and laser textured substrates. Tribological tests were performed using a reciprocating ball-on-flat configuration to study the effects of laser surface texturing the substrate on the durability of the coatings. It was found that laser texturing the stainless steel substrates significantly prolonged the coating life, slightly decreased

the coefficient of friction, and effectively prevented large-scale delamination of the coating. Higher laser powers contributed to larger surface roughness and deeper texture grooves that led to better wear mechanisms. These texture grooves stored more PTFE and supplied the solid lubricant to the worn interface to restore the interface lubrication and thus delayed the coating failure.

SPOTLIGHT PRESENTATION

3:00 pm – 3:40 pm

3963437: Effect of Counterbody Material on Tribofilm Formation of PTFE-Chromium Composites

Mark Sidebottom, Faysal Haque, Miami University, Oxford, OH; Sifat Ullah, Rensselaer Polytechnic Institute, Troy, NY

Different filler particles (e.g., α-Al2O3, activated carbon nano fillers etc.) composited with PTFE reduce wear by ~10,000x when slid against 304 stainless steel. These composites are known as ultra-low wear materials. Recently, three new composites (PTFE-Cr, PTFE-Ti, PTFE-Mn) achieved ultra-low wear when slid against Brass 260. However, these composites showed mixed performance against 304 SS. In this study, four different counterbody materials (Cu 110, Zn-galvanized steel, 304 SS, and brass 260) were tested against PTFE-Cr to identify how counterbody material properties affected wear and friction performance. The tests revealed high variation in friction coefficient (μ~0.15-0.28) and wear rate (8x10-9 mm3/Nm < K < 1x10-6 mm3/Nm). To understand the evolution of wear, the tribosystem was analyzed using optical microscopy, profilometry, and surface energy measurements. Variance in transfer film morpohology was dependent on the counterbody material the PTFE-Cr composite slid against.

3:40 pm – 4:20 pm – Break

4:20 pm – 4:40 pm

3961476: Self-Lubricating Polyimide for EV Wear and Friction Applications

Hau-Nan Lee, Yasuaki Mashimo, Ruth Jackowiak, Yuichi Maruyama, Takuya Miyauchi, Lucas Amspacher, DuPont Vespel Technology, Wilmington, DE

DuPont Vespel® has developed new polyimide-based self-lubricating materials that perform in high pressure and velocity (PV) conditions. These materials also show low friction and excellent wear-resistance in dry or lubricated conditions, which makes them ideal tribological solutions for thrust washers, bushings, and seal rings in driveline applications for electric vehicles. In this study, we report tribological performance of three polyimide-based materials containing different solid lubricant packages. The tribological tests were performed using block-on-ring and pin-on-disk configurations under dry condition. The formation of transfer films on the steel counterpart was investigated by optical microscopy and elemental analysis. To understand the tribological performance of the materials under lubricated conditions, we developed a thrust washer test protocol to determine the PV limit, wear, and friction of the materials in an automotive transmission fluid. The new materials show more than 5 times higher PV limits in dry condition and 50% higher PV limit under lubricated condition, compared to current polyimide product offerings. The tribological testing results of other engineering polymer-based and metallic materials will also be presented as comparisons.

4:40 pm – 5:00 pm

3931243: Relative Scuffing Resistance of Aerospace Bearing Materials and Lubricants

Carl Hager, Jr., The Timken Company, North Canton, OH; Robert Sadinski, Air Force Research Laboratory, Dayton, OH

Rotorcraft propulsion systems should continue to operate at drive system power for a minimum of 30 minutes after loss of lubricant or lubrication system, according to Aeronautical Design Standard ADS-50-PRF. Rolling element bearings within these systems are typically manufactured from steel alloys. The combination of alloy selection and heat treatment can significantly affect the propensity for adhesive wear to occur between rolling elements and raceways. This type of damage can be exacerbated by the loss of lubricant supply to the contacts. Modern hybrid bearings utilize steel alloy raceways with ceramic rolling elements, typically silicon nitride. Hybrid material contacts are often less susceptible to adhesive wear than all-steel contacts. For this work, bench level lubricated rolling/sliding wear tests were conducted to rank the relative adhesive wear resistance of six bearing steel alloys, as well as the pairing of each alloy with silicon nitride. Tests were conducted with an ISO VG 10 polyalphaolefin oil containing only rust and oxidation inhibitors, as well as five fully formulated aviation gear oils. The relative ranking of each material pair, and lubricant effects on test results, will be presented.

5:00 pm – 5:20 pm

3930929: Improving Tribological Properties of Low-Cost Carbon Steels via Chromizing

Tomas Grejtak, Jun Qu, Oak Ridge National Laboratory, Oak Ridge, TN

Chromizing is a surface treatment method applied to ferrous alloys to improve their corrosion and mechanical properties. However, the influence of chromizing on the tribological properties of steel materials with different microstructure and composition is not well understood. In this work, we demonstrate that the low-cost carbon steels can achieve the mechanical properties of more expensive tool steels via an affordable and high throughput chromium diffusion process. The tribological and hardness properties of AISI 1095 carbon steel, 52100 bearing steel and A2, D2 and M2 tool steels were investigated via abrasion wear testing, nanoindentation, microindentation, and morphological characterization. The results showed that the chromizing significantly increases the hardness and wear resistance of 1095 and 52100 steels while the effect on the wear resistance in the D2 and M2 tool steels was insignificant.

Session 2B (Salon B)

Lubricants II

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

Session Vice Chair: Dairene Uy, Shell Global Solutions (US), Inc., Houston, TX

SPOTLIGHT PRESENTATION

2:00 pm – 2:40 pm

3962263: CNTs to Enhance Heat Transfer of EV Fluids

Jun Qu, Chanaka Kumara, Wenbo Wang, Hsin Wang, James Haynes, Oak Ridge National Laboratory, Oak Ridge, TN; Ning Ren, Jacob Bonta, Edward Murphy, Roger England, Valvoline Global Operations, Lexington, KY

The e-motor in an EV rotates 15,000 rpm and potentially goes up to 30,000 rpm in the future. The copper winding on the e-motor gets very hot, which is cooled by the lubricant. Increasing heat transfer efficiency currently is a primary challenge for e-motor oils to allow higher currents for higher torque output. The remarkable thermal conductivity (2800–6000 W/mK, 10X higher than copper) of carbon nanotubes (CNTs) present another opportunity for being used as additives for the e-motor fluids to improve the heat transfer capacity. However, CNTs have poor suspendability in fluids and tend to aggregate and precipitate. This study innovated covalent functionalization for CNTs to enable stable suspension and uniform dispersion of CNTs in both polar and non-polar fluids. Initial research has added 0.1 wt.% of modified CNTs into an EV base oil, resulting in 10% higher thermal conductivity and 10% higher volumetric heat capacity with <4% viscosity increase, resulting in 8% improved heat transfer efficiency (Mouromtseff Number). The effects of CNT type, diameter, length, and concentration on the fluid's thermal and rheological properties are being investigated. Research sponsored by the Vehicle Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy (DOE).

2:40 pm – 3:00 pm

3963106: The Study of the Effect of Water on Engine Oil Rheology and Antiwear Performance in HEVs (Hybrid Electric Vehicles) Application

Dairene Uy, Shell Global Solutions (US), Inc., Houston, TX; Hongyu Li, Hua Hu, Jiandi Jiang, Junfang Nie, Weizi Li, Shell (Shanghai) Technology Limited, Shanghai, China; Jiping Zhang, Yan Wang, Chenhui Zhang, Tsinghua University, Beijing, China

Contamination of as much as 20% water was observed in field trial of hybrid electric vehicles in particular plug-in model. The presence of water can affect engine oil antiwear performance in complex ways. To gain better understanding on the effect of water contamination on the antiwear performance, experimental investigations including rheology properties, oil film thickness measurement and boundary antiwear performance on several 0W-20 formulations with different water contents were conducted. Tribofilm were analyzed using X-ray photoelectron spectroscopy. It is found that water have a long-lasting detrimental effect on tribofilm formation, while formulation with different detergent-system showed different water resistance property regarding on oil film thickness in high-speed elastohydrodynamic lubrication and SRV wear volume in boundary lubrication regime. Antiwear performance was checked on simplified blend with ZDDP, water and different detergents, demonstrating detergent selection plays an important role in offsetting the detrimental effect of water on antiwear performance.

3:00 pm – 3:20 pm (Open Slot)

3:20 pm – 3:40 pm

3965747: Tribological Properties of Nano Al_2O_3 Gear Oil From Lube Oil Blending Plant Effluent Oil for Automotive Gearbox

Kaisan Usman, National Agency for Science and Engineering Infrastructure, Abuja, Nigeria; Shafiu Lawal, Yusuf Dambatta, Laminu Kuburi, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

The establishment of lube oil blending plants in Nigeria have led to a continuous discharge of industrial effluent in densely populated states like Lagos, Port Harcourt, Ibadan, Kano, Kaduna, etc., that threatens well-being of humanity, plants, aquatic lives and even construction soils. This paper focuses on the determination of tribological properties of Nano Al_2O_3 oil for extreme pressure application developed from lube oil blending plants effluent oil as an alternative means of mitigating negative effects associated with the effluent to the living environment. The Al_2O_3 nanoparticles were characterized with the use of Fourier transform infrared (FTIR), X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM). The tribological properties of the four Nano lubricant samples were studied with varying weight percentages of Al_2O_3 in the pure effluent oil ranging from 0.1 wt.% to 0.4 wt.% in a step of one to understand the behavior of the materials and comparison was made with pure effluent oil. The antiwear property was observed to have considerably improved at 0.4 wt.% nanoparticles concentration with 26.14%, whereas, friction was observed to have slightly increased with the dispersion of Al_2O_3 nanoparticles with 6% at 0.3 wt.%. Based on the results obtained, the study indicated that the tribological properties of effluent oil can be enhanced with the dispersion of nanoparticles.

3:40 pm – 4:20 pm – Break

4:20 pm – 4:40 pm

3931086: The Effect of Rheological Feature of Graphene Oxide-Involved Emulsion on its Corresponding Lubricity Performance

Hsin-Hung Ou, China Steel Corp., Kaohsiung, Taiwan

This study aims to investigate the effect of rheological property of graphene oxide (GO)-involved emulsion on its corresponding lubrication behavior. The friction of GO-involved emulsion could be reduced by a factor of 1.2 as compared to that of the base emulsion. The worn surface of steel specimen after lubrication demonstrated that the presence of GO shrank the wear size and depth by 7.6% and 14%, respectively. The welding loading of GO involved oil also

gave rise to a 315 kg level, while that of base oil only allowed 250 kg. The improved lubricity performance of GO involved emulsion was attributed to the fact that GO enhanced either anchoring reaction between oil drops (increased oil viscosity) or chemical reaction toward steel substrate. Furthermore, the variations of d50 oil droplet sizes for base and GO emulsion were 16.9% and 11.2%, respectively, suggesting a slight improvement on emulsion stability with the presence of GO during lubrication. This result was plausible since carboxyl groups within GO are protonated at acidic condition such that the GO particles turned to less hydrophilic and form GO aggregates, resulting to a prevention of coalescence between oil drops. On the other hand, the ID/IG values of GO within emulsion before and after lubrication were 0.61 and 0.66, respectively, revealing a trivial increase in the disorderliness degrees after lubrication, which was corresponding to the change of d110 lattice, as determined in HR-TEM image.

Session 2C (Salon C)

Tribochemistry II

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

SPOTLIGHT PRESENTATION

2:00 pm – 2:40 pm

3771581: A New Friction Modifier Mechanism Based on Pressure-Induced Hydrogen Bonding

Thomas Reddyhoff, James Ewen, Pushkar Deshpande, Imperial College London, South Kensington, London, United Kingdom; Mark Frogley, Diamond Light Sources, Didcot, United Kingdom; Mark Welch, Wren Montgomery, Natural History Museum, London, United Kingdom

We present new research into the use of n-alcohols as "traction-modifier" additives that can be blended with oils in order to reduce elstohydrodynamic friction (traction) without impacting film thickness. This is based on a recent discovery that neat n-alcohols can self-assemble under pressure to form layered structures that provide liquid superlubricity, (i.e., a friction coefficient below 0.01, inside lubricated contacts. This occurs within the central, high-pressure region within a contact so that film thickness is unaffected. Furthermore, similar beneficial behavior occurs even after n-alcohols have been diluted by a hydrocarbon base oil. These performance gains are supported by ball-on-disc tribometer friction and film thickness data, while insights into the mechanism are provided by FTIR measurements made on lubricant samples within a high-pressure diamond anvil cell. The link between molecular structure and friction reducing performance is discussed along with the practicalities of implementing such additives in practice.

SPOTLIGHT PRESENTATION

2:40 pm – 3:20 pm

3757795: Understanding the Effect of Forces on Tribochemical Reaction Rates

Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

The effect of applied stress σ on the rates of tribochemical reactions is described using the Bell model, where the rate varies as $\exp(\sigma\Delta V‡/kBT)$, where $V‡$ is the activation volume. Strategies for measuring reaction pathways are illustrated using the gas-phase lubrication of copper by dimethyl disulfide (DMDS) where the rate of reaction of on a Cu(100) single crystal substrate is measured by exerting the force using an atomic force microscopy tip. The measured angular dependence of the methyl thiolate decomposition rate suggests that the kinetics can be analyzed using quantum mechanical methods that are used to analyze thermal reaction rates and is confirmed by measuring the effect of a normal stress on the reaction rate, which is excellent agreement with values calculated using quantum theory. This approach is extended to studying shear-induced methyl thiolate decomposition, which occur more rapidly and on investigating the tribochemical decomposition of carboxylates on Cu(100).

3:20 pm – 3:40 pm

3755889: Description of High Throughput Elemental Analysis in Oil Samples Utilizing ICP-OES and Automation to Overcome Common Issues in Measurement

Christopher Conklin, Paul Krampitz, Agilent Technologies, Wood Dale, IL

The determination of elements in used and unused lubricating oils and base oils and rapid screening of used oils for wear-metals such as Fe, Cu, and Al is a common approach to monitoring wear in engine, gearbox, and other components. The trace metals that enter these lubricating oils as mechanical wear from moving parts is likely to be present in the oil as metallic particles rather than dissolved in the oil; thus, it can be essential to homogenize each sample before analysis to ensure representative data. This talk will discuss high throughput analysis of used lubricating oils using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and an autosampler that homogenizes samples immediately before analysis, resulting in improved throughput and results.

3:40 pm – 4:20 pm – Break

(Session 2C continued)

4:20 pm – 4:40 pm

3959765: Exploring the Role of Metalworking Fluids in Tribochemistry: Enhancing Performance and Efficiency on the Surface Level

Jesse Ziobro, Univar Solutions, Houston, TX

The field of metalworking fluids (MWFs) has seen significant advancements in recent years, with a particular focus on the effects of tribochemistry. Tribochemistry refers to the study of chemical reactions that occur at the interface between a metal surface in relative motion. The interplay between the MWF and metal can have significant impact on the performance and longevity of the tool used in the metalworking process. This presentation will explore the effects of tribochemistry on MWFs, including the formation of tribofilms, the impact on surface finish, and the potential for corrosion and wear. Additionally, the role of additives in MWFs will be discussed, as well as emerging technologies that may further enhance the understanding and utilization of tribochemistry in metalworking fluids.

4:40 pm – 5:00 pm

3966149: Surface-Protective Tribofilms via Tribocatalysis and Surface-Active Precursors

Q. Jane Wang, Jannat Ahmed, Yip-Wah Chung, Northwestern University, Evanston, IL; Stephen Berkebile, DEVCOM Army Research Laboratory, Aberdeen Proving Ground, MD

This study investigates the mechanisms involved in the in-situ formation of lubricious and wear-protective tribofilms in systems utilizing chromium oxide surfaces and dodecane as the lubricant. Through the use of reactive molecular dynamics simulations, we explored the process of dodecane fragmentation and tribopoly - merization, while also examining the impact of environmental oxygen on the fragmentation rate. Our visualization of the simulation outputs revealed that chromium oxide acts as a catalyst, facilitating the fragmentation of dodecane molecules through the synergistic effects of Cr 3+ sites and oxygen vacancies. Subsequently, the fragmented molecules polymerize, leading to the formation of tribopolymers. We further extended our simulation by introducing five mole percent of cyclopropanecarboxylic acid (CPCa) into dodecane. Notably, CPCa was found to accelerate the fragmentation of dodecane, resulting in tribopolymers that directly attach to the surface, thereby enhancing its lubrication efficacy.

5:00 pm – 5:20 pm

3931288: Minimizing Engine Wear in the Sequence IVA Through Tribofilm Formation

Darryl Williams, Grant Pollard, Afton Chemical, Corp. Richmond, VA

Engine wear protection is the key metric in the Sequence IVA test. While obsolete, this test remains a good platform for evaluating camshaft wear with engine lubricants. We have found that tribofilm formation is a key element in providing good performance in this test. Surface analysis results will be presented from test specimens and related to the measured wear in the test. Surface analysis by SEM allows definition of portions of the lifter pad where tribofilms are formed.

Session 2D (Salon E)

Surfaces and Interfaces II

(Including Nanotribology)

Session Chairs: Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA and Gianpietro Moras, Fraunhofer IWM, Freiburg, Germany

Session Vice Chairs: Vimanyu Chadha, University of Pittsburgh, Pittsburgh, PA and Loren Baugh, Auburn University, Auburn, AL

2:00 pm – 2:20 pm

3931532: Analytical Friction Models for Molecular Adsorbates

Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

Atomic-scale nanoscale friction models, based on ideas from Tomlinson and Prandtl, conventionally use simple periodic sliding potentials to model the velocity and temperature dependences but this approach is not well suited to describing the friction of adsorbed molecular overlayers. To address this, we use the ideas of Evans and Polanyi to develop a thermodynamic theory to analyze stress-dependent reaction rates. We also use a simple model interaction potential between the tip and the outer surface of the organic substrate to develop analytical models for molecular friction of self-assembled monolayers (SAMs) on surfaces, so-call friction modifiers. In particular, this potential can be coupled to the molecular tilt to provide an analytical model for the chain-length dependence of SAM friction that is in good agreement with experiment. Interestingly, this model does not invoke intermolecular van der Waals' interaction to explain the effect. Finally, this strategy is used to model the chain-length and velocity-dependence of shear-induced tribochemical reaction rates.

2:20 pm – 2:40 pm

3959548: Effects of Hot Switching on Contact Reliability of Pt-Coated Microswitches at Low Contact Voltages

Deepak Kumar, Carnegie Mellon University, Pittsburgh, PA

The reliability issues, particularly with the MEMS switch contacts, have hampered the commercialization of these switches. Under cold switching conditions, the platinum (Pt)-coated MEMS switches, demonstrated a long lifetime (300 million cycles). However, hot switching at high contact voltages (Vc) (>1V) exacerbates contact erosion and surface degradation, which shortens the lifetime of MEMS switches. Little attention has been paid to the switching behavior of Pt-coated MEMS switches at low Vc (<1V). We hypothesize that below 0.5 V, well below the work function of Pt, hot switching damage will be greatly diminished. In the present work, using a designed MEMS test setup, we investigated the hot switching behavior of O2 plasma-treated Pt-coated MEMS switches at lower Vc, down to 0.1 V. To gain the fundamental understanding of various phenomena, including field evaporation, field emission, electromigration, arcing, and bridge formation/ohmic heating, that can contribute to contact surface degradation, the hot switching behavior at leading (switch closure) and trailing edge (switch opening) of the switching cycle is also investigated. Scanning electron microscope (SEM) is used to inspect the degradation mechanisms, post experiments. Results indicated that hot switching damage decreased significantly, improving reliability at low contact voltages. The outcomes of the research are valuable in hot switching applications of nanoswitches, where contact voltages are very low.

2:40 pm – 3:00 pm

3972299: UHMWPE Polymer Composite and Hybrid Composite Coatings for Tribological Applications

Abdul Samad Mohammed, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Ultra-high molecular weight polyethylene (UHMWPE) falls under a class of polymers referred to as thermoplastics and finds its use in a variety of applications requiring a high degree of impact and wear resistance in both medical and industrial applications. It has found its way either in the bulk form or as a coating into various tribological applications, ranging from biomedical to bearing applications due to its excellent abrasion resistance coupled with low friction coefficients. However, in spite of its excellent inherent properties, UHMWPE does suffer from few limitations such as low load bearing capacity and low thermal stability. Hence, various researchers developed different techniques to enhance these properties by fabricating UHMWPE composite/hybrid composite coatings to make it suitable for demanding tribological applications. This talk focuses on two such successful attempts made recently by our group in developing UHMWPE composite and hybrid nanocomposite coatings for bearing and bio-medical applications, respectively. An overview of the selection of proper reinforcements, keeping in mind the targeted applications, efficient filler dispersion techniques, developed coating procedures, substrate pre-treatment procedures and various characterization techniques useful for effectively interpreting the results will be presented.

3:00 pm – 3:20 pm

3958274: Friction in Adhesive Contacts Between Hard Indenters and Soft Elastomers: Experiments and Simulations

Iakov Lyashenko, Valentin Popov, Berlin University of Technology, Berlin, Germany

The effects of roughness, hard particles in contact zone, and chemical inhomogeneities on contact properties (normal and tangential contacts) in adhesive contacts between hard indenters and soft elastomers were experimentally investigated. Influence of indentation depth, radius of indenter, elastomer thickness, elastic modulus of an elastomer, velocity of indenter motion was analyzed. The case was investigated in which elastomer's surface was coated with a thin layer of a chalk dust to exclude adhesion between contacted bodies. Based on experiments, an adhesive strength and mechanical energy dissipation in a full cycle indentation/detachment was analyzed. It is shown that if the amplitude of the indenter oscillations is less than this critical value, there is no dissipation in a contact due to adhesion. We also performed theoretical modelling in the frameworks of the boundary element method (BEM), method of dimensionality reduction (MDR), also proposed different phenomenological models were proposed. This work was supported by Deutsche Forschungsgemeinschaft (Project DFG PO 810-55-3).

3:20 pm – 4:00 pm – Break

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AM | **TFC TECHNICAL SESSIONS TIME GRID** | Tuesday, November 14

Joint Plenary Session – Salon EFGH

KEYNOTE PRESENTATION

8 – 9 am Challenges of Selecting the Correct Electric Vehicle Driveline Fluid, p. 26
Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

9 – 9:20 am **Networking Break – Exhibits & Posters** (Foyer)

	Session 3A Biotribology I	Session 3B Lubricants III	Session 3C Fluid Lubrication I	Session 3D Surfaces & Interfaces III
Location	**Salon A**	**Salon B**	**Salon C**	**Salon E**
TIME **9:20 am**		Active Control of Friction Coefficient Under Lubricated with Ionic Liquids, S. Kawada, p. 27	**SPOTLIGHT PRESENTATION** The Slippery Slope – Temperature, Pressure and Speed Dependent Friction Modifier Performance in a Wet Clutch, D. Williams, p. 28	Environmentally-Sustainable Thickeners for Greases: Engineering a Replacement for Lithium Salts, P. Egberts, p. 30
9:40 am	**SPOTLIGHT PRESENTATION** Slippery pHysics, A. Pitenis, p. 26	Surfactant Aggregation and Tribological Properties in Water: A Study of Sodium 2-Hexyldecanoate, H. Gu, p. 27		Developing Acoustic Emission Techniques to Monitor Rubbing Contacts, T. Reddyhoff, p. 30
10 am		Electrical Impedance Spectroscopy to Analyze Lubricant Composition and Performance, T. Reddyhoff, p. 28	Experimental Investigation into Minimum Flowrate Conditions for Ultra-Smooth Surfaces, M. Handschuh, p. 29	Tribological Performance of Polymeric Coatings for HFO-1234yf-Based EV Air Conditioning Compressors, A. Raut, p. 30
10:20 am	A Coupled BEM-FEM Contact Mechanics Model of the Finger-Device Interface in Electroadhesive Haptic Devices, S. Chatterjee, p. 26	Tribological Properties When MoDTC, ZDDP and OFM are Used Together, S. Nambo, p. 28	Elastohydrodynamic Lubrication with Water Droplets in Oil Emulsion, F. Zhang, p. 29	A Friction Determination in Sheet Metal Forming, A. Pirnazarov, p. 30
10:40 am	Multiphysics and Variability of the Finger-Material Interface for Consumer Product Design, M. Cynthia Hipwell, p. 27	Molecular Simulation Approach for Dynamics of Extreme Pressure Agents, H. Washizu, p. 28	Lubrication Subjected to the Effect of Electromagnetic Fields: Recent Research Progress and A Generalized All-Field Reynolds Equation, X. Wang, p. 29	
11 am	Numerical Investigation of Rate-Dependent Adhesion in Viscoelastic Contacts with Application to Articular Cartilage, M. Eriten, p. 27			

PM **TFC TECHNICAL SESSIONS TIME GRID** | Tuesday, November 14 | Wednesday, November 15

Plenary Session – Salon D

KEYNOTE PRESENTATION

1 – 2 pm Development of Power Dense and Energy Efficient Bearings to Address the Needs of Modern Machinery, p. 31
Michael Kotzalas, Director of Global Customer Engineering, The Timken Company (USA)

3:40 – 4 pm **Networking Break – Exhibits & Posters** (Foyer)

	Session 4A Energy/Enviroment/Mfg. I	Session 4B Materials Tribology III	Session 4D Machine Elements/Systems I
Location	**Salon A**	**Salon B**	**Salon D**
2 pm	Machining Evaluation of Novel Phosphate Ester for Hard Metal Machining, W. Harwood, p. 31	Oil-Free Superlubricity on Rough Steel Surfaces under Sustained Sliding-Rolling Contact, A. Sumant, p. 32	
2:20 pm	**SPOTLIGHT PRESENTATION** In Situ Investigations into the Adhesion and Compression of Catalyst-Relevant Metal Nanoparticles, T. Jacobs, p. 31	Deposition and Properties of Electroplated MoS_2 Solid Lubricant Coatings, M. Dugger, p. 32	An Abnormal Rolling Contact Fatigue Failure with Fluorine Grease, H. Tanaka, p. 33
2:40 pm		Performance Driven Metrics to Assess Microstructural Characteristics of Molybdenum Disulfide Coatings, T. Babuska, p. 32	Extreme Condition Tribology – High Temperature Vacuum Bearing Operation, C. DellaCorte, p. 34
3 pm		Quantifying Water Diffusion in Molybdenum Disulfide Coatings Using ToF-SIMS Depth Profiling, N. Vergara, p. 32	
3:20 pm		3964090: Self-Lubricating Novel 2D High Entropy Alloy on Steel Surfaces, S. Sunkara, p. 33	Rolling Element Bearing Damage in the Presence of Applied Electric Current, L. Sanchez-Camacho, p. 34
3:40 pm	**Break**	**Break**	**Break**
4 pm		The Influence of Solid Lubricant Reservoir's Morpho-Dimensional Evolution on the Sliding Wear of Sintered Iron-Based Self-Lubricant Composites, J. Daniel De Mello, p. 33	Productivity Improvement of The Loom Shed by Optimizing Friction, A. Pirnazarov, p. 34
4:20 pm		Al_2O_3/SiC Composite with Graphite as Self-Lubricant – A Material-by-Design Development Approach for Cutting Tools, S. Akhtar, p. 33	White Etch Cracks in Wind Bearings, M. Sridhar, p. 34
4:40 pm			
5 pm			

TIME

Wednesday, Nov. 15

Session 5D
(Salon D)

"Beyond the Cutting Edge" Plenary Symposium

Highlights from Tribology Letters

8 am
More on Mouthfeel – Imbibing Bubbly Beverages, T. Reddyhoff, p. 35

8:30 am
Linking Strength, Friction, and Ordering in Metallic Glasses, N. Argibay, p. 35

9 am
The Ultrafast Finger Snap is Mediated by a Frictional Skin Latch, E. Challita, p. 35

9:30 am – Break

10 am
Linking Molecular Structure and Lubrication Mechanisms in Tetraalkylammonium Orthoborate Ionic Liquids, F. Mangolini, p. 35

10:30 am
Tribotronic Control and Electrochemcial Properties of Nanofluid Interfaces, J. Krim, p. 36

11 am
Nanosensors for In Situ Measurement of Pressure and Temperature in EHD Contacts, D. Philippon, p. 36

Joint Plenary Session
8:00 am – 9:00 am (Salon EFGH)
Tuesday, November 14, 2023

KEYNOTE PRESENTATION

Challenges of Selecting the Correct Electric Vehicle Driveline Fluid

Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

In this new, ever-changing world of electric vehicles, the latest hardware design trends require the fluid to lubricate the gearbox while also cooling the motor and inverter. Because of these new unique requirements, the driveline fluid selection can be very difficult. Many of these new properties do not have established test methods, nor are their impacts completely understood. These properties would include high-speed durability, aeration and foaming, copper corrosion, E&M field, material compatibility, oil/water separation, oxidation stability, and dielectric strength. This keynote presentation will highlight the hardware supplier's perspective of challenges and testing gaps associated with each property.

Troy Muransky is lead materials engineer for American Axle & Manufacturing. He received his bachelor of science degrees in chemistry and chemical engineering from the University of Michigan and Wayne State University, respectively. His 17 years in the automotive industry include various roles in Materials, Process, and Environmental Engineering, as well as Analytical Chemistry, Quality, and Laboratory Management. Troy's technical expertise is in lubricants, surface treatments, and coatings with focus on proper material selection, testing, troubleshooting, and launch support for driveline applications. He currently serves as chair and ASTM D7452 (L-42) reviewer for the Lubricant Review Institute (LRI) SAE J2360 Gear Oil Approval Committee, and is also an active member of ASTM, SAE, and STLE.

Tuesday, November 14, 2023

Session 3A (Salon A)

Biotribology I

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

Session starts at 9:40 am

SPOTLIGHT PRESENTATION

9:40 am – 10:20 am

3972425: Slippery pHysics

Angela Pitenis, Allison Chau, Conor Pugsley, Madeleine Miyamoto, Yongkui Tang, Claus Eisenbach, Thomas Mates, Craig Hawker, Megan Valentine, University of California, Santa Barbara, Santa Barbara, CA

Hydrogels are three-dimensional, crosslinked networks of hydrophilic polymers swollen in water. This class of soft materials is used in many industries (e.g., biomedicine, agriculture, wastewater management) due to their high-water content, capacity for water retention, and tunable mechanical properties. Polyacryla - mide hydrogels have also attracted scientific interest in the tribology community due to their fascinating energy-dissipation properties. In this study, we observe that increasing solution pH reduces the friction coefficient of polyacrylamide hydrogels in sliding contact with hemispherical probes of either borosilicate glass or poly - tetrafluoroethylene (PTFE). We propose that the mechanisms of pH-dependent polyacrylamide friction may be a combination of electrostatics and hydrolysis.

10:20 am – 10:40 am

3931172: A Coupled BEM-FEM Contact Mechanics Model of the Finger-Device Interface in Electroadhesive Haptic Devices

Sitangshu Chatterjee, M. Cynthia Hipwell, Texas A&M University, College Station, TX

Electro-adhesive haptic devices apply electrostatic forces to modulate the friction force (by changing the true interfacial contact area) and render tactile sensations. Almost all existing studies predict the frictional performance using either Finite Element or Boundary Element models. However, each method has its own limitations and is individually inadequate to capture the multiscale roughness of the finger, comprised of multilayered tissues with different material properties. Thus, a good contact mechanics model is essential to predict the friction force and strain energy density at mechanoreceptors to design better devices. In this study, we develop a coupled BEM-FEM model. First, a BEM model is used to solve the microscale contact mechanics model and accurately predict the air gap distribution and true contact area, which are used to compute the normal electro-adhesive and tangential friction force, respectively. The forces from the BEM model are then used in an FEM model to study how the stresses and strains propagate through the multi-layered structure of the human finger. Thus, this model allows us to accurately predict the friction performance in electro-adhesive devices. Additionally, the strain energy densities at the mechanoreceptor locations also help us understand how the friction affects haptic perception. The learnings from this study can also be extended to optimize electro-adhesive braking performance between any rough surfaces with complex underlying structures.

10:40 am – 11:00 am

3748381: Multiphysics and Variability of the Finger-Material Interface for Consumer Product Design

M. Cynthia Hipwell, Xinyi Li, Texas A&M University, College Station, TX; Yinzhong Guo, Dow Chemical Co., Lake Jackson, TX

The sense of touch has been found to affect people's preference of consumer products through touch of its surface or packaging. Studies have shown that people generally perceive low friction surfaces as more pleasant. Texturing is often the approach to reduce the friction, yet the interface is complex due to multi-physical phenomena such as capillary bridges formed by sweat, deformation and contact as well as the textures ranging from macroscale to nanoscale on both surfaces. In addition, the existence of lipids and sebum makes the friction force and the tactile feeling of the textured surface more difficult to predict by affecting the interface in different ways. In this work, we propose a multi-physics model to elucidate the underlying physics and mechanisms of the finger-material interface at the single asperity level, which predicts well the measured friction force and tactile perception of two plastic films used for food packaging.

11:00 am – 11:20 am

3939738: Numerical Investigation of Rate-Dependent Adhesion in Viscoelastic Contacts with Application to Articular Cartilage

Melih Eriten, Uraching Chowdhury, University of Wisconsin-Madison, Madison, WI

Viscoelastic contacts are known to exhibit rate-dependent adhesion. Previously, the authors tested porcine articular cartilage and observed similar rate-dependence in adhesion. The aim of this study is to model those experiments and investigate the influence of bulk viscoelasticity and interfacial properties on the rate-dependent adhesion observed. A finite element model of a rigid sphere contacting a linear viscoelastic half-space is constructed. Constitutive parameters for the half-space are tuned to the measured relaxations. Interfacial interactions are modeled via traction-separation laws. The quasistatic interfacial models deliver rate-dependent adhesion response in close agreement with the experiments. This finding suggests that adhesive process zone at the contact edge expands at high unloading rates due to limited bulk relaxation over the contact. This expansion leads to increase in pull-off forces and apparent work of adhesion. Simulated crack-shapes, tractions and viscoelastic energy dissipation at the contact edges closely follow the predictions of the Greenwood-Johnson 1981 model.

Session 3B (Salon B)

Lubricants III

Session Chair: Shouhei Kawada, Kansai University, Osaka, Suita-shi, Japan

9:20 am – 9:40 am

3930612: Active Control of Friction Coefficient Under Lubricated with Ionic Liquids

Shouhei Kawada, Kazuki Akamatsu, Kansai University, Osaka, Suita-shi, Japan; Shunsuke Tanji, Masaaki Miyatake, Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

To realize a sustainable society, energy loss due to friction must be reduced to the minimum in mechanical systems. On the other hand, high friction force is required for efficient power transmission. Maintaining oil film thickness is a very important factor in terms of maintenance tribology. This investigation aims to develop novel lubrication system that achieve all these requirements. Ionic liquids are expected to active control the structure and thickness of the tribo-layer by imparting an electrical potential to the friction surface due to the electrically charged lubricant. This investigation researched the correlation between the chemical structure and physical properties of ionic liquids with friction coefficient and responsiveness.

9:40 am – 10:00 am

3923096: Surfactant Aggregation and Tribological Properties in Water: A Study of Sodium 2-Hexyldecanoate

Haiyang Gu, Tomoko Hirayama, Naoki Yamashita, Nobuhiro Sato, Kyoto University, Sennan-gun, Osaka, Japan; Tomoaki Okano, Idemitsu Kosan Co.,Ltd., Chiba, Japan; Masako Yamada, KEK, Ibaraki, Japan

Surfactants have emerged as promising additives for enhancing the lubrication performance of water-based lubricant surfaces, owing to their ability to adsorb on metal surfaces and reduce friction under boundary lubrication conditions. Their unique molecular structure, featuring a hydrophobic end and a hydrophilic end, enables them to form various aggregates in aqueous solutions, including micelles, vesicles or lamellar. In this study, as an example, the aggregation behavior of sodium 2-hydroxydecanoate (2HDNa) in aqueous solution and its impact on friction and anti-wear properties were investigated. The findings reveal that 2HDNa exhibits large vesicles at low concentrations, which transition into micelles as the concentration increases. The presence of vesicles significantly reduces the friction coefficient and improves the antiwear properties by forming a bilayer film on the metal surface, as evidenced by neutron reflectometry. These findings emphasize the lubrication performance of vesicles and highlight the importance of controlling surfactant concentration in water-based lubrication.

(Session 3B continued)

10:00 am – 10:20 am

3771597: Electrical Impedance Spectroscopy to Analyze Lubricant Composition and Performance

Thomas Reddyhoff, Yu Min, Thomas Kirkby, Jie Zhang, Imperial College London, South Kensington, London, United Kingdom; Arndt Joedicke, Shell, Hamburg, Germany

It is becoming increasingly important to be able to monitor the condition of lubricated contacts, and electrical methods provide a promising solution, given their robust sensing at relatively low cost without needing an optical window. Traditionally, either contact resistance or capacitance have been measured in order to partially reflect lubrication conditions. However, more recently, Electrical Impedance Spectroscopy (EIS) is being explored since it can provide richer information in the form of magnitude/phase spectra. EIS monitoring involves a setting up a circuit around the contact and applying an alternating voltage with varying frequency while measuring the flow of current. The measured relationship between voltage and current (i.e., the impedance) varies as a function of frequency and can also be modelled as a network of electrical components. The parameters of these components (e.g., resistances and capacitances) can be found by fitting theory to experiments data and the resulting values used to characterize lubrication conditions. In this work, we demonstrate the use of EIS as a means of concurrently monitoring lubrication regime, hydrodynamic film thickness, boundary film formation, and lubricant degradation. Results, for a range of lubricants, are obtained from both an ex-situ probe and from within a rolling/sliding contact. The practical implementation of this monitoring approach is also discussed.

10:20 am – 10:40 am

3931396: Tribological Properties When MoDTC, ZDDP and OFM are Used Together

Sohei Nambo, Weiqi Shen, Tomoko Hirayama, Naoki Yamashita, Naoya Hatano, Kyoto University, Kyoto, Japan; Yasuhiro Niwa, KEK, Tsukuba, Japan

To reduce friction under boundary lubrication, molybdenum compounds and organic friction modifiers (OFMs), such as fatty acids and amines, are added to lubricating oils. However, the combination use of these friction modifiers is not fully understood. Though N-oleoylsarcosine, one of OFMs, was found to exhibit excellent friction properties when used with molybdenum dialkyl dithio carbamate (MoDTC) and zinc dialkyl dithio phosphate (ZDDP), the cause of low friction has not been elucidated, partly due to the complexity of the polar group. In this study, friction tests and chemical analyses were conducted using MoDTC, ZDDP, and OFMs which have similar structures to Noleoylsarcosine and simple polar groups. By clarifying how the friction properties and surface conditions change, depending on the structures of OFMs used in combination with MoDTC, a knowledge on the combination use of friction modifiers was obtained.

10:40 am – 11:00 am

3761911: Molecular Simulation Approach for Dynamics of Extreme Pressure Agents

Hitoshi Washizu, Kyosuke Kawakita, Mutsuki Homma, Riku Araki, Yoshiki Ishii, University of Hyogo, Kobe, Hyogo, Japan; Hiroaki Koshima, Idemitsu Kosan, Co., Ltd., Sodegaura, Chiba, Japan

Carbonic acids and organophosphates are representative compounds of oiliness additives and extreme pressure additives, respectively. It is quite interesting that these two molecules are quite similar in physicochemical nature, but the tribological effect is quite different. In this study, we used molecular dynamics simulation to understand the behavior of organophosphates in oil. We first found that organophosphtes make strong aggregates in oil, whereas carbonic acids do not. This is the reason why carbonic acids adsorb on the metal or metal oxides surface as oiliness additives, and the organophosphates do not work on the surface in mild condition (i.e., in low temperature and in mild boundary lubrication). We then extend our simulation to the several types of organophosphates, including mono-phosphates and di-phosphates, and including double bond in hydrocarbon chain. The size of aggregates and the diffusion coefficients are due to the molecular structure. We also simulate the adsorption process on the solid surface using reactive molecular dynamics. The nature of charge transfer is different in the molecular structure. We then extend our reactive method to organosulfates additives. The adsorption dynamics are almost the same that of organophosphates but shows difference due to the functional groups.

Session 3C (Salon C)

Fluid Lubrication I

Session Chair: Bart Raeymaekers, Virginia Tech, Blacksburg, VA

SPOTLIGHT PRESENTATION

9:20 – 10:00 am

3930900: The Slippery Slope – Temperature, Pressure and Speed Dependent Friction Modifier Performance in a Wet Clutch

Darryl Williams, Afton Chemical Corp., Richmond, VA

Friction modifiers play a significant role in controlling NVH in wet clutch applications. The complexity of a wet clutch – consisting of a friction material, a steel surface, and a fully formulated transmission fluid – can obscure the well-known effects of friction modifiers in wet clutch test data. The Briscoe and Evans model is applied to show the predicted linear relationships between Langmuir-Blodgett film shear strength and Ln(v), pressure, or temperature. There is a limited sliding speed range over which the model may be applied in these tests. We show the importance of using an estimated actual contact area rather than the clutch surface area for this purpose. This approach can be a useful way to study friction modifier performance in clutches.

10:00 am – 10:20 am

3931524: Experimental Investigation into Minimum Flowrate Conditions for Ultra-Smooth Surfaces

Michael Handschuh, Anthony Ngo, Ahmet Kahraman, The Ohio State University, Columbus, OH

Maximizing efficiency of power transmission systems continues to be the driving mechanism behind innovation and overall advancements in transmission design. Whether due to environmental or expenditure concerns, any additional efficiency improvement is important. In a power transmission system, two types of power losses are present: load-dependent frictional losses due to load carrying components and load-independent drag losses of rotating components. This experimental study investigates the quantity of lubrication required for ultra-smooth surfaces operating at elevated speeds targeting aerospace and electric vehicle applications. A high-speed twin-disc tribometer was operated over various velocities, contact pressures, and lubricant temperature and flowrate conditions applicable to gear contacts while simultaneously measuring contact torque and surface temperature. Measurements reveal the minimum amount of lubrication to prevent scuffing and increase efficiency for ultra-smooth surfaces. Results show that load-dependent losses are married to the temperature of the disc surfaces and are directly impacted by lubricant flowrate. Power transmission designers can implement these findings and modify delivery requirements to gear meshes throughout a transmission to help optimize overall efficiency.

10:20 am – 10:40 am

3766169: Elastohydrodynamic Lubrication with Water Droplets in Oil Emulsion

Fan Zhang, Nicolas Fillot, Guillermo E. Morales-Espejel, INSA-LaMCoS, Villeurbanne, France

The current work investigates water-in-oil flow at the inlet of EHD contacts using both experimental and numerical methods. A high-speed camera was used to observe a micro-sized water-in-oil emulsion flow at the inlet of an EHL point contact for the first time. Based on the experimental findings, a numerical model was developed. The Navier-Stokes equation and Newton's second law were solved sequentially to trace the movements of water droplets in oil. The effects of several operational factors on the flow of a water-in-oil emulsion, such as rolling velocity, water droplet size, applied load, and lubricant viscosity, have been investigated. The findings of this work demonstrate the critical conditions under which water-in-oil emulsion affects EHL contacts and give a possible explanation for the disparities in the literature.

10:40 am – 11:00 am

3938517: Lubrication Subjected to the Effect of Electromagnetic Fields: Recent Research Progress and A Generalized All-Field Reynolds Equation

Xiaoman Wang, Q. Jane Wang, Northwestern University, Evanston, IL; Ning Ren, Roger England, Valvoline Inc., Lexington, KY

Electrical and magnetic fields have been shown to both positively and negatively affect lubrication system performance, as the presence of electrical and magnetic fields can significantly change the properties of the lubricants. Electric vehicles (EVs) have exhibited lubrication-based failures due to the effects of magnetic fields and electrical current, adding to the demand for an in-depth study of lubrication systems subjected to these conditions. This presentation highlights recent research on lubrication related to electrical or magnetic fields, which are: 1.) electric double layer in lubrication, 2.) electrorheological fluids, 3.) magnetorheological fluids, 4.) ferrofluids, and 5.) typical fluids used in the current EVs. Commonly used lubricants in each area are reviewed; lubrication mechanisms are analyzed, and successful related mathematical models are summarized. Methods for and results from numerical analyses and experimental exploration are discussed, and typical failures seen in EV applications caused by electric or magnetic field are evaluated. Based on the progress of the research in related fields, a generalized all-field Reynolds equation is proposed to describe the relevant scenarios mentioned above.

Session 3D (Salon D)

Surfaces and Interfaces III

(Including Nanotribology)

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

9:20 am – 9:40 am

3762152: Environmentally-Sustainable Thickeners for Greases: Engineering a Replacement for Lithium Salts

Philip Egberts, Babak Soltannia, Leonardo Martin-Alarcon, Jackson Uhryn, Milana Trifkovic, University of Calgary, Calgary, Alberta, Canada

Sustainable nanoparticle materials can be used to thicken base oils into greases without the use of lithium soaps. In this study, we approach grease development from the base oil up and link mechanical (rheological) and tribological (friction) properties with the microstructure of the lubricants using laser scanning confocal microscopy. More specifically, greases thickened with two different nanoparticles will be examined: nanoclay (Cloisite 20A) thickened grease; and a combination of nanoclay and tempo-oxidized cellulose nanofibers (TOCN). The impact of oleic acid, a common dispersing agent, on the rheological and tribological properties will also be examined. We show that particle-particle interactions impact hydrodynamic sliding, which can be linked with rheological properties, while particle-steel interactions impact boundary lubrication properties.

9:40 am – 10:00 am

3764102: Developing Acoustic Emission Techniques to Monitor Rubbing Contacts

Thomas Reddyhoff, Robert Gutierrez, Imperial College London, Bristol, United Kingdom

The machine condition monitoring market is expanding as there is an increasing interest in reducing economic losses to friction and wear related problems. Acoustic emission (AE) offers in use monitoring of rubbing contacts with no need for direct contact with the rubbing surfaces or an optical window. A test setup has been developed, which can simultaneously measure the AE and friction force produced from a ball-on-disc reciprocating contact. Signal processing methods involving histogram counts, short-time fourier transform (STFT), and machine learning for correlating AE to friction force have been explored. It was found that the log of an STFT and histogram count rate for small bin voltages both show high correlations with friction. Based on this, models were formed to predict the friction coefficient from AE data. This paves the way for AE to be used to remotely monitor rubbing contacts.

10:00 am – 10:20 am

3932829: Tribological Performance of Polymeric Coatings for HFO-1234yf-Based EV Air Conditioning Compressors

Ajinkya Raut, Ahmad Amiri, Andreas Polycarpou, Texas A&M University, College Station, TX

The use of HFO-1234yf as a climate-friendly refrigerant for air conditioning and refrigerator compressors is becoming increasingly popular. However, there is a need to investigate its effectiveness in electric vehicle air conditioning systems. With the growing demand for lightweight materials in electric vehicles, it is crucial to develop parts made of light aluminum and magnesium alloys to improve vehicle efficiency, however, they mostly suffer from low tribological properties. To get around this issue, coating with high-performance polymers was suggested as a common solution. This study evaluates the tribological performance of advanced polymeric coatings (ATSP, PTFE, and PEEK) on lightweight aluminum alloy surfaces with HFO-1234yf and polyalkylene glycol (PAG) lubricant under starved lubrication conditions. Scuffing and wear experiments were conducted on a specially designed tribometer. Results indicate that all three coatings significantly outperformed the bare substrate. Further surface analysis was conducted to study the wear mechanisms of the polymer coatings. These findings provide valuable insight into the effectiveness of polymeric coatings for HFO-1234yf-based electric vehicle air conditioning compressors.

10:20 am – 10:40 am

3963312: A Friction Determination in Sheet Metal Forming

Abdurasul Pirnazarov, Anvar Makhkamov, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan

This investigation focuses on the impact of friction in the deep drawing process. Tribological tests were carried out using a pin-on-disc machine and modified strip drawing tests, which were aimed at simulating behavior and determining the coefficient of friction between sheet metal and tools during forming. Experiments were carried out using a pin-on-disc machine for the determination of the coefficient of friction and behavior between sheet metal and tools during forming. Reciprocating sliding tests were examined for frictional characteristics as well as the impact of lubricant and other factors on the coefficient of friction of cold-rolled HSLA (High Strength Low Alloy) with a set of two types of oils.

Plenary Session
1:00 pm – 2:00 pm (Salon D)
Tuesday, November 14, 2023

KEYNOTE PRESENTATION

Development of Power Dense and Energy Efficient Bearings to Address the Needs of Modern Machinery

Michael Kotzalas, Director of Global Customer Engineering, The Timken Company (USA)

The drive for carbon neutrality has created demand for energy efficiency in all aspects of our industrialized world. Prior generations of machine designers were more focused on reliability and performance, which is still a requirement today. However, energy efficiency and reduced carbon footprint have now become just, or even more, important in their design tradeoff studies. To address this shift in priorities, the rolling bearing industry – an industry developed over a century ago to eliminate friction and enable the first industrial revolution – is in focus. Bearing designers have relied on tribology to find these solutions. This has been through studying the impact of lubricant rheology and film formation capabilities, contact surfaces geometry, and material wear characterization to meet customer requirements. These enabling technologies will be discussed during this presentation and real-world examples will be used to highlight how they have been deployed.

Michael Kotzalas is currently the Director of Global Customer Engineering for The Timken Company, responsible for the application and service engineering activities in all market segments. Working for Timken since 1999, he has worked his way through the corporate R&D, product engineering and customer engineering groups as he progressed through the company. He received his bachelor's, master's, and doctorate degrees in mechanical engineering from The Pennsylvania State University and specialized in rolling element bearing technologies during his graduate work. He is an active member of ASME, STLE and ABMA, where he has served as chair of the ASME Tribology Division, STLE's Wind Energy Tribology Technical Committee, an Associate Editor for STLE's Tribology Transactions journal, and ABMA Chair of ISO TC4/SC9 for standards involving tapered roller bearings, respectively. He has published 16 peer-reviewed papers in journals and conference proceedings and co-authored the fifth edition of the two-volume textbook, ***Rolling Bearing Analysis.***

Session 4A (Salon A)

Energy/Environment/Manufacturing I

Session Chair: Tevis Jacobs, University of Pittsburgh, Pittsburgh, PA

2:00 pm – 2:20 pm

3756326: Machining Evaluation of Novel Phosphate Ester for Hard Metal Machining

William Harwood, Ron Lemke, Italmatch Chemicals, Wilmington, IL

Environmental pressure to reduce CO_2 emissions globally continues to pressure manufacturers to improve efficiency of vehicles and aircraft by reducing weight and increasing power density. Harder, lightweight and more heat resistant materials enable designers to do more with less material. Italmatch Chemicals, Lubricant Performance Additives, embarked on a partnership with The Advanced Manufacturing Research Centre, UK (AMRC) to develop scientific, real-world representative test methodology and ultimately a performance additive to enable efficient manufacturing when using these materials. Utilizing single point milling tests and Taylor curve analysis in titanium and high nickel alloys, significant tool life increases were observed, in collaboration with AMRC and Italmatch LPA, successfully developed a novel polymer phosphate technology that improves productivity when machining modern hard metal alloys utilized in today's aerospace industry.

SPOTLIGHT PRESENTATION

2:20 pm – 3:00 pm

3964054: In Situ Investigations into the Adhesion and Compression of Catalyst-Relevant Metal Nanoparticles

Tevis Jacobs, Ruikang Ding, Andrew Baker, Soodabeh Azadehranjbar, University of Pittsburgh, Pittsburgh, PA; Ingrid Padilla Espinosa, Ashlie Martini, University of California, Merced, Merced, CA

We have used in-situ manipulation of metal nanoparticles, coupled with atomistic simulations of the same materials, to investigate the performance of catalyst-relevant metal nanoparticles. First, we used in-situ adhesion testing, and matched simulations, on nanoparticles composed of various metals in contact with a variety of oxide substrates to understand the physics of adhesion. The results showed that, instead of being governed by traditional fracture mechanics, particle adhesion is more closely described by the adhesive strength of an interface failing in tension. We could then relate this adhesive strength to material properties of the system. Second, we used matched experiments and simulations of nanoparticle compression to show how the elastic stiffness and compression strength of small-metal nanoparticles varies with shape and size. Taken together, these investigations reveal the fundamental science that will guide the creation of stronger and more stable nanoparticle catalysts.

Session 4B (Salon B)

Materials Tribology III

Session Chair: Tomas Babuska, Sandia National Laboratories, Albuquerque, NM

2:00 pm – 2:20 pm

3761702: Oil-Free Superlubricity on Rough Steel Surfaces under Sustained Sliding-Rolling Contact

Anirudha Sumant, Aditya Ayyagari, Benjamin Gould, Aaron Greco, Argonne National Laboratory, Lemont, IL

Although great progress has been made demonstrating superlubricity utilizing various two-dimensional (2D) materials as a solid lubricant, in various environments and at moderate to high contact pressures, the sustained, long-term reliability of these solid lubricants in more complex tribological conditions is yet to be established to consider them as a potential candidate for replacing oil-based lubricants. In this study, we show the demonstration of a fully dry solid lubricant showing superlubricity in rough steel against steel sliding-rolling contacts at high contact pressures (1GPa). We utilize MoS_2+Graphene Oxide as a solid lubricant to produce ultra-low friction of 0.005 under rolling-sliding conditions for up to 200 hours (70 km) of uninterrupted rolling-sliding. This was observed to result from complex physico-chemical and physico-mechanical phenomena occurring in situ in the tribolayer. We'll discuss the mechanism of formation of tribolayer and will try to explain how shearing and reorientation of MoS_2 along with the formation of amorphous carbon are playing a key role in friction reduction. This demonstration paves the way for further development and realization of oil-free superlubricity in various real-world applications and helps toward the decarbonization goal in the lubrication industry.

2:20 pm – 2:40 pm

3959713: Deposition and Properties of Electroplated MoS_2 Solid Lubricant Coatings

Michael Dugger, Christopher Reed, Tomas Babuska, Dhego Banga, Josh Sugar, Ping Lu, John Curry, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide thin films are excellent solid lubricants for aerospace applications due to their steady-state friction coefficient of 0.05 or lower in inert atmospheres, wide operating temperature range and high contact pressure capability. These films are commonly deposited by sputtering from targets of pressed MoS_2 powder or MoS_2 plus oxide or metallic dopants. Uniform coatings on complex shapes by sputtering requires fixturing and moving the parts during deposition. In this work, conformal coatings of MoS_2 have been created via electrodeposition from an aqueous solution of tetrathiomolybdate ions at room temperature. These films are amorphous, contain some MoOx and exhibit friction performance in limited duration tests that is comparable to sputtered coatings. These films can also be doped by including the desired ions in the bath. The structure, composition, performance and aging behavior of electrodeposited MoS_2 solid lubricant films will be discussed.

2:40 pm – 3:00 pm

3950741: Performance Driven Metrics to Assess Microstructural Characteristics of Molybdenum Disulfide Coatings

Tomas Babuska, Michael Dugger, Steven Larson, Mark Rodriguez, John Curry, Sandia National Laboratories, Albuquerque, NM

Sputter-deposited molybdenum disulfide (MoS_2) solid lubricant coatings have been used for decades in aerospace applications due to their ultra-low steady-state coefficients of friction (μss < 0.05). Developing MoS_2 coatings for demanding applications with predictable and reliable performance over time (i.e., high-quality) requires tuning the coating microstructure through process variations (process-structure). Achieving desirable coating properties (structure-property) such as wear resistance, low μi, high density, and resistance to oxidation can be accomplished through microstructural control. In this work, we investigate the role of processing parameters such as argon sputtering pressure, bias voltage, adhesion layer, and power density on the resulting coating microstructural characteristics, tribological properties and oxidation resistance. Additionally, we investigate the batch-to-batch repeatability and impact of indirect processing variables on the coating microstructure and properties for multiple deposition runs using screening parameters such as wear rate and nanoindentation to quantify batch quality. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

3:00 pm – 3:20 pm

3931324: Quantifying Water Diffusion in Molybdenum Disulfide Coatings Using ToF-SIMS Depth Profiling

Nicolas Molina Vergara, Robert Chrostowski, Filippo Mangolini, The University of Texas at Austin, Austin, TX; John Curry, Michael Dugger, Tomas Babuska, Sandia National Laboratories, Albuquerque, NM

Molybdenum disulfide (MoS_2) has been used as solid lubricant in aerospace applications because of its low friction response in inert environments. However, exposure to atmospheric conditions and periods of inactivity can cause MoS_2 to "age" into a high friction state. This poses a significant challenge in the reliable use of MoS_2. Despite the volume of the published literature, our understanding of the surface phenomena taking place during aging of MoS_2 is still limited. To address this knowledge gap, we performed ToF-SIMS depth profiling analysis using an isotopic tracer (D2O) to quantify and characterize the diffusion of water in MoS_2 by means of an isotopic tracer. This work was funded by the Laboratory Directed Research and Development program at Sandia National Laboratories, a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the US DOE's National Nuclear Security Administration under contract DE-NA0003525.

3:20 pm – 3:40 pm

3964090: Self-Lubricating Novel 2D High Entropy Alloy on Steel Surfaces

Sai Varun Sunkara, Shuxi Wang, Sukriti Manna, Subramanian K. R. S. Sankaranarayanan, Amin Salehi-Khojin, University of Illinois at Chicago, Chicago, IL; Yuzi Liu, Anirudha Sumant, Argonne National Laboratory, Lemont, IL

Traditional thin film high entropy alloys (HEAs) in tribology have shown good wear resistance and ability to work under extreme conditions but with moderate friction coefficient. This work introduces a novel two-dimensional (2D) HEA synthesized by chemical vapor transport (CVT) process and subsequently coated onto a stainless steel substrate via simple spray coating technique. We demonstrate excellent lubricious behavior of 2D-HEA using ball-on-disk experiments with steel tribo-pair in ambient air with coefficients of friction as low as 0.068, wear rates in the magnitude of 10-9 mm3/(N-m), and functions at high contact pressures (0.94 GPa). Detailed analysis from various characterization modalities coupled with AIMD simulations show that its superior performance is attributed not only to its structure and composition but also its exceptional tribocatalytic activity that leads to operando self-lubricating tribolayer formation during sliding. We'll discuss possible mechanisms responsible for such exceptional performance towards developing more reliable and long-lasting lubricants.

3:40 pm – 4:00 pm – Break

4:00 pm – 4:20 pm

3930260: The Influence of Solid Lubricant Reservoir's Morpho-Dimensional Evolution on the Sliding Wear of Sintered Iron-Based Self-Lubricant Composites

Jose Daniel De Mello, Nicolás Araya, Rafael Arenhart, Guilherme Neves, Cristiano Binder, Aloisio Klein, Universidade Federal de Santa Catarina, Florianopolis, Santa Catarina, Brazil

This study investigates the influence of the morpho-dimensional (porosity, solidity, circularity, eccentricity and Feret diameter) evolution of pores (e.g., solid lubricant reservoirs on the tribological behavior of impregnated materials). In addition, a new parameter, the mean carbon intensity inside each individualized pore, was proposed to further understand the solid lubrication phenomenon in sintered composites. PM techniques produced low alloy sinter-hardened steel specimens vacuum-impregnated with graphite particles. Interrupted incremental load tests (7 N increments every 10 minutes) were used to study the evolution of open pores (solid lubricants reservoirs) in the wear scars. During tribological testing, the impregnated pores get sealed. The narrow sections connecting pores deform and close, reducing porosity and the Feret diameter of individual pores. Then pores get smaller and sealed up to the point where the lubricity regime ends. Small and narrow pores retain better the impregnated graphite, slowly releasing it, helping to maintain the lubricity regime.

4:20 pm – 4:40 pm

3969621: Al_2O_3/SiC Composite with Graphite as Self-Lubricant – A Material-by-Design Development Approach for Cutting Tools

Syed Sohail Akhtar, Abba Abdulhamid Abubakar, Abbas Saeed Hakeem, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

The current research focuses on using a material-by-design approach to develop Al_2O_3/SiC composites with graphite for cutting tool inserts that have a balanced combination of structural and thermal properties as well as improved tribological response. During the material design stage, several combinations of Al_2O_3 and SiC together with graphite as self-lubricant are selected based on in-house designed codes that predict mechanical and thermal for tailored cutting tools. The constitutive behavior of the composites is predicted using a mean-field homogenization scheme while the theoretical optimum thermal characteristics are predicted using an effective medium approximation. The Spark Plasma Sintering process was used to synthesize the samples for validation of the designs. Tribological tests are carried out under dry conditions to see the self-lubrication behavior of the samples in terms of their coefficient of friction and wear rates. These experimental data are then compared against the predicted data obtained through mathematical models developed to estimate the wear performance. FESEM and XRD techniques are used to support the experimental trends by comparing the microstructure and wear track images of the samples. The optimum combinations of Al_2O_3, SiC, and the addition of graphite have led to the expected effect of lowering the coefficient of friction and compressive strength while increasing the material's hardness.

Session 4D (Salon D)

Machine Elements and Systems I

Session Chair: Christopher DellaCorte, University of Akron, Akron, OH

Session starts at 2:20 pm

2:20 pm – 2:40 pm

3756412: An Abnormal Rolling Contact Fatigue Failure with Fluorine Grease

Hiroyoshi Tanaka, Kyushu University, Fukuoka, Japan

This study introduces an abnormal rolling contact fatigue failure with fluorine grease which consists of Perfluoropolyether, PFPE, oil. Some PFPE oil decompose to acid by moisture in ambient air. In this study, the rolling contact fatigue (RCF) test was conducted to know the effect of fluorine grease on fatigue life of rolling element bearings. In order to know effects of environmental gas, the RCF test was conducted in air and argon. After the RCF test, hydrogen content in bearing steel was measured by thermal desorption spectrometry. Also, structural changes were discussed by sectioning observation just below the rolling surface.

(Session 4D continued)

2:40 pm – 3:00 pm

3905089: Extreme Condition Tribology – High Temperature Vacuum Bearing Operation

Christopher DellaCorte, University of Akron, Akron, OH

Friction and wear behavior of rolling element bearings is highly dependent upon operating environment. In many cases, the environment dictates the lubricants and lubrication methods used to ensure proper bearing operation. Bearings that operate in vacuum must employ specialty lubricants and lubrication methods that can range from vacuum compatible oils and greases to dry film lubricants. Bearings that operate at high temperature must employ specialty construction materials as well as specialty lubricants. In this presentation, bearing materials and lubricants suitable for high temperature bearing operation are presented. Their performance is demonstrated in a unique high vacuum, high speed, high load bearing test rig. Future research plans to evaluate the effects of test conditions (load, speed, lubricant choice) on bearing life will be discussed.

3:00 pm – 3:20 pm (Open Slot)

3:20 pm – 3:40 pm

3930194: Rolling Element Bearing Damage in the Presence of Applied Electric Current

Lizeth Sanchez-Camacho, Ryan Evans, Carl Hager, Jr., The Timken Co., North Canton, OH

Equipment designers prevented the passage of electric current through rolling element bearings as a standard design principle for decades to prevent arc pitting and other known types of bearing damage. However, the proximity of bearings to electrical generators, motors, and inverters in modern wind energy and battery electric vehicle designs has reinvigorated research about the effects of low-level or stray electric current passage in operating bearings. The emergence of white etch cracking (WEC) and other previously uncommon damage mechanisms created questions about the role electric current has in promoting high-cycle damage modes. This work presents a study of the influence of applied electric current and lubricant selection on bearing surface damage over millions of operating cycles. Micro-pitting, WEC, and the creation of a surface white layer were investigated by optical microscopy in conjunction with scanning electron microscopy after bearing tests with various levels of applied current and two lubricant oil types (additized and non-additized). A black oxide coating was also applied to evaluate its effect on WEC formation. It was found that these damage modes could be turned on and off in bearings, depending on the type of oil used and the applied electric current. Higher applied electric currents directionally increased bearing surface damage in these tests.

3:40 pm – 4:00 pm – Break

4:00 pm – 4:20 pm

3931643: Productivity Improvement of The Loom Shed by Optimizing Friction

Abdurasul Pirnazarov, Namangan Institute of Engineering and Technology, Kosonsoy, Namangan, Uzbekistan

The productivity of the loom is governed by the speed, efficiency, and quality of the fabric produced. During the weaving process, loom stoppages not only reduce productivity but also affect the fabric's quality. In woven fabric manufacturing, weft ends are generally sized so that they can withstand various stresses encountered in the weaving process. The breakage rate of weft yarn is highly sensitive to stretch and shows a large difference with a change in friction on solid materials. In a weaving machine, it is a challenging task to find the optimum level of friction to get a minimum weft breakage rate. The present study was done to analyze the effect of friction on weft insertion and optimize friction with a minimum weft breakage rate.

4:20 pm – 4:40 pm

3964459: White Etch Cracks in Wind Bearings

Mandyam Sridhar, GE Research, Bengaluru, Karnataka, India

White Etch Crack (WEC) failures can reduce bearing life by >90 %. WEC is an industrywide issue which includes wind turbine bearings. For this issue, there is no consensus about the root causes in the industry. This work critically reviews literature work (mainly coupon level tests) to identify factors affecting WEC. The four main factors affecting bearing life are material & manufacture, bearing design and type, operating conditions and lubricant (base oil and additive). Results from four test configurations: 4-ball test, Thrust test, MPR tests and FE8 rig have been reviewed here. Even though the above factors contribute to reduction of Weibull life, a clear correlation between low Weibull life and WEC formation cannot be established. Lube additive has most significant influence in life reduction and slip has lowest influence. Other factors which contribute to life reduction between lube additive and slip are current, material quality, surface hardening, Lube# and base oil in that order. Based on this critical literature review, lubricant additive, current and material quality emerge as major factors influencing the reduction of wind turbine bearing life.

Wednesday, November 15, 2023

Session 5D (Salon D)

"Beyond the Cutting Edge" Plenary Symposium

(Highlights from Tribology Letters)

Session Chair: Wilfred Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

8:00 am – 8:30 am

3771598: More on Mouthfeel – Imbibing Bubbly Beverages

Thomas Reddyhoff, Sorin Vladescu, Connor Myant, Imperial College London, South Kensington, London, United Kingdom; Sophie Bozorgi, Guy Carpenter, Kings College London, London, United Kingdom; Stefan Baier, Motif FoodWorks, Boston, MA

The perception of carbonation is an important factor in beverage consumption which must be understood in order to develop healthier products. This presentation describes the effects of carbonated water on oral lubrication mechanisms involved in beverage mouthfeel and hence taste perception. Friction was measured in a compliant PDMS-glass contact simulating the tongue-palate interface (under representative speeds and loads), while fluorescence microscopy was used to visualize both the flow of liquid and oral mucosal pellicle coverage. Results from tests, in which carbonated water is entrained into this contact, reveal two distinct tribological mechanisms – namely bubble-induced starvation and salivary pellicle removal. Both of these will modulate the flow of tastants to taste buds and are suggested to be important in the experience of taste and refreshment. For example, this may be one reason why flat colas taste sweeter.

8:30 am – 9:00 am

3935552: Linking Strength, Friction, and Ordering in Metallic Glasses

Nicolas Argibay, Ames National Laboratory, Ames, IA; Michael Chandross, Sandia National Laboratories, Albuquerque, NM

The friction and strength of shearing metal interfaces was previously linked to grain size in a predictable way for pure metals and dilute alloys, although the accuracy of these correlations was shown to be limited to inert conditions where oxidation and adsorbates have a negligible effect on interface properties. Recent work shows that macroscale friction experiments can also be used to probe the fundamental strength of structurally and chemically disordered alloys, including metallic glasses, with predictable results again limited to inert environments. We show how tribological experiments are being used to inform development of a theoretical framework for the strength of alloys as a function of their structural and chemical ordering and discuss opportunities for alloy composition and structure optimization to promote desirable mechanical behavior.

9:00 am – 9:30 am

3756396: The Ultrafast Finger Snap is Mediated by a Frictional Skin Latch

Elio Challita, Raghav Acharya, Saad Bhamla, Georgia Tech, Atlanta, GA; Mark Ilton, Harvey Mudd College, Claremont, CA

The snap of a finger is a ubiquitous human motion that has been used as a form of communication across human cultures throughout millennia. Using high-speed imaging, we present the first study of the dynamics of finger snapping. We show that the finger snap can achieve angular accelerations of 1.6 × 106 °/s–2 in 7 ms, making it one of the fastest movements the human body can produce. Our analysis shows that friction between finger pads acts as a latch in controlling this ultrafast movement. Using an experimental and mathematical approach, we show how skin friction lies in an optimally tuned regime, enabling it to play a dual role in both loading potential energy and mediating the release of that energy during the finger snapping motion. Our work provides design insight towards the frictional complexity in many robotic and ultra-fast energy-release structures.

9:30 am – 10:00 am – Break

10:00 am – 10:30 am

3933692: Linking Molecular Structure and Lubrication Mechanisms in Tetraalkylammonium Orthoborate Ionic Liquids

Filippo Mangolini, Jieming Yan, Hsu-Ming Lien, The University of Texas at Austin, Austin, TX

While ionic liquids (ILs) have attracted wide interest as potential lubricants owing to their unique properties (e.g., high thermal stability) and good tribological properties, our understanding of the mechanisms by which ILs reduce friction and/or wear is still elusive. Here, we synthesize a homologous series of halogen-free ILs, namely tetraalkylammonium orthoborate ILs, and combine macroscale tribological experiments with surface-analytical measurements to gain insights into the relationship between the IL molecular structure and their lubrication mechanisms/performance. The results of steel-versus-steel tribological tests indicate an improvement of the friction-reducing properties of these ILs as the length of the alkyl chains attached to ammonium cations increases. Based on ex-situ X-ray photoelectron spectroscopy (XPS) analyses of the surface chemistry of steel after sliding tests, a phenomenological model is proposed for the observed tribological behavior.

(Session 5D continued)

10:30 am – 11:00 am

3761773: Tribotronic Control and Electrochemcial Properties of Nanofluid Interfaces

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

We have employed Quartz Crystal Microbalance (QCM) and cyclic voltammetry (CV) methods to explore nanotribological and electrochemical attributes of platinum or gold electrodes immersed in nanosuspensions of charged species (nanoparticles, ionic liquids, nanodiamonds). The setup consists of a QCM immersed in a nanosuspension whose sensing electrode faces a nearby counter electrode. An electric field perpendicular to the QCM surface is created when a potential is applied between the two electrodes, which allows the charged constituents in the suspension to be repositioned. QCM measurements can detect differences in friction under various field conditions, and thus detectably tune the friction in both nanoparticle and ionic liquid systems. CV simultaneously monitors the system's electrochecmical attributes. The versatility, speed, and simplicity of QCM for friction measurements renders it an ideal tool for the rapidly expanding research area of tribotronics.

11:00 am – 11:30 am

3764635: Nanosensors for In Situ Measurement of Pressure and Temperature in EHD Contacts

David Philippon, Tarek Seoudi, Lionel Lafarge, Nicolas Devaux, Philippe Vergne, INSA Lyon-LaMCoS, Villeurbanne, France; Nicolas Fillot, INSA-LaMCoS, Villeurbanne, France; Alexandre Mondelin, SKF Aerospace France, Châteauneuf-sur-Isère, France

A new methodology based on the photoluminescence properties of non-intrusive nanosensors is presented for in-situ measurement of pressure and temperature in lubricating confined films. Pressure and temperature calibrations of these sensors dispersed in a selected fluid were established through experiments in diamond anvil cells (DAC). Afterwards, measurements were carried out in elastohydrodynamic (EHD) contacts involving different contacting paired materials (glass, steel, Si_3N_4 and sapphire) and submitted to various operating conditions. The experimental results were compared with numerical simulations. Experimental pressure profiles obtained in isothermal experiments show a very good agreement with the values predicted by the numerical model. Non-isothermal cases were also carried out. Temperature rises in the central zone of EHD contacts involving various material pairs were measured and compared to predictions, leading to a very satisfying agreement.

Graduate Student Posters (Salon A)

3962816: In Situ AFM Observation of ZDDP-Derived Tribochemical Reaction Film Formation Under Controlled Atmosphere Environment

Chinari Shimura, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

Zinc dialkyldithiophosphate (ZDDP) is widely used in lubricating oils as an antiwear additive. ZDDP is known to form a reaction film consisting of metal phosphate and polyphosphate on the sliding surface through a tribochemical reaction. The formation of these films exerts the effect of improving wear resistance and seizure resistance. Oxygen in the atmosphere is thought to be necessary for the formation of these reaction films, but there are many unclear points about the detailed reaction processes. In this study, we set up an AFM in an atmosphere-controlled environment using nitrogen and performed in-situ observation of the formation process of ZDDP-derived tribo-films by performing nano-friction between the tip of the AFM tip and a steel substrate. As a result, it was confirmed that the presence or absence of oxygen in the atmosphere did not affect the growth rate of ZDDP-derived tribo-films. Based on these experimental results, we report the results of consideration of the phosphate formation process by tribochemical reactions.

3954098: Predicting Traction Fluid Performance Using Materials Informatics

Tsuyoshi Fukaya, Yohei Shimizu, Hitoshi Washizu, University of Hyogo, Kobe, Japan; Eiji Tomiyama, University of Hyogo and RIST, Kobe, Japan

Materials Informatics (MI), which applies information science methods to improve the efficiency of materials development, can search for optimal materials from many materials, and the use of MI is expected to accelerate materials development. This study focuses on the physical properties of traction fluid. First, machine learning is conducted using 37 compounds used as base oils for lubricants as supervised data. Since regression prediction is difficult due to low accuracy, the explanatory variables are changed, and machine learning was conducted again. The results suggest that changing the explanatory variables may improve accuracy and allow regression predictions to be made. From the MI perspective, the explanatory variables should be the physical property values obtained from the simulation. Currently, simulations are being performed and machine learning is being conducted based on the physical property values obtained.

3931382: Study on Potential of Mean Force of Carbon-Addition Bonds on the Surface of Diamond-Like Carbon Under Different Preparation Conditions.

Koshiro Torimoto, Hirotoshi Akiyama, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Motoyuki Murashima, Tohoku University, Sendai, Japan

The adsorption properties of DLC surfaces and additives in oil have been found to have a decisive influence on the nano-interface tribofilm formed in the early stages of friction, the final tribofilm, and friction properties. The characteristics of tribofilm formation depend on the atomic structures of DLC films such as sp^2/sp^3 ratio and the amount of hydrogens. Using molecular dynamics

simulation, we investigate the bond strength between multiple DLCs, which are prepared in different conditions, and additive molecules. We use LAMMPS as the simulator and Reaxff for the force field that can handle chemical reactions as well as charge transfer. To measure the bond strength, we computed the potential of mean force (PMF) between the DLC surface and the additive molecule using Jarzynski equation. Our calculation shows that the more sp^2 structures, the smaller the PMF value (bond strength becomes stronger). In this talk, we discuss how the PMFs differ depending on the structure of DLCs.

3931399: Simulation of Solid Friction of Metal in Micron Scale using SPH Method

Keito Nitta, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Le Sang, Ho Chi Minh City University of Information Technology, Ho Chi Minh, Viet Nam; Natsuko Sugimura, National Institute of Technology, Kagoshima College, Kirishima, Japan

Friction between two sliding objects depends on various factors such as surface roughness, load, sliding speed, temperature, and time. Here, we perform simulations to observe the friction occurring at the sliding interface under controlled conditions. This study focuses on simulating sliding of metals in micron scale using the Smoothed Particle Hydrodynamics (SPH) method, which approximates a continuum as a large number of particles and calculates their dynamics. Coarse (CG) particles are used to simulate large systems, and the PT (Prandtl-Tomlinson) model is applied to calculate friction forces. The simulation results confirm the Stick-Slip phenomenon, in which the friction force curve oscillates periodically due to atomic-level friction against the PT oscillator. Dependence of surface roughness is found by changing the number of particles in contact area and a significant effect is found to the frictional force.

33938574: The Effect of Surface Properties on Friction in the Solid Friction Simulation Using the Smoothed Particle Hydrodynamics Method

Mizuki Era, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Natsuko Sugimura, NIT, Kagoshima College, Kagoshima, Japan

Lubricants and coatings that reduce friction have been widely discussed, however, there are still many unresolved issues regarding solid friction, such as seizure. Therefore, in this study, we created two models with different surface roughness to investigate the effect of the surface roughness on the heat of friction. In this study, the metal was aluminum. The sliding and vertical initial velocities were fixed in both models. The results showed that the trend of increase was more intense for the model with the larger protuberance, and the frictional heat was higher. This is because the interfacial interaction is determined by the neighboring particles, and the larger the contact surface, the more neighboring particles are in contact, and thus the interfacial interaction is also larger. We will prepare several models with different surface roughness and sliding speeds to further analyze the effects of surface roughness and sliding speed on the heat of friction.

3931667: Development of an In-Situ Scanning Probe Microscopy Equipped with Raman Spectrometer

Ryosuke Kitamura, Kaisei Sato, Tomoki Kawasaki, Tokyo University of Science, Kohoku Ward, Yokohama, City, Kanagawa, Japan; Seiya Watanabe, Osaka University, Toyonaka-shi, Osaka, Japan; Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

Tribochemical reaction films derived from lubricant additives have a significant impact on friction and wear properties in the boundary lubrication regime. However, because the phenomena at the friction interface are complex, such as large changes in temperature and stress, and the interaction of various molecules, the film formation process and lubrication mechanism are not yet fully understood. In-situ observation of the sliding interface is an important and effective method to understand the mechanism. In this study, we have developed a scanning probe tribometer incorporating an in-situ Raman spectrometer that can simultaneously measure the friction coefficient, surface profile, and chemical composition in a minute area on the sliding surface while applying high stress (approximately 1.0 GPa). In this presentation, we report the observation results of Raman spectra on sliding surface applying high compression/shear stress using this device.

3960741: Analysis of the Chain Matching Using Molecular Dynamics Simulation

Takehiro Kobayashi, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Japan

Organic friction modifier molecules are composed of alkyl chains and polar groups on the end. The polar group adsorbs on the metal surface and the molecules form a self-assembled monolayer (SAM). There is the concept of “chain matching” in a boundary lubrication firm. When the chain length of the fatty acid additives and base oil are equal, the load-carrying capacity or thickness of the OFM film exhibits a higher value than in case of other base oils. Although this idea is supported by experiments, the precise mechanism on a molecular level has yet to be understood. In this study, the all-atom MD simulation is used to solve the precise mechanism of chain matching. Interestingly, the molecules are most regularly oriented in the combination of the same chain length of the organic additive and the base oil. This result shows that MD simulation also support the idea of chain matching.

3938589: Analysis of Reaction Dynamics of ZnDTP and MoDTC Lubricant Additives on Iron Nascent and Oxide Surfaces Using a Novel Universal Neural Network Potential

Tomohito Horio, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Akihiro Nagoya, Preferred Computational Chemistry, Inc., Tokyo, Japan; Tasuku Onodera, ENEOS Corporation, Tokyo, Japan

ZnDTP and MoDTC are known as extreme pressure additives. On metal surface, their adsorption, subsequent chemical reaction and synergy are not well understood. This is an obstacle to further improve tribological performance. We analyzed adsorption and chemical reaction of two additives on nascent and oxidized iron surfaces by molecular dynamics (MD) simulation. In the simulations, a universal neural network potential (NNP) implemented in Matlantis™ was used. The model consisted of several molecules of ZnDTP, MoDTC and n-Octane sandwiched between substrates. To simulate friction, sliding velocity and contact pressure were applied. We observed multiple adsorptions of some ZnDTP molecules and they formed phosphate structure in the form of bridged two zinc atoms. This result corresponds to an experimental fact that tribofilm with gradient structure in zinc concentrations is formed. Details of simulation and results will be discussed in our presentation.

3945101: Detailed Analysis of Chemical Reactions Near the Surface of Hydrogen-Free DLC Film During Sliding

Yudai Tanaka, Ryuichi Okamoto, Hitoshi Washizu, University of Hyogo, Kobe, Hyogo, Japan; Hirotoshi Akiyama, University of Hyogo and Nippon Grease Co.,Ltd., Kobe, Japan

Friction Fade-out(FFO) is the phenomenon that the friction coefficient drops to 0.0001 order when a ZrO_2 pin slides on a hydrogenated diamond-like carbon (DLC) film under specific environments such as alcohol and hydrogen gases. It has been considered that the characteristics of the ZrO_2, such as the catalysis of hydrogenation, play significant roles in FFO. In a previous study, when hydrogen-free DLC was used, it was found that the polymerization reaction occurred on the DLC surface, not on ZrO_2. In this study, molecular dynamics simulations are performed using ReaxFF, a reactive force field that can also handle chemical reactions and charge transfer, to investigate the strength of the bonds between ethanol and other molecules involved in the polymerization of carbon and FFO on the hydrogen-free DLC film surface. In addition, physicochemical analysis is performed for different surface conditions such as hydrogen-termination of the DLC surface.

3950839: Evaluation of Surface Topography Measurement Techniques for As-Built Additively Manufactured Metal-Specimens

Loren Baugh, Samsul Mahmood, Kyle Schulze, Nima Shamsaei, Robert Jackson, Auburn University, Auburn, AL

The proliferation of metal additive manufacturing has brought into focus the crucial role of surface characterization in determining the properties and performance of printed parts across diverse applications. This study aims to establish an optimal methodology for acquiring critical surface parameters of additively manufactured as-built specimens that pertains to the part's surface properties. The discussion focuses on critical parameters, measurement techniques, data analysis, and practicality of usage. Moreover, the study examines the surface characterization of fatigue samples in their as-built state. The investigation reveals that the surface roughness of these samples can vary based on their placement on the build plate. Additionally, the directional dependence of surface roughness has been evaluated for various printing parameters. The proposed approach enables a comprehensive assessment of surface parameters acquired from a variety of instruments, facilitating comparative analysis. It also provides an opportunity to gain a deeper insight into the factors that influence roughness beyond traditional linear measurements, allowing for a more comprehensive understanding.

3952249: Analysis of Friction Behavior of Crystalline Polymers With and Without Fillers by Coarse-Grained Molecular Dynamics Method

Kazuki Ito, Masaki Hayama, Hitoshi Washizu, University of Hyogo, Kobe, Japan; Yuji Higuchi, Kyushu University, Fukuoka, Japan

In recent years, metallic materials have been shifted to polymer materials to achieve lighter weight and higher functionality in products. To improve the mechanical properties, polymer materials are reinforced with fillers. For the further improvement of the mechanical properties in composite polymer materials, understanding the relation between the structure and mechanical properties at the molecular scale is essential. We think that the clarification of the general properties of polymers and fillers leads to material design. In this study, we use polyethylene as the model of crystalline polymer and carbon nanotubes (CNTs) as the filler model. We perform friction simulations on crystalline and amorphous layers by the coarse-grained molecular dynamics method. The friction and wear behaviors with and without fillers are compared. We aim to reveal a universal understanding of the effects of adding fillers to polymer materials.

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STLE Tribology & Lubrication for E-Mobility Conference

Program Schedule-at-a-Glance

As of October 30, 2023 – Subject to Change. **All times represent US Eastern Time.**

All E-Mobility conference events are to be held in the Cleveland Marriott Downtown at Key Tower. All sessions are in Salon EFGH.

Monday, November 13, 2023

Poster Session
6:00 pm – 7:30 pm (Foyer)

Networking Reception & Award Presentations
6:00 pm – 7:30 pm (Foyer)

Tuesday, November 14, 2023

Speakers Breakfast
7:00 am – 7:45 am (Erie/Superior)

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Joint Plenary Session
8:00 am – 9:00 am (Salon EFGH)

Keynote Presentation: Challenges of Selecting the Correct Electric Vehicle Driveline Fluid, Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

Networking/Refreshment Break (Exhibits & Posters)
9:00 am – 9:20 am (Foyer)

Technical Sessions – 9:20 am – 12:00 pm

- 3E – Electric Vehicles I
  Commercial Electric Vehicles – 9:20 am – 9:40 am
  Fluids – 9:40 am – 10:40 am

Refreshment Break/Poster Session
10:40 am – 11:00 am (Foyer)

Technical Sessions/continued

- 3E – Electric Vehicles I & Fluids/continued
  11:00 am – 12:00 pm

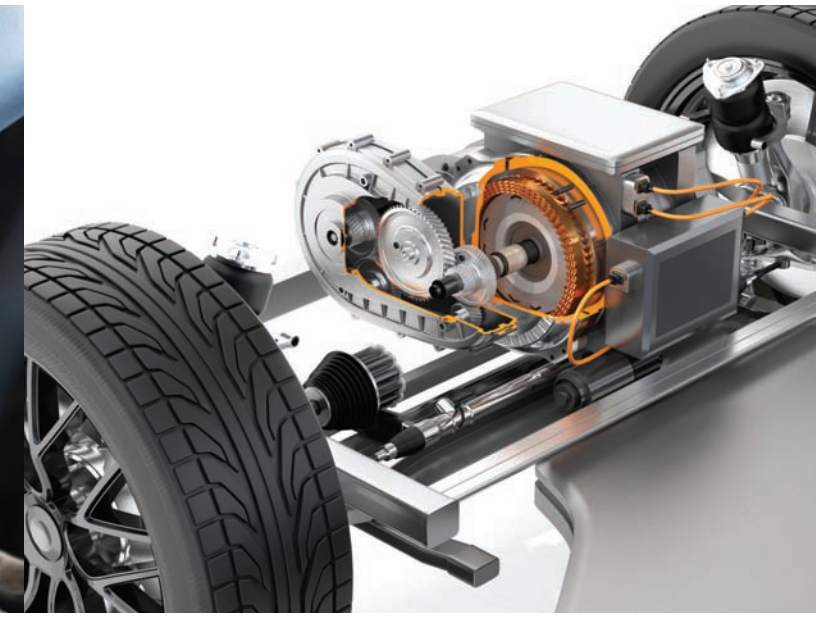
Lunch on Your Own/Posters
12:00 pm – 1:15 pm

Technical Sessions – 1:10 pm – 5:00 pm

- 4E – Electric Vehicles II
  Panel Session: Esters – 1:30 pm – 2:30 pm

Networking/Refreshment Break (Posters Session)
2:30 pm – 3:00 pm & 4:00 pm – 4:20 pm (Foyer)

- 4E – Electric Vehicles II/continued
  Foaming – 3:00 pm – 4:00 pm
- 4E – Electric Vehicles II/continued
  Grease – 4:20 pm – 4:40 pm
  Coatings – 4:40 pm – 5:00 pm



Wednesday, November 15, 2023

General Attendee Breakfast
7:00 am – 7:45 am (Foyer)

Technical Sessions – 8:00 am – 11:40 am

- 5E – Electric Vehicles III
  Modeling – 8:00 am – 9:20 am

Networking/Refreshment Break (Posters Session)
9:20 am – 9:40 am (Foyer)

- 5E – Electric Vehicles III/ continued
  Panel Session: Materials Compatibility – 9:40 am – 11:40 am

Lunch on Your Own/Posters
11:40 am – 1:00 pm

Technical Sessions – 1:00 pm – 4:00 pm

- 6E – Electric Vehicles IV
  Testing – 1:00 pm – 2:20 pm

Networking/Refreshment Break (Posters Session)
2:20 pm – 3:00 pm (Foyer)

- 6E – Electric Vehicles IV/continued
  Testing/continued – 3:00 pm – 4:20 pm

Closing Remarks
4:20 pm – 4:30 pm

EV Panel Sessions

Q&A opportunities with top industry leaders discussing the latest topics and trends in the field, as well as exchange ideas and engage with the conference content with your peers.

Tuesday, November 14 – Esters

- Using Synthetic Esters as Performance Components For E-Fluids, pg. 46
- Sustainability Effects of Esters in Electric Vehicle Lubricants – Efficiency and Biobased Content, pg. 46
- Optimizing EV Fluids by Balancing Performance and Sustainability with Ester Technology, pg. 46

Wednesday, November 15 – Material Compatability

- Conductive Layer Deposits and the Development of Bench Test Technology for Electric Vehicle Drivetrains, pg. 49
- Impact of Thermal Transient Effects on the Corrosivity of Lubricants: Results of Cyclic Temperature Profiles (Part I), pg. 49
- Effects of Test Conditions on an Oil Emersed Energized Copper Circuit Board, pg. 49
- Electrification Effects on Oxidation Performance and Corresponding Changes in Dielectric Properties of Drivetrain Lubricants, pg. 49
- Electric Motor Winding Durability: A Simple Ex Situ Test for Determining the Integrity of Insulating Coatings on Conductive Metal Wires, pg. 49
- Investigation of Magnet Wire Compatibility with Electric Transmission Fluids for Enhanced eMotor Performance, pg. 50

AM | **EV TECHNICAL SESSIONS TIME GRID** | Tuesday, November 14

Joint Plenary Session – Salon EFGH

KEYNOTE PRESENTATION

8 – 9 am Challenges of Selecting the Correct Electric Vehicle Driveline Fluid, p. 26
Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

9 – 9:20 am **Networking Break – Exhibits & Posters** (Foyer)

PM

	Session 3E Electric Vehicles I	Session 4E Electric Vehicles II: Panel Sessions
Location	**Salon EFGH**	**Salon EFGH**
TIME		
9:20 am	**Commercial EV** Hardware and Lubricant Considerations for Commercial Vehicle Electric Drive Fluids (EDFs), I. Stewart, p. 44	**1:10 pm** Electric Vehicle Drive System Speciality Fluids, A. Kolekar, p. 45 **Esters** **1:30 pm** Using Synthetic Esters as Performance Components For E-Fluids, S. Lucazeau, p. 46 **1:45 pm** Sustainability Effects of Esters in Electric Vehicle Lubricants – Efficiency and Biobased Content, A. Kurchan, p. 46 **2 pm** Optimizing EV Fluids by Balancing Performance and Sustainability with Ester Technology, R. Rambacher, p. 46 **2:15 pm – Panel Session Q&A** **2:30 pm – Refreshment/Poster Break** **Foaming** **3 pm** A Study of the Effects of Foam and Antifoam Performance in Electric Vehicle Base Fluids, S. Peerzada, p. 46 **3:20 pm** Low Foaming/Aeration and Low Traction Coefficient Synthetic Lubricant Solutions for High-Speed Electric Drivetrain Fluids, P. Ma, p. 46 **3:40 pm** Aeration Characteristics of EV Transmission Fluids: Testing and Comparison Between Specifications, R. Hein, p. 47 **4 pm – Refreshment/Poster Break** **Grease** **4:20 pm** Greases Based on Perfluoropolyether (PFPE) Oils for E-Mobility High-Speed Bearing, G. Poterala, p. 47 **Coatings** **4:40 pm** Hydrogenated Diamond-Like Carbon Coatings in the Protection of Differential Cross-Shafts, C. Scholz, p. 47
9:40 am	**Fluids** Novel EV Fluid Formulation Developments to Enhance Performance and Meet OEM EV Fluid Requirements, B. Lotfi, p. 44	
10 am	Latest Developments in Driveline e-Fluid Types for Electric Vehicle (EV) Transmissions and Axles, M. Gahagan, p. 44	
10:20 am	The Next Generation Ultra Low Viscosity Electric Drive Fluids (EDFs) Enabled by the Synergy Between the Additive and Base Oil Technologies, C. Gowdy, p. 45	
10:40 am	**Break**	
11 am	Improving Heat Transfer Properties of EV Transmission Fluids Using Oil Soluble PAGs, S. Glänzer, p. 45	
11:20 am	Effect of Polymers on the Electrical Properties of Lubricants for EVs, J. Scherger, p. 45	
11:40 am	Dedicated E-Fluids for Energy Efficiency, H. Thaker, p. 45	

AM | **EV TECHNICAL SESSIONS TIME GRID** | Wednesday, November 15

9 – 9:20 am **Networking Break – Posters Session** (Foyer)

PM

	Session 5E Electric Vehicles III	Session 6E Electric Vehicles IV
Location	**Salon EFGH**	**Salon EFGH**
TIME		
	Modelling	**Testing**
8 am	Modelling of the Triboelectric Contact of a Roller Bearing, S. Paulus, p. 48	**1 pm** Investigation eTribology and eRheology – Current Rigs and Results, P. Lee, p. 50
8:20 am	Simulation of Electrical Properties of Drivetrains Including Bearings and Gears, H. Grillenberger, p. 48	**1:20 pm** Application of the Four-Ball EP Test as an FZG (A10/16.6R/90) Scuffing Screening Test with Reference Fluid Assessment, K. Cogen, p. 50
8:40 am	Modeling Electrical Contact During a Rolling Vibratory Motion Considering Mixed Lubrication, R. Jackson, p. 48	**1:40 pm** Effect of Phosphorus and Sulfur-Based Additives on Wear and Micro-Pitting Under Rolling and Sliding Conditions, Y. Jeung, p. 50
9 am	Evaluating the Potential Impact of Lubricant Cooling Capability: Applying and Constructing Thermal Models for HEV and EV Drivetrains, T. Newcomb, p. 48	**2 pm** Validation of EV Fluids – An In-Depth Exploration of System Efficiency, Durability, and Thermal Performance, F. Sarti, p. 51
9:20 am	**Poster Break**	**2:20 pm – Refreshment/Poster Break**
	Panel Sessions: Material Compatability	
9:40 am	Problem Description	**3 pm** E-Fluid Effects Made Visible Through Full-Scale EDU Testing, S. Patterson, p. 51
9:50 am	Conductive Layer Deposits and the Development of Bench Test Technology for Electric Vehicle Drivetrains, G. Miiller, p. 49	**3:20 pm** Development of High-Speed/High-Load Three-Roller Type Pitting Wear Tester for Tribo-Elements Sliding Parts of Electric Vehicle, T. Kunii, p. 51
10:05 am	Impact of Thermal Transient Effects on the Corrosivity of Lubricants – Results of Cyclic Temperature Profiles (Part I), G. Hunt, p. 49	**3:40 pm** The Investigation of Lubricant Viscosity on Fatigue Wear of Gear/Bearing Steel Under Rolling Contact Conditions, R. Ohashi, p. 51
10:20 am	Effects of Test Conditions on an Oil Emersed Energized Copper Circuit Board, H. Thaker, p. 49	**4 pm** Test Methods to Address Next Generation Tribological Applications in Electric Vehicles, T. Khosla, p. 52
10:35 am	Electrification Effects on Oxidation Performance and Corresponding Changes in Dielectric Properties of Drivetrain Lubricants, J. Conner, p. 49	**4:20 pm** Closing Remarks
10:50 am	Electric Motor Winding Durability – A Simple Ex Situ Test for Determining the Integrity of Insulating Coatings on Conductive Metal Wires, T. Petek, p. 49	
11:05 am	Investigation of Magnet Wire Compatibility with Electric Transmission Fluids for Enhanced eMotor Performance, Y. Kwak, p. 50	
11:20 am	Panel Session Q&A	

Tuesday, November 14, 2023

Joint Plenary Session
8:00 am – 9:00 am (Salon EFGH)

KEYNOTE PRESENTATION

Challenges of Selecting the Correct Electric Vehicle Driveline Fluid

Troy Muransky, Lead Materials Engineer, American Axle & Manufacturing (USA)

See page 26 for details.

Session 3E (Salon EFGH)

Electric Vehicles I

COMMERCIAL EV

Session Chair: Hyeok Hahn, Chevron, Inc., Richmond, CA

9:20 am – 9:40 am

3961325: Hardware and Lubricant Considerations for Commercial Vehicle Electric Drive Fluids (EDFs)

Co-Presenters: Ian Stewart, Afton Chemical Corp., Richmond, VA, and Amy Zyski, Dana Inc., Maumee, OH

Co-Authors: Chris Cleveland, Michael Glasgow, Dan Horvath, Tracy McCombs, Stephen Walker, Afton Chemical Corp., Darren Ziskovsky, Bill Waltz, Dana Inc., Maumee, OH

The global shift from combustion engines to electric vehicles requires ingenuity in driveline hardware. Transmission and axle designs are being wholly reimagined to enable electrification, requiring the introduction of new gear and bearing configurations to accommodate the higher rotational speeds, loads, and stresses associated with electric motors, along with new coating and sealing materials to protect power electrics and other componentry. As eMobility expands beyond passenger vehicles (PV) and other light duty (LD) applications to commercial vehicles (CVs; Class 6-8), drivetrain designs are further increasing the performance and compatibility demands placed upon lubricants used in these applications. Existing electric drive fluids (EDFs) must adapt to meet these needs. Here, hardware design considerations for CV electrification are expounded. The effect of different variables driving the balance between individual lubricant performance requirements for CV battery, eMotor, inverter, and gearbox systems is presented. The relevance, or potential lack thereof, of standard ASTM guidance or contemporary PV/LD EDF criteria, such as durability, oxidation, and materials compatibility, for gauging EDF and CV affinity is discussed. Likewise, conventional driveline fluid formulation styles and componentry need to be reconsidered (i.e., ATF vs. MTF vs. Axle et.). This presentation will explore those challenges and the merits of parallel hardware and EDF formulation during development.

FLUIDS

Session Chair: Hyeok Hahn, Chevron, Inc., Richmond, CA

9:40 am – 10:00 am

3935796: Novel EV Fluid Formulation Developments to Enhance Performance and Meet OEM EV Fluid Requirements

Babak Lotfi, Gordon Lee, ExxonMobil Technology & Engineering, Annandale, NJ

Early fluid solution approaches for lubricating electric vehicle gearboxes mostly involved utilizing existing, off-the-shelf ATFs. These fluids were lower in viscosity than their traditional gear oil counterparts, and readily available to manufacturers through existing fluid inventory. As gearbox designs have matured, the first-generation fluid designs are proving to be no longer appropriate, leading to the need for bespoke fluids with targeted performance properties. Over recent years integrated electric drive units (EDUs) where a single fluid is being used to lubricant gears, bearings, clutches and also used for thermal management of e-motor and electronic components has become popular in electric vehicle powertrain designs. These integrated systems provide additional challenges and opportunities driving lower viscosity formulations, and highlighting the need for dielectric properties, thermal management, and material compatibility. In this presentation, we will review our current work in developing optimized fluids specifically engineered to enhance fluids properties in three key areas: energy efficiency (leading to reduced battery stress and potentially extending driving range), low speed wear (protecting the gearbox), and aeration (tie back into efficiency, new & aged oil). We will compare the results of different formulations and discuss how we can improve key performance areas using advanced formulations to deliver superior properties and ultimately meet OEMs requirements.

10:00 am – 10:20 am

3940690: Latest Developments in Driveline e-Fluid Types for Electric Vehicle (EV) Transmissions and Axles

Michael Gahagan, Lubrizol Ltd., Derby, Derbyshire, United Kingdom

Entirely new driveline e-fluid classes are being developed as a now integral part of the electric vehicle (EV) powertrain engineering technology revolution. This has been driven by the need for new dedicated fluids to directly cool electrical components while fulfilling the requirements of lubricant thermal and fluid electrical insulating properties and corrosion protection under new, severe operating conditions. Notwithstanding the familiar challenges of transmission, gear, and bearing lubrication; recent research and development has led to such a new e-fluid type by optimizing the additive components present in the e-fluid. Additionally, eliminating the need for sulfur-containing additive chemistry (coined “sulfur-free” technology) has seen state-of-the-art fluid technology types just entering the market, which will be described. Fluid electrical properties will be discussed plus results observed from advanced electrical circuit corrosion methods. The fluid’s enhanced ability to effectively protect component hardware in a range of fluid viscosity types will also be highlighted.

10:20 am – 10:40 am

3975098: The Next Generation Ultra Low Viscosity Electric Drive Fluids (EDFs) Enabled by the Synergy Between the Additive and Base Oil Technologies

Co-Presenters: Christopher Gowdy, Afton Chemical, Richmond, VA and Jason Rosalli, Novvi, Alameda, CA

Co-Authors: Chris Cleveland, Ian Stewart, Michael Meffert, Afton Chemical, Richmond, VA; Jason Wells, William Downey, Novvi, Alameda, CA

As the industry continues its transition to electrified vehicles, there is an ever-increasing emphasis on the role of the electric drive fluid (EDF). One specific area of focus in the design and development of the fluid is energy efficiency, which has to do eAxle operation and battery range. In order to achieve these efficiency gains, the implementation of ultra-low viscosities (KV(100C) < 4 cSt) and novel additive and base oil technologies to mitigate churning and frictional losses. Such EDFs are only viable when the additive and finished fluid formulations are robust and balanced to provide the appropriate level of wear, scuffing and pitting protection, oxidation prevention and compatibility with and protection of the key materials components. In this presentation, we will review some recent work in the development of such EDFs.

10:40 am – 11:00 am – Refreshment/Poster Break

11:00 am – 11:20 am

3962846: Improving Heat Transfer Properties of EV Transmission Fluids Using Oil Soluble PAGs

Steffen Glänzer, Clariant, Frankfurt, Germany

Several key parameters, such as anti-wear properties, energy efficiency, electric properties, foam, and material compatibility, must be considered when developing formulations of transmission fluids for electric vehicles. It is especially desirable to maximize the heat transfer properties of these fluids in wet motor applications to improve the efficiency of the electric motor. PAG Group V base fluids are well known in industrial applications, such as industrial gear oil, compressor fluids and hydraulic fluids. However, the immiscibility with hydrocarbons limited their application in automotive oils so far. Here, we will discuss new ultra-low viscosity PAG Group V base oils that demonstrate exceptionally high heat transfer properties, are hydrolytically stable and are compatible with Group I-III mineral oils, Group IV PAO and Group V ester base oils. These mixtures show enhanced properties and can improve vehicle efficiency in wet transmission fluids.

11:20 am – 11:40 am

3962676: Effect of Polymers on the Electrical Properties of Lubricants for EVs

Jacob Scherger, Functional Products Inc., Macedonia, OH

One of the key areas specified in the SAE J3200 'Fluid for Automotive Electrified Drivetrains' standard is the electric properties of the fluid. It will become important for formulators to know how different types of additives might affect a fluid's conductivity, dissipation factor, and/or dielectric breakdown voltage. Optimal performance in terms of electrical properties will likely not involve maximizing or minimizing any of these properties, but operating in a moderate range to both prevent static build-up (where sudden releases lead to pitting in bearings, or where fires might occur in extreme cases) and current shorting to unwanted areas or components. In this study, the effect of polymer additives on a lubricant's electrical properties are examined in terms of polymer chemistry, polymer concentration, and base fluid. Polymers have unique physics due to their macromolecular structure, which can affect surface chemistry and mass or charge transport through bulk fluids. The strength of these effects are compared to those of non-polymer additives.

11:40 am – 12:00 pm

3960387: Dedicated E-Fluids for Energy Efficiency

Hitesh Thaker, Changlin Zhao, Infineum USA L.P., Linden, NJ

The automotive industry trends toward improved fuel efficiency and CO_2 emission reduction have resulted in automotive manufacturers incorporating greater levels of electrification, and developing more compact, higher voltage designs. The new generation e-fluids for these applications need to offer reduced energy consumption at lower viscosities while providing necessary hardware protection. Careful optimization of e-fluid parameters like viscometrics and additives is required to achieve high energy efficiency in controlled testing environments and real-world conditions.

Session 4E (Salon EFGH)

Electric Vehicles II

Sessions begin at 1:10 pm

1:10 pm – 1:30 pm

3964246: Electric Vehicle Drive System Specialty Fluids

Anant Kolekar, Valvoline LLC, Lexington, KY

The recent growth in the electric vehicle (EV) market has significantly affected the automotive industry along with the lubricant industry. For the lubricant industry, EV requirements are unique compared to Internal Combustion Engine Vehicles (ICEVs) where electrical, thermal, extreme pressure and foam performances are becoming more critical. The driving range or efficiency and the durability boost are becoming significant goals for EVs that pave the way towards a greener future. In EVs, gears and bearings rotate at very high speeds (8,000-30,000 RPM) and experience significant fluctuations in power, torque and speed, which demand for more precise testing work to improve standard ICEV transmission fluid tests. EV DSFs target vital EV requirements to improve friction reduction, overall efficiency, electrical compatibility and insulation, and electric motor and drive system heat transfer. There is an imperative need to design the best of all worlds EV fluid that maintains excellent mechanical, electrical and tribological properties to give optimal driving range and fuel economy performance. The unique benchtop test is developed to study further on the high-speed foam impact. Different ingredients were compared by designing and developing benchtop tests, transmission rigs and full vehicle tests. There were significant improvements in the overall vehicle efficiency (up to 3%) and reductions in operating temperatures (up to 9 °C).

(Session 4E continued)

PANEL SESSIONS: ESTERS

Session Chair: Neil Canter, Chemical Solutions, Willow Grove, PA

1:30 pm – 1:45 pm

3957569: Using Synthetic Esters as Performance Components For E-Fluids

Siegfried Lucazeau, NYCO, PARIS Cedex 08, France

It is now generally recognized by the industry that direct cooling in e-mobility applications delivers extended hardware lifetime as well as improved energy efficiency. Synthetic esters, when carefully designed, do possess high performance features for such applications: excellent heat transfer properties, a high level of fire safety, low traction coefficients, and superior resistance to oxidation. It has also been shown such esters did not affect the performance of additive packages on copper protection or mechanical properties. This work has been extended to blends of esters with Group III base fluids, considering two different approaches: 1) introduce a hydrocarbon in an ester base fluid to improve cost-effectiveness and reduce its impact on elastomers, and 2) boost the performance of a Group III-based formulation using esters to reduce traction and improve fire safety. Making blends allows formulators to find ways around some of the drawbacks of both Group III and synthetic ester base fluids.

1:45 pm – 2:00 pm

3959714: Sustainability Effects of Esters in Electric Vehicle Lubricants – Efficiency and Biobased Content

Alexei Kurchan, Gareth Moody, Cargill Inc., Wilmington, DE

The increase in electrification of vehicles can have a dramatic impact on lowering CO_2 emissions. Lubricant can further improve sustainability benefits via improving intrinsic and extrinsic aspects of EV operation and maintenance. The intrinsic benefits are provided by using biobased raw materials. Here, the CO_2 created in production and transportation of lubricants can be partially or entirely offset by carbon sequestration during growing of crops. The second extrinsic benefits are gained from increased efficiency and extension of vehicle range. This talk will combine both these effects and discuss how the holistic approach to lubricant formulation can have the maximum impact on sustainability.

2:00 pm – 2:15 pm

3962962: Optimizing EV Fluids by Balancing Performance and Sustainability with Ester Technology

Rob Rambacher, Jared Nelson, Emery Oleochemicals, Cincinnati, OH

Thermal management fluids will be a vital part of the new generation of electric vehicles. While most battery systems currently use indirect cooling systems, it is assumed that in the future either direct or immersion cooling techniques will be implemented. For these high-efficiency systems, a new generation of fluids will need to be developed moving away from traditional water-glycol blends. Esters can play an important role in the formulation and development of new EV fluids. This Group V base stock chemistry has shown to have higher breakdown voltages as well as more favorable combinations of low viscosity and high flashpoint. Due to higher costs for more advanced ester technology, blends with petrochemical base stocks can provide a good balance of material sustainability, system sustainability, high performance, and economics. In our latest research, we have evaluated the dielectric and cooling properties of ester blends with petrochemical base stocks.

2:15 pm – 2:30 pm – Panel Session Q&A

2:30 pm – 3:00 pm – Refreshment/Poster Break

FOAMING

Session Chair: Yungwan Kwak, Afton Chemical Corp., Richmond, VA

3:00 pm – 3:20 pm

3969218: A Study of the Effects of Foam and Antifoam Performance in Electric Vehicle Base Fluids

Safia Peerzada, Münzing North America, LP, Bloomfield, NJ

As electric vehicles (EVs) enter the automotive market, one vital area involves the development of fluids specifically for EVs. Compared to fluids for traditional internal combustion engine (ICE) vehicles, fluids for EVs are required to provide lubrication and cooling under much higher shear conditions and are also required to stabilize the vehicle's electronics and battery's temperature. These different requirements often lead to EV base fluids exhibiting different foaming tendency compared to traditional fluids due to the different fluid chemistry and viscosity. While the fluid is in use, the antifoam functions to minimize foam buildup, which is undesirable for reasons such as reduction of lubrication and poor heat removal. A study of foam tendency in several EV base fluids using new foam test methods to simulate real-world application will be reviewed. Furthermore, the performance of various antifoam chemistries will be studied to understand the most optimal antifoam for EV fluids.

3:20 pm – 3:40 pm

3960517: Low Foaming/Aeration and Low Traction Coefficient Synthetic Lubricant Solutions for High-Speed Electric Drivetrain Fluids

Philip Ma, Donna Mosher, Chad Steele, BASF, Tarrytown, NY

Internal combustion engines (ICEs) are being replaced by electric motors as power sources for both passenger cars and heavy-duty trucks. OEMs are using off-the-shelf lubricant fluids, such as industrial gear oils (IGO), automatic transmission fluids (ATFs), manual transmission fluids (MTFs), dual clutch transmission fluids (DCT), etc., as electric drivetrain fluids (EDFs). EDFs are driving toward lower viscosity for better heat transfer capacity and better energy efficiency, and in the meantime satisfying all the other challenging requirements, such as gear/bearing scuffing/wear protection, coating/seal material compatibility, electric properties, etc. In this paper, we will highlight the importance of low foaming and low aeration, low traction coefficient which are critical for the

performance of low viscosity EDF during the high rotation-per-minute (rpm) speed applications. EDFs with ultra-low foaming/aeration can potentially reduce electric induced bearing damage (EIBD), bearing creep (BC), thus provide better bearing protection and life, and in the meantime provide better heat transfer capacity. Low traction coefficient fluids will also contribute to better lubricant energy efficiency in comparison to other fluids with the same viscosity.

3:40 pm – 4:00 pm

3964010: Aeration Characteristics of EV Transmission Fluids: Testing and Comparison Between Specifications

Ricardo Hein, CONEXO, Inc., Acworth, GA

Previous STLE meetings addressed oil aeration as a key stressor for E-fluids operating in EV transmissions. This talk will present the comparative testing results of EV transmission fluids, the apparatus, and the testing method. It includes information on how this efficient and cost-effective tester simulates the complexity of EV transmission operation in order to correlate the aeration characteristics in E-fluids. Under the newly developed testing method, the fluid volumes are reduced, the speed is increased to ultra-high, the air dispersion gear is fully immersed, and the temperatures are raised. We compared several market-available fluids that ranged in quality and specifications. This benchtop aeration tester offers a concrete solution to rethink the fluid design and hardware architecture for low aeration. Manufacturers of EV transmissions, E-fluids, antifoam agents and other additives will benefit from the implementation of this testing method.

4:00 pm – 4:20 pm – Refreshment/Poster Break

GREASE

Session Chair: Yungwan Kwak, Afton Chemical Corp., Richmond, VA

4:20 pm – 4:40 pm

3959450: Greases Based on Perfluoropolyether (PFPE) Oils for E-Mobility High-Speed Bearing

Greg Poterala, Solvay Specialty Polymers, Commerce Township, MI

The shift towards electric vehicles plays an important role in the transition to a more sustainable mobility. Electrical powertrains are pushed to higher rotational speed in order to efficiently improve the power density. This brings new challenging requirements for the roller bearings, in which advanced EV grease formulations are needed to reduce friction, wear, and NVH on long run while preventing electrical erosion. To address these challenges, we have tested different grease compositions based on PFPE. These fluids are synthetic lubricants largely used for highly demanding applications thanks to their outstanding thermal and oxidative stability, chemical inertness, and hydrolytic stability. In this presentation, we will report the influence of the characteristics of the grease components on the bearing performance at high speed: the viscosity of the PFPE base oil, the type of thickener as well as the additives. We will also discuss the optimization of the electrical properties of the PFPE-based lubricating grease for EV bearing application.

COATINGS

Session Chair: Yungwan Kwak, Afton Chemical, Richmond, VA

4:40 – 5:00 pm

3964058: Hydrogenated Diamond-Like Carbon Coatings in the Protection of Differential Cross-Shafts

Christian Scholz, Timea Stelzig, Oliver Hunold, Oerlikon, Bingen, Germany; Constantino Costa, Oerlikon, Rock Hill, SC

The rapid movement of the automotive industry to develop and commercialize electric vehicles is placing growing demands not only on the lubricants enabling optimum operation but also on identifying alternative, synergistic solutions to keep cost flexibility and durability of the components. The general trend to move to low viscosity fluids presents challenges when it comes to wear and friction management. In general, three methods can be carried out to reduce friction loss and limit wear: 1.) changing the design of the component, 2.) optimizing lubrication in terms of the lubricant composition and/or component materials and 3.) implement advanced novel coatings. Coatings play the role of protective layers to reduce friction coefficient and increase wear resistance of the components. In this work, we present the beneficial effect of hydrogenated diamond-like carbon coatings on the performance of differential cross-shafts wear and friction behavior.

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Wednesday, November 15, 2023

Session 5E (Salon EFGH)

Electric Vehicles III

MODELLING

Session Chair: Babak Lotfi, ExxonMobil Technology & Engineering, Annandale, NJ

8:00 am – 8:20 am

3959913: Modelling of the Triboelectric Contact of a Roller Bearing

Stefan Paulus, Simon Graf, Oliver Koch, RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

In modern inverter-fed electric drive systems, rotor bearings are loaded by parasitic voltage. When this voltage exceeds the breakdown voltage of the lubricant, it discharges across the lubrication gap. This can lead to damages and premature failure of the used roller bearings. To understand and predict the electrical phenomena inside a rolling contact, roller bearings have to be described as electrical circuit system. In this work, the transfer from the mechanical component roller bearing to an electrical equivalent system is shown. Furthermore, the electrical properties of roller bearings are modeled regarding the capacitive and resistive behaviors of the lubricant and the bearing components. In addition to that, the resistance of occurring discharge channels is taken into consideration. The investigated parameters include the running speed, the ambient lubricant temperature and the mechanical and electrical load. With help of this model, the influence of the operating conditions on the electrical behavior of a roller bearing can be described.

8:20 am – 8:40 am

3962867: Simulation of Electrical Properties of Drivetrains Including Bearings and Gears

Hannes Grillenberger, Andreas Meinel, Bernhard Jakob, Martin Correns, Schaeffler Technologies AG & Co KG, Herzogenaurach, Germany

Electric potentials in generators and electric motors may cause damaging parasitic currents in drivetrain components like bearings or gears. These currents can lead to subsequent damages like re-melting, re-hardening, grey staining, or aging of the lubricant. An effective and efficient design of the gearbox or motor can only be achieved by simulation that includes mechanical, thermal, and electrical properties for every operating condition. This presentation shows a method to calculate these properties for gears and bearings within a mechanical system. It considers the exact geometry, load distribution, friction, surface roughness, and lubrication conditions. This detailed knowledge enables high quality results, and the system can be optimized for a variety of load cycles. This presentation shows physical background, implementation in a software tool, method workflow and validation. Finally, some corrective measures to avoid parasitic currents will be introduced.

8:40 am – 9:00 am

3950663: Modeling Electrical Contact During a Rolling Vibratory Motion Considering Mixed Lubrication

Robert Jackson, Auburn University, Auburn, AL; Santosh Angadi, Gannon University, Erie, PA

In many devices and applications, electrical contacts are exposed to vibrations, sliding, or rolling conditions and are prone to the fretting-based degradation. This could also have applications to electrified rolling element bearings, such as in electric vehicles. Thus, lubricants are often employed in such contacts to reduce wear and fretting corrosion. However, due to the non-conductive behavior of the lubricants with fluorocarbons and hydrocarbons, lubricants lead to a few adverse problems. Also, the fluid dynamics upon excitation, motion causes extended breaks or gaps in between the conducting surfaces. Factors such as surface roughness and fluid viscosity will determine the time taken for the two surfaces of the connectors to separate from a solid conductive contact. In this work, a coupled structural-fluid theoretical model is developed for evaluating such intermittent contact breaks/gaps when two metallic rough surfaces in contact are under vibrations. The model is capable of predicting the increase in the fluid film as well as the contact resistance change with time due to the possible connector vibration.

9:00 am – 9:20 am

3962949: Evaluating the Potential Impact of Lubricant Cooling Capability: Applying and Constructing Thermal Models for HEV and EV Drivetrains

Timothy Newcomb, The Lubrizol Corp., Wickliffe, OH

The importance of cooling electric motors is driving the construction of e-lubricants that are optimized for heat transfer. The lubricant properties that influence heat transfer are viscosity, thermal conductivity, specific heat capacity and density. The importance of each depends on the flow regime. There are many electric drive unit configurations and, without design details or access to actual hardware, flow regimes can only be approximated or guessed. The lubricant's heat transfer ability can be assessed using a "figure-of-merit", which incorporates the flow regime impact on the thermal properties. In this presentation, we will review the figure-of-merit models as they relate to lubricant thermal properties and compare them to models derived for general e-motor systems where some of the design information is known. We will share our work on the thermal characterization of actual electric drive unit hardware and contrast the thermal models constructed from this work to the prior estimates.

9:20 am – 9:40 am – Poster Break

PANEL SESSIONS: MATERIAL COMPATABILITY

Session Chair: Matthias Hof, Emery Oleochemicals GmbH, Duesseldorf, Germany

9:40 am – 9:50 am – Problem Description

9:50 am – 10:05 am

3894802: Conductive Layer Deposits and the Development of Bench Test Technology for Electric Vehicle Drivetrains

Greg Miiller, William VanBergen, Savant Inc., Midland, MI; Alexei Kurchan, David Gillespie, Cargill, Newark, NJ; Gunther Mueller, APL, Landau, Landau, Germany; Timothy Newcomb, Gregory Hunt, The Lubrizol Corp., Wickliffe, OH

As the enhancement of EV technology continues, so do the improvements with fluids and additives utilized within them. Varying conditions, depending on the EV system and usage, can cause the formation of conductive deposits and corrosion within drivetrain. Corrosion is a well-known entity and tools to evaluate under these conditions are imperative. However, the formation of conducting layer deposits, a corrosion product, has also been identified as a failure mechanism for current electric motor designs. Different drivetrain base stocks along with additive formulations may have inherently different corrosion rates producing conducting layer deposits in both solution and vapor phases. To help resolve these issues, a group of industry experts involving both OEMs and lubricant experts from across the globe, have developed bench tests to better predict these conductive and corrosion deposits. The apparatus developed are the conductive deposit test and the wire corrosion test. This paper covers several different aspects of the EV drivetrains and fluids performing in the CDT and WCT that show correlation to field data along with reactions due to the dilution of esters, base stocks and traction reducers.

10:05 am – 10:20 am

3939138: Impact of Thermal Transient Effects on the Corrosivity of Lubricants – Results of Cyclic Temperature Profiles (Part I)

Gregory Hunt, Lindsey Choo, Timothy Newcomb, The Lubrizol Corp., Belper, United Kingdom

Lubricant corrosion performance is generally assessed isothermally. The selection of the test temperature has a large influence on the extent of corrosion, typically higher temperatures are more severe. However, vehicles operate over a variety of temperatures, with fluctuations from the nominal temperature being common. There is a question as to whether a short excursion to high temperature would negatively influence the corrosion once the fluid has returned to the nominal condition. This transient temperature relationship with corrosion performance has not previously been investigated. Corrosion is typically assessed using the ASTM D130 copper corrosion strip test which provides a visual rating. However, as the ASTM D130 is a qualitative test, it is not an optimal tool for this type of investigation. A more appropriate method is the Wire Corrosion Test (WCT) because this test follows corrosion processes by monitoring changes in resistance. The WCT, therefore, is both quantitative and highly sensitive. In this first study, a set of sulfur containing oils was exposed to a cyclic thermal profile, where the temperatures were transitioned between high and low values. The corrosion during the cycling test was found to be more significant than expected. This implies that brief excursions at high temperatures could have greater impact on the corrosion performance over the life of the lubricant than previously expected – this is of particular interest in electric drive units (EDUs).

10:20 am – 10:35 am

3962166: Effects of Test Conditions on an Oil Emersed Energized Copper Circuit Board

Hitesh Thaker, Scott Campbell, Infineum, Linden, NJ

An energized copper corrosion test (ECT) has been developed to study the effects on copper surfaces as they may relate to the performance of e-Fluids used in areas such as motor, battery, and electronics. Performance of fluids in these areas is critical to the effective implementation of current and next generation electric vehicle drivelines. Energized corrosion testing is still evolving with much variation in competing test designs. This presentation is intended to highlight learnings centered around the variations of certain physical test parameters and their effects on test outcomes.

10:35 am – 10:50 am

3964730: Electrification Effects on Oxidation Performance and Corresponding Changes in Dielectric Properties of Drivetrain Lubricants

Joshua Conner, Southwest Research Institute, San Antonio, TX

As electric drive unit design continues to incorporate a common fluid for lubrication of the rotating components and cooling of the electric motor, the electrification of lubricant testing equipment enables test methods that are more representative of electric vehicle applications. This study evaluates: (1.) how oxidation affects the dielectric properties (relative permittivity, dissipation factor, electrical conductivity, and dielectric breakdown voltage) of various drivetrain lubricants and (2.) how oxidation performance may be impacted by different types of electric and magnetic fields. A common drivetrain lubricant oxidation test was used to study these effects under both electrified and non-electrified conditions.

10:50 am – 11:05 am

3955654: Electric Motor Winding Durability – A Simple Ex Situ Test for Determining the Integrity of Insulating Coatings on Conductive Metal Wires

Tyler Petek, Richard Brenda, Lubrizol Ltd., Derby, Derbyshire, United Kingdom

Electric motors in automotive applications have led to new material challenges for the working fluids which enable their operation, including lubricants. One such challenge is the new introduction of polymeric materials used as thin film insulators on copper windings in a motor. Thin motor windings must be electrically insulated from each other to enable high power density motor function. Insulator degradation leading to electrical shorts may result in catastrophic motor failure. Specific application testing is needed to ensure that the insulation properties are not harmed

during the motor lifetime. For this purpose, this presentation will discuss a simple test developed to measure the effects of long-term exposure of insulated wires to the lubricating fluid. The test uses industry standard wires with a polyimide type coating and measures their post-exposure insulating properties. The wires undergo accelerated aging in different fluids at high temperature. Once the aging is complete, the wires are installed into the test cell where a conductive fluid fills any void which may have formed in the coating. This creates an ionically conductive path to the wire. A standard potentiostat measures the conductivity through the voids to quantify the coating void fraction. The test can differentiate between fluids that will harm the coating and those that will not while also measuring the functionally important properties.

11:05 am – 11:20 am

3955641: Investigation of Magnet Wire Compatibility with Electric Transmission Fluids for Enhanced eMotor Performance

Yungwan Kwak, Afton Chemical Corp., Richmond, VA

The implementation of new global regulations aimed at reducing pollutants, greenhouse emissions, and improving fuel economy has prompted OEMs to accelerate vehicle electrification efforts. In this regard, the electric motor (eMotor) plays a crucial role as one of the key components in the electric drive unit. The eMotor utilizes a significant amount of magnet wire (MW), which is a copper wire coated with a polymeric insulation material that comes into contact with an electric transmission fluid (ETF). Therefore, the compatibility of MW with ETFs emerges as the primary performance requirement, as poor compatibility can result in decreased performance, electrical shorts, or even catastrophic eMotor failure. This talk presents new insights into MW compatibility with various ETFs. Key performance criteria investigated include adhesion, breakdown voltage, and partial discharge behavior of the insulation coating. The study investigates MWs with different shapes (round and rectangular) and various types of coating materials, such as polyester, polyamide, and polyimide. Furthermore, the impact of water concentration in ETF on MW performance during aging is examined. It is demonstrated that the additive package or formulation chemistry of the lubricant plays a pivotal role in generating significant differences in MW performance. The authors elucidate the mechanisms behind MW deterioration and propose strategies for optimizing lubricant formulations to enhance MW compatibility.

11:20 am – 11:40 am – Panel Session Q&A

Session 6E (Salon EFGH)

Electric Vehicles IV

TESTING

Session Chair: Leonardo Farfan-Cabrera, Instituto Tecnológico Y De Estudios Superiores De Monterrey, Monterrey, Mexico

1:00 pm - 1:20 pm

Investigation eTribology and eRheology – Current Rigs and Results

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

With EV fluid research being a relatively new field, this presentation will explore the current available rigs, both adapted and manufactured, that are available for testing in national labs, research institutes and universities. We will also highlight current published papers and patents in the field and common research themes noted-to-date.

1:20 pm – 1:40 pm

3959446: Application of the Four-Ball EP Test as an FZG (A10/16.6R/90) Scuffing Screening Test with Reference Fluid Assessment

Kerry Cogen, Yanzhao Wang, Infineum USA L.P., Linden, NJ

Scuffing performance is a key metric in assessing electrified vehicle fluid performance. The FZG (A10/16.6R/90) gear scuffing test is typically used, but it is resource intensive. A bench screener test, based on the 4 Ball EP Test (ASTM 2783), has been developed to facilitate prioritizing oils to be run in the more resource-intensive gear test. The screener test also makes it possible to study the formation of tribofilm as a function of load. This systematic approach to analyzing film formation with load offers the opportunity to better understand tribofilm formation and the impact on scuffing performance.

1:40 pm – 2:00 pm

3962105: Effect of Phosphorus and Sulfur-Based Additives on Wear and Micro-Pitting Under Rolling and Sliding Conditions

Yunah Jeung, Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Ryotaro Ohashi, Kenya Nakayama, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan

As the E-axle is being made smaller, the speed of motor rotation is increasing, and low-viscosity transmission lubricating oil is required in order to reduce stirring resistance and improve cooling performance. As a result, the gears and bearings of transmissions are forced to move under poor lubrication conditions, so lubricating oils are required to have further improved wear resistance. Phosphorus- and sulfur-based additives are commonly used to improve wear resistance, but their anti-wear mechanisms are not well understood. As a result of an investigation using a mini-traction machine (MTM), it was confirmed that the S-type additive exhibited a greater antiwear effect than the P-type additive. The antiwear and antipitting fatigue mechanisms were discussed based on the surface analysis results of the tribo-reaction films on sliding surfaces derived from P-based and S-based additives.

2:00 pm – 2:20 pm

3953867: Validation of EV Fluids: An In-Depth Exploration of System Efficiency, Durability, and Thermal Performance

Flavio Sarti, TotalEnergies, Solaize, France

The electric vehicle industry has advanced rapidly. As new electric powertrain technologies continue to evolve, new and promising prospects for electric vehicle fluids are emerging. Multipurpose fluids (lubrication, thermal control, component protection) are starting to be used, which raises the question of how to develop and validate them. The classic approach to transmission fluid development consists of multi-level testing (from contact (tribometers) to components (gears, bearings, pumps, seals) to final application in the vehicle). To enhance this approach, TotalEnergies is incorporating novel in-house tests derived from previous EV fleet campaigns. The use of vehicle data and fluid samples is essential to shorten the testing cycle while maintaining the representativeness of a real road test.

2:20 pm – 3:00 pm – Refreshment/Poster Break

Session Chair: Carlos Sanchez, Southwest Research Institute, San Antonio, TX

3:00 pm – 3:20 pm

3952381: E-Fluid Effects Made Visible Through Full-Scale EDU Testing

Suzanne Patterson, Auke Faber, David Whitticar, The Lubrizol Corp., Wickliffe, OH

The global transition to electrified powertrains necessitates new lubricants which provide e-device durability, minimize power loss, and participate in thermal management. The correlation of mechanical efficiency in traditional gearboxes to fluid viscosity, traction, and friction has been extensively studied, and we are now studying those correlations to power loss in e-axles, with and without embedded motors. We are also studying the relationship between thermal management of an e-device and a fluid's viscosity, heat capacity, and thermal conductivity. For full scale electric drive unit testing, Lubrizol has upgraded our three-motor transmission test stands with the addition of a 400-kW battery simulator and can precisely control embedded electric machines with a pair of universal inverters. This upgrade allows testing of myriad lubricants in almost any e-device, generating fundamental knowledge for how to formulate the highest performing e-fluids.

3:20 pm – 3:40 pm

3962033: Development of High-Speed/High-Load Three-Roller Type Pitting Wear Tester for Tribo-Elements Sliding Parts of Electric Vehicle

Takuto Kunii, Vishal Khosla, Jun Xiao, Michael Vinogradov, Rtec-Instruments, Chiba, Kashiwa, Japan; Shinya Sasaki, Tokyo University of Science, Tokyo, Japan

The E-Axle as a transmission/motor system in electric vehicles is becoming an alternative to traditional engines. In the development of the E-axle, increasing the rotation speed of the motor and improving the efficiency of the transmission are urgent issues in order to make the system more compact. The high-speed rotation of the transmission and the resulting low viscosity of the lubricating oil affect the poor lubrication of the gear and bearing surfaces and the increase of pitting wear. Pitching wear causes transmission vibration and noise and reduces powertrain efficiency and life. In this research, we have developed a three-roller pitting wear tester that enables higher speed (>4.0m/s) and higher load (>2000N) testing. Using this device, we investigated the effect of the slip ratio on the occurrence and progression of micro-pitting on the rolling friction surface of gear steel using an acoustic emission method.

3:40 pm – 4:00 pm

3923522: The Investigation of Lubricant Viscosity on Fatigue Wear of Gear/Bearing Steel Under Rolling Contact Conditions

Ryotaro Ohashi, Graduate School of Tokyo University of Science, Katsushika-ku, Tokyo, Japan; Kaisei Sato, Shinya Sasaki, Tokyo University of Science, Katsushika-ku, Tokyo, Japan

In recent times, the popularity of electric vehicles (EVs) has grown significantly, necessitating the enhancement of fatigue wear resistance in reducers due to the higher rotational speeds of motors. Lubricant viscosity has been found to affect gear failures like pitting, but the mechanism is not fully understood. In this study, in addition to the rolling-sliding condition, we used a pure rolling condition. Ball-on-disc traction tests with different viscosity poly-alpha-olefin (PAO) were conducted, and the damaged area on the discs was evaluated using a laser microscope and MATLAB. Results showed that increasing lubricant viscosity increased the damaged area on the discs. Higher viscosity in a base oil like PAO increases the pressure-viscosity coefficient, leading to higher contact pressure. This yielded a correlation between the pitting and viscosities of PAO. To optimize the fatigue wear resistance of EV reducers, it is necessary to design lubricant from the fundamental perspective of its viscosity.

(Session 6E continued)

4:00 pm - 4:20 pm

Test Methods to Address Next Generation Tribological Applications in Electric Vehicles

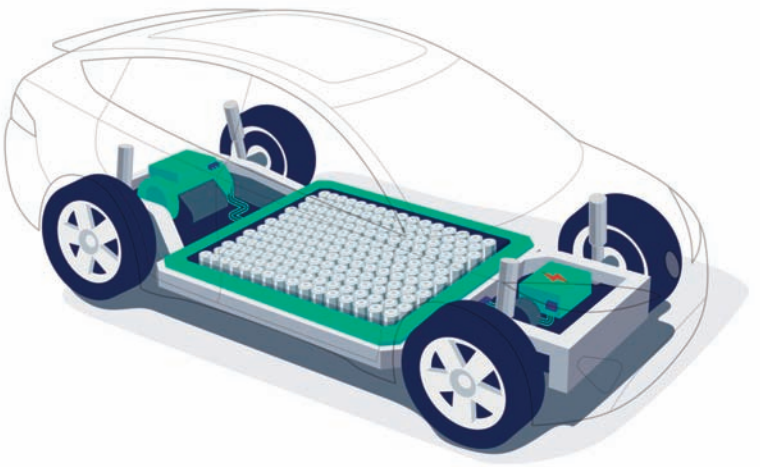
Tushar Khosla, Michael Vinogradov, Vishal Khosla, Rtec Instruments, San Jose, CA

Electric vehicles present new challenges and opportunities for the tribology community to come up with creative solutions in line with the requirements of industry and ultimately towards a sustainable future. Repeatable, reliable, safe and sensitive test methods for electrification of traditional tests such as 4-Ball, traction tests, pin-on-disc, ball-on-disc, block-on-ring, reciprocating, etc., is an important step towards characterizing the effect of applied techniques. In this presentation, we present testing solutions and preliminary data to characterize impedance, resistance and lubrication properties of oils and greases under electrified conditions. EVs also offer more features and touchscreens for control and entertainment. There are more surfaces for interaction than a car built a few years ago. Methods for characterizing electrical connectors, including fretting failures and failure analysis of coatings under electrified conditions, will also be discussed.

4:20 pm – 4:30 pm

Closing Remarks

Peter Lee, Southwest Research Institute, San Antonio, TX



Electric Vehicle Posters (Salon A)

3975429: Toward a Single Fluid: Balancing Lubrication and Thermal Management Through Ti3C2Tz MXene Nanoparticles

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

Mexene particles, Ti_3C_2Tz nanosheets exhibit high thermal conductivity, electrical conductivity, and mechanical strength, making them promising candidates as lubricant additives to design a single fluid for electric vehicles. Using a single fluid in vehicles for balanced lubrication and thermal management can improve fuel economy, reduce emissions, and improve performance. These fluids can be used as transmission, differential, and power steering fluids where lubrication and thermal management are essential factors to avoid the wear of vehicle component. In this research, we evaluate the performance of Ti_3C_2Tz as an additive to enhance the heat transfer, rheological properties, and tribological performance of silicone and Polyalphaolefin (PAO) base oils. Experimental results showed that adding Ti_3C_2Tz improved thermal conductivity by 16% and 23% in silicone and PAO oils, respectively. The rheological data revealed that adding Ti_3C_2Tz nanosheets reduced the viscosity by 12.3% (at 0.09 wt%) and 18.1% (0.04 wt%) in silicone and PAO oil, respectively. The addition of Ti3C2Tz reduced the friction by 23% (0.09 wt%) and 65% (0.04 wt%) in silicone and PAO oils, respectively. The improved properties and reduced fluidic drag in viscosity and friction can offer the utilization of Ti3C2Tz MXene-based fluid in EV applications, which will help to achieve improved fuel economy by meeting the stringent requirements of EVs compared to ICE vehicles.

3965022: Effect of a Bio-Derived Lubricant on the Tribological Properties of Electrified Contacts

Leonardo Farfan-Cabrera, Carlos Rubio-Hernández, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Ali Erdemir, Texas A&M University, College Station, TX; Peter Lee, Southwest Research Institute, San Antonio, TX

Interest in highly functional EV Lubricants has increased tremendously. They need to fulfill a wide range of functionality including excellent electrical, thermal, tribological and chemical properties, material compatibility and eco-friendliness. Considering state-of-the-art progress being made in bio-based lubricants, novel fluid formulations using these oils as additives in mineral or synthetic-base oils hold great promise in meeting the multifunctional requirements of EV drivetrains. This work presents the results of a systematic study involving the use of Jatropha crude oil as an additive in a Group II mineral oil on dielectric strength and tribological properties in a four-ball tester instrumented with DC power.

3964760: eTribology – Electrified Mini Traction Machine Test Results

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

SwRI in partnership with PCS Instruments have electrified a Mini Traction Machine to allow AC and DC voltage with various currents, voltages, and frequencies to be applied across the ball-and-disk test specimens. Different behaviors have been observed with the presence of AC and DC voltage versus the non-electrified tests. Traction coefficient across the Stribeck curve increases, as does wear volume and the wear type changes. Lubricants used were an Ultra-Low Viscosity and Dexron VI automatic transmission oil, and an automatic gear oil. Tests were performed at different temperatures and electrified conditions. These results will be presented and discussed.

3964759: eRheology – Test Methods and Analysis of E Lubricants

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

Lubricants in electric vehicles tend to behave differently in the presence of an electric field. There are many rheological test methods used for engine and drivetrain applications that are relevant to EV systems. Rheology can be used to evaluate lubricants for viscoelastic behavior, churning losses, and viscosity, to name a few. Several lubricant properties were investigated using different rheological test systems while subjected to an electric field. This work will discuss current test methods used for evaluating driveline fluids and greases, and new methodologies being developed to meet the demands of electrification.

3964146: Fluid Durability Study in Electrified Drivetrains

Cole Frazier, Southwest Research Institute, San Antonio, TX

Three complementary programs have been undertaken to determine the real-world conditions that stress a fluid in an electric or hybrid-electric vehicle (EV/HEV) drive unit and determine what a “failed” fluid looks like at the end of its life. By utilizing in-vehicle testing on chassis dynamometers, road conditions have been closely replicated to simulate the stressors that a fluid undergoes during its life cycle. This report provides an update on testing results for the Toyota RAV4 Prime Hybrid and Hyundai Ioniq5, which were disassembled, documented, extensively instrumented, tested for efficiency and range, and set on a 100,000-mile fluid durability test cycle. Incidental findings, used fluid analysis and operational data will be presented from each vehicle.

3963911: Effect of a Protic Ionic Liquid on Friction and Wear Performance of an-Ultra-Low Viscosity Synthetic Oil under Electrified Sliding Conditions

Seungjoo Lee, Ali Erdemir, Texas A&M University, College Station, TX; Leonardo Farfan-Cabrera, Tecnologico de Monterrey, Monterrey, Nuevo Leon, Mexico; Patricia Iglesias, Rochester Institute of Technology, Rochester, NY

Market penetration of electric vehicles (EVs) has been growing rapidly in recent years to meet the future transportation needs of the world community. As opposed to the tribological issues in traditional internal combustion vehicles, not much is known about the tribological issues in EVs, especially under electrified contact conditions. In this study, we used a pin-on-disk machine under ASTM G99 conditions to explore the friction and wear behavior of an ultra-low viscosity oil (PAO2) under electrified sliding conditions with and without the use of a protic ionic liquid. Combining excellent thermal stability with high electrical conductivity, the protic ionic liquid had a significant positive effect on the friction and wear behavior on steel test pairs. Post-test structural and surface analytical studies revealed the formation of very different kinds of tribofilms when electrified and the ionic liquid was used. Specifically, tribofilms contained higher levels of carbon nanostructures under electrification and in the presence of ionic liquid which together resulted in superior wear performance.

Advanced Rheo-Tribological Testing of Greases for EVs Including Electrical Parameters

Paul Staudinger, Kartik Pondicherry, Anton-Paar GmbH, Graz, Austria; J. Heinrich, Anton-Paar Germany GmbH, Ostfildern, Germany

Ball bearings are a complex rheo-tribological system which gets even more so in combination with greases. The intricate rheological characteristics of greases, in contrast to oils, makes the mathematical modelling and prediction of the torque behavior of rotating or oscillating greased rolling bearings very difficult. Rheo-tribological measurements, therefore, represent an important method for predicting material behavior for this application. In connection with growing electromobility, the measurement of electrical parameters of the rotating ball bearing-grease-system is also becoming a focus of interest. The present work shows the influence of a conductive and a non-conductive grease on torque and impedance over a wide rotational speed range.

As of October 30, 2023 – Subject to Change.

Code:
TFC = No. + A, B, C, or D
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A

Abubakar, Abba Abdulhamid, 4B
Acharya, Biplav, 5D
Acharya, Raghav, 5D
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Farfan-Cabrera, Leonardo I., EVP
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Flynn-Hepford, Matthew, 1C
Frazier, Cole T., EVP
Frogley, Mark, 2C
Fukaya, Tsuyoshi, GSP

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Gillespie, David, 5E
Glänzer, Steffen, 3E
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Gowdy, Christopher, 3E
Graf, Simon, 5E
Greco, Aaron, 4B
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Handschuh, Michael, 3C
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Hatano, Naoya, 3B
Hawker, Craig, 3A
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Haynes, James, 2B
Hein, Ricardo, 4E
Heinrich, Julius, EVP
Higuchi, Yuji, GSP
Hipwell, M. Cynthia, 1A, 3A, 3A
Hirayama, Tomoko, 3B, 3B
Homma, Mutsuki, 3B
Horio, Tomohito, 1B, GSP
Horvath, Dan, 3E
Hu, Hua, 2B
Hunold, Oliver, 4E
Hunt, Gregory, 5E, 5E

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Electric Vehicles

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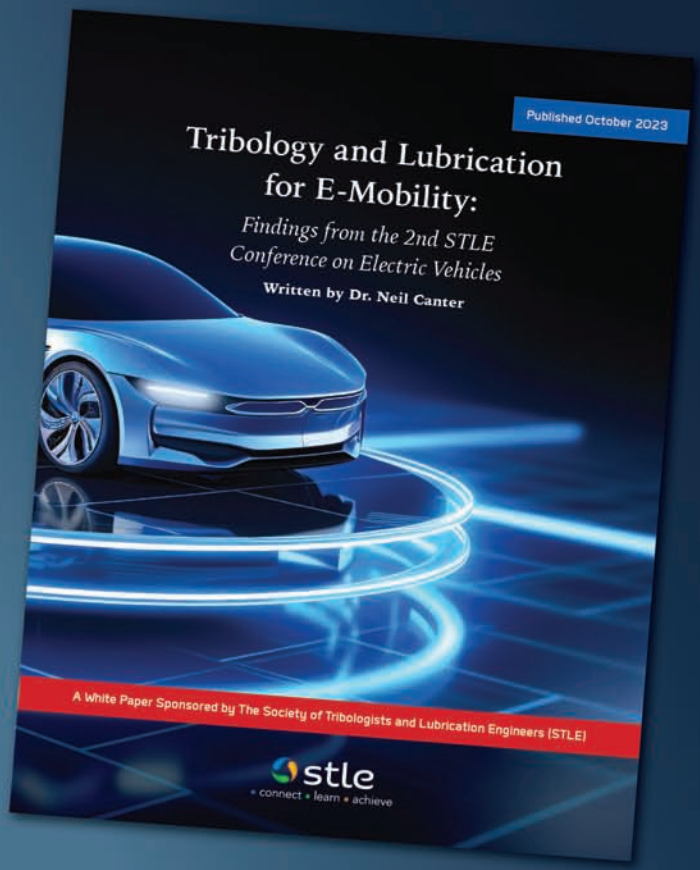

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This white paper summarizes the key findings and challenges discussed at the 2022 STLE Tribology & Lubrication for E-Mobility Conference held in San Antonio, Texas (USA), in November 2022, exploring the latest advancements and outlook for the electric vehicle market and technologies impacting the tribology and lubrication field.

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