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PROCEEDINGS

Content

Plenary Talk 1
Keynote/Invited/Oral Talk 8
September 15, 2024 8
Track 1-I: Friction and Lubrication 8
Track 1-II: Friction and Lubrication 14
Track 1-III: Friction and Lubrication 21
Track 2: Wear and Fatigue 26
Track 3-I: Coatings and Surfaces Engineering 32
Track 4: Tribo-chemistry and Lubricants 38
Track 5: Biotribology and Biomimetics 46
Track 6 Nanotribology and Superlubricity 53
Symposium 2: Triboelectric Nanogenerators for Energy and Sensors 58
Track 8 Aerospace and Ocean Tribology 61
Track 9 Industrial Tribology and Instruments 68
September 16, 2024 74
Track 1-I: Friction and Lubrication 74
Track 1-II: Friction and Lubrication 84
Track 1-III: Friction and Lubrication 93
Track 2: Wear and Fatigue 104
Track 3-I: Coatings and Surfaces Engineering 115
Track 4: Tribo-chemistry and Lubricants 125
Track 5: Biotribology and Biomimetics 136
Track 6 Nanotribology and Superlubricity 144
Symposium 2: Triboelectric Nanogenerators for Energy and Sensors 153
Track 8 Aerospace and Ocean Tribology 159
Track 9 Industrial Tribology and Instruments 169
September 17, 2024 178
Track 1-I: Friction and Lubrication 178
Track 1-II: Friction and Lubrication 186
Track 1-III: Friction and Lubrication 197
Track 2: Wear and Fatigue 208
Track 3-I: Coatings and Surfaces Engineering 219
Track 3 - II Coatings and Surfaces Engineering 228
Track 4: Tribo-chemistry and Lubricants 234
Track 5: Biotribology and Biomimetics 246
Track 6: Nanotribology and Superlubricity 254
Track 7: Tribology in New Energy System 262
Track 9: Industry Tribology and Instruments 269
September 18, 2024 271
Track 1-I: Friction and Lubrication 271
Track 1-II: Friction and Lubrication 277
Track 1-III: Friction and Lubrication 279

Track 2: Wear and Fatigue........285
Track 3-I: Coatings and Surfaces Engineering........291
Track 5: Biotribology and Biomimetics........300
Track 6: Nanotribology and Superlubricity........308
Track 7: Tribology in New Energy System........315
Poster........322
Group A........322
Track 1: Friction and Lubrication........322
Track 5: Biotribology and Biomimetics........322
Track 6: Nanotribology and Superlubricity........322
Group B........341
Track 2: Wear and Fatigue........341
Track 8: Aerospace and Ocean Tribology........341
Symposium Posters........341
Group C........356
Track 3: Coatings and Surfaces Engineering........356
Track 9: Industry Tribology and Instruments........356
Group D........372
Track 4: Tribo-chemistry and Lubricants........372
Track 7: Tribology in New Energy System........372

Plenary Talk

Tribology in Australia – Past, Present and the Future

Pawel Podsiadlo
Curtin University

Tribology roots in Australia are tracing back to Indigenous Australians using friction to start fires, sharpen tools, and smooth wooden implements. With the new settlers, the use of tribology aligned with European practices. In first half of 20th century, the development of agricultural sectors and the expansion of mines and cities necessitated the increase of machine reliability and the reduction of operating costs. It is against this backdrop Anthony Michell invented the pivoting pad bearing. Frank Bowden conducted the ground-breaking research on adhesive interactions between contacting surfaces. Conrad Jaeger developed the flash temperature equations and analysed the role of surface finish, explained gouge formation, and the stick-slip phenomenon.
In second half of 20th century, the advancement of tribology aligned with the movement from primary industry to one reliant on mining and processing industries. Some notable achievements include the wave model developed by Peter Oxley provided the understanding of low-cycle fatigue wear. Studies of squeeze film bearings conducted by Eric Hahn resulted in improved designs of rotating machinery. The works conducted by Gwidon Stachowiak on ceramics and correlation between grits angularity and wear led to improvements of the wear resistance of PSZ ceramics and the designs of abrasive surfaces.
Tribology in Australia has continued its growth over last decades. Activities include applying nanotechnology to create advanced materials, developing lubricants and coatings for high temperature and corrosive environments, integrating smart sensors and AI for wear monitoring, and designing components to reduce friction losses, and wear in energy generation.
Teaching tribology in Australia expanded across major universities, supported by a leading textbook "Engineering Tribology" by Gwidon Stachowiak and Andrew Batchelor.
Future will focus on the mining and mineral processing sectors. It promises a growing influence in the advancement of autonomous vehicles, self-lubricating materials, smart infrastructure, medical devices, and more.
Achievements of Australian tribologists and future directions are presented.

Key Words Tribology, Australia

Tribology in China

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Southwest Jiaotong University

History of tribology researches in China is reviewed briefly in this paper. Development stages are divided and some memorable events in tribology researches in China are introduced in my personal view. The statistics of the funding from National Natural Science Foundation of China (NSFC) and of published research papers on tribology in the database of Web of Science are analyzed in order to better understand the state-of-the-art of tribology researches in China, including most active research institutions and fields. In addition, major research contents are obtained according to keywords and main achievements in tribology related to lubrication, lubricating materials, superlubricity, wear, biotribology and bionic-tribology, nanotribology, surface engineering, tribology in extreme conditions, machine elements, particularly for recent years, are summarized. This paper shows that tribology is a rapid developing discipline in China and China has been one of the most important contributors in world tribology.

Key Words Tribology; China;

Industrial and Academic Tribology Research in India - Current Status

Sujeet Sinha
Indian Institute of Technology Delhi

With the current economic developments in India and a big thrust towards green technology and sustainability, tribology research has diversified from the industrial maintenance and lubricant centric tribology of few decades ago to new areas such as nanotribology, bio-tribology, smart coatings, wind turbine gears etc. In this talk, a brief overview of the current research activities in tribological research in India will be presented. The talk will be divided into industrial and academic research, and also what is the status of their collaborations. The industry has continued to work on the problems related to the maintenance of bearings, lubrication of machineries, mining equipment etc. but some new issues are presently being focused. Some of these examples are problems related to wind turbine gears, large IC engines, hydrogen energy tribology, electric vehicle tribology, ship propeller, nuclear powerplant tribology and so on. In the academic environment, several new topics are being researched in different university/institute research labs. Bio-tribology and coatings have gained much momentum in academic research but there is also sufficient push towards new and environmentally friendly lubricant and grease additives for non-ferrous alloys etc. This talk will also provide some of the issues faced in industrial and

academic tribological research arenas in India and how perhaps those issues could be tackled in the near future.

Key Words Tribology in Asia

Advances of Tribology in Japan

Noritsugu Umehara
Nagoya University

The Japanese Society of Tribologists (JAST) was founded as the Japanese Society of Lubrication in 1956. More than 2000 members have been promoting research concerning on tribology in order to contribute to the progress of theory concerning tribology and to improve technology. Excellent and outstanding achievements in industries and academic fields have been awarded as technical awards and paper awards. These topics in latest awards are the followings; Technology to improve the performance of transaxle fluid for electric vehicles, Highly efficient fixed constant velocity joint, Development and Practical Application of Mechanical Seal with Low Loss and High Sealing Performance by Surface Texturing Technology, Technology to Enhance Rolling Bearing Performance by Strengthening Rolling Elements, Development of Next-Generation Calcium Complex Grease, Elucidation of friction mechanism of CNx in base oil by observation of in situ reflectance spectroscopic analysis of friction interface, Development of Highly Durable Sliding Triboelectric Nanogenerator Using Diamond-Like Carbon Films, Estimation Method of Micropitting Life from S-N Curve Established by Residual Stress Measurements and Numerical Contact Analysis and so on. We wish that Japan's commitment to tribology research continues to drive innovation and foster collaboration on a global scale.

Key Words Japan; Advance; Tribology

K-Tribology: Now and Beyond

Dae-Eun Kim
Yonsei University

Tribology has played an essential role in the advancement of technology and the development of economy all over the globe. As such, a significant part of the Korean industry has benefitted from design solutions and remedies that stem from tribological considerations. Starting from the early printing technology in the 13th century that involved contact between metal and printing medium, Korea has grown tremendously in the traditional application fields of tribology such as automotive, manufacturing, heavy industry, shipbuilding, and electronics over the last few

decades. Apart from these traditional fields, tribology is expected to contribute significantly to emerging industries related to energy, environment, and biotechnology in Korea.

Tribology research and development are actively conducted in Korean universities, national labs, and companies. National labs associated with fundamental science, machinery, materials, atomic energy, and chemistry have contributed significantly to tribology in Korea over the years. As for tribology research in universities, a wide spectrum of topics is covered ranging from micro-bearings to water lubrication. Tribology activities in Korea are centered around the Korean Tribology Society (KTS) which was established in 1984. KTS holds two domestic conferences a year and also organizes an international conference (K-TRIB) every three years. KTS also publishes a journal named Tribology and Lubricants, with Tribology Letters and Coatings being affiliated journals to the society. Particularly, with the rapidly increasing global need to conserve energy and protect the environment, the vision of KTS is to achieve a sustainable prosperous future through "Efficiency, Energy, Environment (3E)", namely, to mitigate energy and environmental problems by maximizing the efficiency of moving systems through tribological breakthroughs. Considering the great relevance of friction, wear, and lubrication issues in this endeavor, efforts in tribology will continue to expand in parallel with technology and economic development in Korea and around the world.

Key Words Korea; Energy; Tribology

UNLOCKING THE POTENTIAL OF AGRICULTURAL WASTE AS SUSTAINABLE TRIBO-MATERIALS IN MALAYSIA

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"Exploring the conversion of agricultural waste, into tribo-materials in Malaysia" delves into the utilization of agricultural waste to tackle sustainability issues and drive material advancement. In Malaysia the agricultural sector produces amounts of waste such as rice husks, byproducts from palm oil processing, pineapple and kenaf leaves as well as sugarcane bagasse. Traditionally perceived as liabilities, these agricultural byproducts have inherent properties that make them promising candidates for tribo-materials, which are materials with frictional properties required for a variety of applications such as tribology, wear resistance, and energy harvesting. By assessing the tribo-mechanical properties and suitability of these waste resources, their potential in tribological applications can be underscored, opening avenues for eco-friendly alternatives to conventional materials. Through research and innovative strategies, Malaysia has the potential to tap into its abundance to produce cost effective and environmentally friendly tribo-materials thereby reducing reliance on non-renewable resources and addressing environmental deterioration. Beyond advantages utilizing waste for tribo-materials holds significant socioeconomic

implications. By enhancing the value of waste opportunities, for generating revenue and fostering development can emerge, ultimately enhancing the well-being of local communities and promoting inclusive economic growth.

Key Words Friction; wear; agricultural waste

Contact Mechanics and Friction: Role of Adhesion

Valentin Popov
Technische Universität Berlin

This talk is devoted to a discussion of the interplay of adhesion and friction and the role of adhesion in tribology. Five topics will be reviewed: (1) Energy dissipation in adhesive contacts, (2) Adhesive contribution to friction, (3) Influence of tangential loading on adhesion, (4) "Negative adhesion" and superlubricity, (5) Adhesion and wear. We start with an overview of the main results of the theory by Johnson, Kendall and Roberts with a special emphasis to energy dissipation in a complete cycle of indentation and detachment. This is the fundamental elementary process in all other phenomena related to adhesion. Based on the JKR theory, we discuss energy dissipation in adhesive contacts of rough surfaces. We then show that the processes occurring in tangential movement of adhesive contact are identical to those in normal direction, and that they lead to adhesive contribution to friction. Inversely, tangential movement influences the adhesive strength. We proceed with discussing the case of negative "adhesion" and its relation to the so-called liquid superlubricity. Finally, we show that basically the same processes as above determine adhesive wear – leading to Rabinowicz criterion.

Key Words Adhesion; Friction; Wear; Energy dissipation; Superlubricity

Theories for Contact and Lubrication in Multifield and A Generalized Multifield Reynolds Equation for EV Related Issues

Q. Jane Wang
Northwestern University

The rapid adoption of electric vehicles (EVs) has presented new tribological challenges due to the presence of the electric field. A generalized multifield Reynolds equation is needed as the core governing equation and theoretical guide to the understanding of tribological phenomena in coupled fields; associated theories and methods should be developed for systematic solutions to

the new challenges. This presentation highlights recent research works on several key areas of contact and lubrication involving electric and/or magnetic fields, lubrication mechanisms and related mathematical models, features of lubrications in different fields, the development of a generalized mechanical-electro-magnetic-thermal-field (MEMT-field) Reynolds equation and its solution framework, as well as associated contact theories, and a method to address electrical breakdown in lubrication.

The many facets of Green Liquid Superlubricity

Jean Michel Martin
Ecole centrale de Lyon

Liquid Superlubricity (LSL) defines a regime when a liquid lubricant is present in the contact and that the dynamic steady-state friction coefficient is below 0.01 under boundary conditions (typically at high loads and/or very low speeds). Moreover, the corresponding wear rate of contacting surfaces should be very low. Green LSL implies the use of organic lubricants being non-toxic and friendly for the environment.
Liquid Superlubricity has been extensively studied over the last ten years in several laboratories all over the world. Under HL and full EHL, such a regime is attainable with some specific mineral and synthetic lubricants and is well explained by viscosity-based theories.
Under boundary and mixed conditions however, the situation is much more challenging and both friction materials and lubricants must be carefully adapted in order to reach LSL. Here, we present several superlubricious systems operating at the macro-scale under severe boundary conditions and approaching green LSL associated with low wear.
We used ta-C- coated steel samples and/or commercially available silicon-based hot-pressed micro-crystalline ceramics substrates (such as SiC, SiO2 and Si3N4). For selected green lubricants, we used polyols (glycerol is a model), and more generally OH-containing molecules including vegetables oils, unsaturated fatty acids and corresponding esters as well as some additives made of medicinal molecules. All lubricants used re preferably solutions (not colloidal suspensions).
The mechanisms for SLS are manyfold and are related to complex tribochemical reactions: i) extended very thin film EHL induced by surface polishing, ii) friction-induced aromatization (graphene, carbon nitride, 2D species, etc.), iii) hydroxyl termination and corresponding hybrid combinations of all of them, this depending on contact severity (lambda ratios).
Computer simulation is very useful to explain how tribochemical reactions can lead to LSL. This technology could be very useful in many fields including EV technology, hydraulic fluids, agri-foods industries and biological applications.

Key Words keyword

Fundamental Advances, Impact and Future Perspective of Modelling in Tribology

Daniele Dini
Imperial College London

This talk will cover recent advances in modelling aspects of a variety of problems where the behaviour of tribological interfaces controls the performance of engineering systems. It will start with an overview of the modelling tools developed to study interfacial phenomena across the scales, and will then move onto demonstrating how in-silico experiments can be used to shed light on physical, chemical and mechanical phenomena that affect frictional interactions and engineering performance in several applications in the energy sector, including electric vehicles (EVs) and triboelectric nanogenerators (TENGs), biomedical applications, consumer goods, and functionalized and hierarchical materials and surfaces.

The main themes discussed are the study of the influence of molecular processes on frictional, rheological and material response, the potential breakdown of continuum theories at the nano- and microscales, as well as important aspects linked to the development of computational models which are twinned with relevant to applications. Many systems involve two or more interlinked phenomena that are governed by mechanisms originating at different scales, for which complex multiscale and multiphysics models are needed. These are still challenging to develop and use, as they require multidisciplinary expertise and collaborative efforts. A few successful examples portraying how predictive models can be used to better the design of surfaces and materials are provided, demonstrating how to conduct successful virtual experiments and their necessary links to laboratory tests.

The presentation will conclude with highlighting the current limitations of existing models and techniques and an outlook at future trends and examples of how to change current engineering practice and place tribological interfaces at the centre of design strategy using a bottom-up approach. This will enable to directly use the insight gained from simulations at the smallest scales for the development of new disruptive solutions and to accelerate screening of new material and lubricant formulations.

Key Words Computational Methods; Multiscale Modelling; Multiphysics; Friction; Lubrication; Energy; Functional Materials; Biomedical Applications

Keynote/Invited/Oral Talk

September 15, 2024

Track 1-I: Friction and Lubrication

KEYNOTE:

Film Thickness and Friction of Rough Surfaces in Mixed Lubrication Regime

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Numerous machine elements work under conditions of mixed lubrication where load is shared between direct asperity contact and elastohydrodynamic lubricating (EHL) film. Mean film thickness is often lower than initial surface roughness exposed to the deformation in the contact. At the same time, surface roughness contributes to film formation in non-trivial way. Therefore, there is an ongoing challenge in precise prediction of transition to mixed lubrication. In classical theory, the increase of friction from full EHL regime corresponds to the first direct contact between surface asperities. To further extend the knowledge it is necessary to simultaneously measure thin lubricating film and friction. This contribution presents recent findings for real and model rough surfaces. Film thickness is bellow smooth surface prediction and friction increases before initial direct asperity contact in early phase of mixed lubrication.

Keywords: elastohydrodynamic contact, mixed lubrication, film thickness

The Experimental Study on Oil Film Behaviors Under Quantitative Oil Supply Conditions

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In most cases, rolling bearings work under limited oil supply. In order to investigate the EHL behaviors of the contact in the ball bearings, this work conducts the experimental study of film thickness at high speed under quantitative oil supply based on the ball-on-ring test rig. The tests are conducted under tractive rolling condition up to 12.5m/s. The results show that, under quantitative supply condition, when the velocity exceeds a certain value, the contact changes from the fully flooded lubrication state to starvation state, the film thickness begins to decrease; the distance between the meniscus and the

center of the contact decrease with the speed; at high speed, the centrifugal force facilitates the replenishment of the oil on the free surface.

Keywords: high speed, quantitative supply, EHL

Investigation of A Method for Measuring Oil Film Thickness at the Ehl Contact Area Utilizing Three-Wavelength Optical Interferometry in A High-Load, High-Peripheral-Speed Traction Visualization Experimental Apparatus

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In recent years, electric vehicles have become more and more widely available, and motors, which are a key element of this electrification, are increasingly geared towards higher speeds in order to reduce size and weight. It is worth noting that commercial vehicles are about to reach a maximum speed of 20,000 rpm, which makes a reduction gearbox that can withstand ultra-high speeds indispensable. The traction drive system is gaining attention as a strong candidate for power transmission due to its low vibration and agitation losses. However, further research is needed to clarify the oil film thickness under super high speed and high load conditions.
Recent studies on ball-on-disks with high peripheral speeds have shown that the Hamrock-Dowson equation may not always be applicable under such conditions. It is worth noting that the loads in these studies were much lower than those experienced in a car's operating environment.
This study discusses the GMFT method, which employs optical interferometry with three wavelengths of light to measure oil film thickness at high peripheral speeds. The GMFT method was used to carry out interferometric imaging of EHL oil films, enabling one-shot measurement, unlike the conventional phase-shift method. The GMFT method was combined with a high-speed color camera to capture images of the EHL oil film under visualization experimental setup conditions. The setup was capable of reproducing EHL conditions up to a maximum peripheral velocity of 20 m/s and a load of up to 1000 N. Interference color images were successfully captured at a high peripheral velocity of 10 m/s by introducing a chromium coating and a telecentric lens. The details have been reported.
Acknowledgement : This work was supported by TRAMI（Transmission Research Association for Mobility Innovation）Grant of 2023.

Keywords: traction testing machine, three-wavelength optical interferometry, high-Load

Effects of 2D Inhomogeneous Material on Tribological Contact Characteristics in Thermal Elastohydrodynamic Lubrication

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2. University of Twente, Netherlands

As the industry evolves, component structural design has become more compact, subject to greater loads, and faced with harsher operating environments. The complexity of heterogeneous materials is characterized by their inhomogeneities and inclusions. Research indicates that under external forces, such as those encountered by bearing assemblies, heterogeneous materials can cause atypical elastic deformation on surfaces and stress concentration beneath the surface, particularly impacting components under high contact stress. To precisely assess the pressure distribution on material surfaces and the subsurface stress landscape in conditions of contact lubrication, detailed grid models are often utilized to derive more accurate stress analyses, thereby highlighting local material discrepancies. However, employing highly dense meshes leads to computation-intensive models with millions of variables, demanding substantial computational power. This study introduces an advanced multigrid method tailored to solve the comprehensive two-dimensional thermal elastohydrodynamic lubrication (EHL) contact scenarios of inhomogeneous materials under various inclusions and operational conditions. The findings reveal that the numerical solution for dry contact aligns closely with theoretical predictions, and the stress-coupled EHL solution matches well with outcomes from conventional EHL models, proving the algorithm's capability and precision in addressing complex contact issues. In scenarios with inclusions, pressure variances and localized stress concentrations are primarily observed near grain boundaries where material properties significantly diverge. The shape of inclusions under steady conditions markedly influences pressure distribution and consequently thermal escalation, though their effect on film thickness distribution remains minimal.

Keywords: thermal elastohydrodynamic lubrication, inhomogeneous material, multigrid method

KEYNOTE:

Plain Bearings for Wind Turbines

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In recent years, the wind energy sector has witnessed significant advancements and

shifts in technology to enhance the efficiency and reliability of wind turbines. One notable trend is the increasing replacement of roller bearings with plain bearings. This transition is driven by the recurrent technical issues associated with roller bearings, which have impacted the performance and maintenance costs of wind turbines. Common problems include white etching cracks (WEC), smearing and damages caused by the passage of electricity. Plain bearings known for their on principle unlimited fatigue lifetime, robustness and high power density offer a promising alternative. This article explores actual developements of plain bearing concepts for rotor bearings and for planetary bearings inside the gearbox. Since on-shore windturbines have to perform multiple startup procedures each day, the design of the plain bearings needs to provide adequate wear safety under mixed friction conditions. New calculation procedures are proposed, to evaluate and to optimize the wear risks by abrasion already in the early design phase. The results of the calculations are validated by experiments.

Keywords: plain bearing, wind turbine, wear safety

INVITED:

Establishment of a Numerical Algorithm for Starved Thermal EHL in Zero Entrainment Condition

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Zero entrainment condition is found in the contacts of neighboring balls in ball screws and retainerless rolling element bearings. Under zero entrainment, since both sides of contact work as inlet and outlet of oil, the cavitation formed in one side moves backwards to be an inlet starvation and the process is repeated until a contact failure is generated. Even under steady-state surface speeds and applied load, the process is a transient one due to the shift of the cavitation to starvation zone. Aiming at such a complicated phenomenon, the authors intend to build a numerical algorithm for the oil starvation occurred in line contact thermal elastohydrodynamic lubrication (EHL) under zero entrainment condition. The algorithm can consider the impact of oil layer attached to both surfaces and predict the influence of the oil starvation on the "temperature-viscosity wedge" effect and the surface dimple.

Keywords: thermal EHL, starvation, numerical algorithm, zero entraining velocity, line contact

Elastohydrodynamic Lubrication Mechanisms of Aqueous Polyethylene Glycols Considering Different Chain Lengths and Water Contents

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Water-soluble polyethylene glycols have become a growing subject of research to achieve liquid superlubricity in elastohydrodynamically lubricated (EHL) contacts. In addition, the possibility of bio-based production makes them a promising candidate for green lubricants. While the influence of various properties of water-soluble polyethylene glycols, such as water content and viscosity, on EHL has been studied in detail, the mechanisms leading to liquid superlubricity are not yet fully understood. Besides the formation of shear layers between unbonded water molecules within the lubricant film, pronounced running-in with specific surface modifications is often discussed. However, most studies in the literature focus on reciprocating motion under mixed lubrication with a drastic reduction in contact pressure due to wear, making it difficult to apply the results to machine elements such as bearings and gears operating under EHL with rolling-sliding motion.

In this study, the EHL friction and film thickness of polyethylene glycols PEG200, PEG300, PEG400, PEG600 and PEG1000 with different molecular weights and water contents are investigated under rolling-sliding motion using ball-on-disk tribometers. Thereby, polished steel/steel or sapphire/steel surfaces were considered. The results show that under fluid film lubrication with separated surfaces, friction decreases continuously with increasing water content and that no threshold water content with a sudden decrease in friction is required to achieve liquid superlubricity. Furthermore, there is no need for running-in, so a stable and persistent, ultra-low friction level can be achieved immediately, even at contact pressures in the gigapascal range. Similar to friction, the film thickness decreases continuously with increasing water content, which is also favored by the decrease in contact viscosity. However, friction and film thickness are both influenced by the chain length distribution of polyethylene glycol, allowing the design of tailored lubricant formulations to achieve low friction and high film thickness.

Keywords: Superlubricity, Aqueous Lubrication, Green Lubricants

Thermal Mixed Elastohydrodynamic Lubrication Modeling and Analysis of The Lubricated Non-Conformal Contacts with Non-Gaussian Surface Roughness and Coating

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The lubricated non-conformal contact generally works in the mixed-EHL regime. Optimizing the surface topography or selecting the right coating is an effective way to improve its performance. This paper presented an improved mixed-TEHL model for the lubricated non-conformal contacts with the effect of roughness and coating in consideration. The effect of coating was solved analytically by employing the Papkovich–Neuber potentials. It was found that the properties of coatings, especially their elastic modulus, significantly affect the pressure and stress distribution. In comparison to other roughness parameters, standard deviation and kurtosis have a significant impact. As expected, the present model can provide an efficient analysis of the tribological behavior and the stress distribution of the lubricated non-conformal contacts.

Keywords: mixed lubrication, surface roughness, coating, fluid-solid coupling.

Numerical Lubrication Performance Evaluation of Quasi-random Nanostructures Surfaces

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2. Xingyi Metal Group, China

Surface topography has strong influences on the tribological performances of engineering surfaces, such as, contact, lubrication, adhesion, wear, etc.. Current studies predominantly examine the effects of various periodic structures or randomly distributed surfaces. Quasi-random nanostructures (QRNS) surfaces, which are inspired by nature, have attracted interests from many research fields because of their possibilities to be self-assembled for scalable manufacturing. We numerically generated QRNS surfaces by Fourier spectral density functions, and characterize their lubrication performances under point contact conditions by using the Reynolds equation and elastohydrodynamic lubrication (EHL) model. The lubrication performance of QRNS surfaces corresponding to different geometry design parameters, applied loads, velocities, and lubricant viscosities on the lubricant film thicknesses of various rough surfaces were investigated. Computational fluid dynamic (CFD) models were developed by using commercial software, FLUENT, to validate the results. It was concluded that QRNS surface has larger averaged film thickness as compared with that of the periodic structures or randomly rough surfaces due to its unique topology connectivity and lubricant retention capabilities. The correlation between surface design parameters and lubrication performance parameters were established in the form of a map, which serves as a quick design reference for lubrication performance evaluation of QRNS surfaces.

Keywords: quasi-random nanostructures, EHL, surface connectivity

Track 1-II: Friction and Lubrication

KEYNOTE:

Cross-Scale Superlubricity

Karsten Stahl, Stefan Hofmann, Thomas Lohner
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Reducing frictional losses in power-transmitting drivetrains is crucial for achieving global sustainability and carbon neutrality. Today, friction accounts for approximately one-quarter of the world's energy consumption. The state of Superlubricity, with coefficients of friction below 0.01, was first described in the early 1990s and was initially related to the ultra-low shear resistance of incommensurate solid materials. In recent years, Superlubricity has since been observed in a wide range of materials, including liquids. Water-containing lubricants based on polyalkylene glycol or glycerol (PAGW) show the potential to drastically reduce frictional power losses in gearboxes. These lubricants have demonstrated liquid Superlubricity on a contact local scale.
This talk provides a brief introduction to the field of Superlubricity, with a particular focus on liquid Superlubricity in elastohydrodynamic rolling-sliding contacts. Water-dissolving polyalkylene glycols with a functional water content (PAGW) are among the most promising base stock candidates for gear lubricants to achieve liquid Superlubricity. In addition, their potential for bio-based production makes them an attractive green lubricant option. Stable and persistent Superlubricity can be achieved by using PAGW which has been validated through testing on ball-on-disk- and twin-disk-tribometers and gear component test rigs. PAGW enables the design of superefficient gearboxes. However, using PAGW for gear lubrication offer several challenges, like the material incompatibility with other gearbox components and the control of water evaporation and its effects on the lubricant's properties.

Keywords: superlubricity, efficiency, sustainability, PAGW, gear

Oil-based Nanophosphate Additives: Interface Adsorption and Interlayer Lubrication

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Titanium alloy has poor tribological properties and is one of the typical difficult to machine materials, and the adhesion between the tool or roll and titanium alloy is very easy to occur in the process of cutting or rolling. Nanomaterial additives can significantly improve the friction-reducing and antiwear properties of lubricating oil, and have been widely studied in tribology.
This work focuses on six kinds of nano phosphate as lubricating oil additives. Here, sodium barium phosphate (HPN) as an example is introduced. A ball-on-disc reciprocating tribometer was used to explore the tribological behavior of HPN as an additive for polyalphaolefin 8 (PAO8) on titanium alloy. Compared with the neat PAO8, after being lubricated with PAO8 containing HPN, the friction coefficient and wear rate decreased by 74.98% and 99.89%, respectively. The tribofilm at the friction interface was characterized and conformed by SEM, EDS, XPS, and cross-sectional TEM. As an additive to PAO8, HPN can participate in the formation of tribofilm and exhibit superior friction-reducing and anti-wear properties for titanium alloy. It was demonstrated that due to the P-O-Ti bonds, HPN can easily adsorb and deposit at the friction interface to form a tribofilm against wear. Besides, the simulation experiments showed that the repulsive force at the solid-liquid interface between HPN and oil molecules is the key to friction reduction and lubrication, and the comparative tribological experiments of different types of base oils were performed to verify the results of molecular dynamics.

Keywords: lubrication, additive, phosphate, anti-wear, nanomaterial

Self-Dispersing MoS2 QDs/Graphene Crumpled Balls as Effective High-Temperature Lubricant Additives

Guiru Du, Yujuan Zhang, Guangbin Yang, Ningning Song, Shengmao Zhang
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Inorganic nanoparticle has been served as efficient lubricant additive. Nonetheless, the tribological properties are unavoidably compromised by the poor dispersibility and limited high-temperature resistance of their surface modifying groups. Herein, we prepare self-dispersing graphene crumpled balls with diverse crumple conformations and MoS_2 QDs/graphene crumpled balls without surface modifies as high-temperature lubricant additives. The results reveal that the dispersibility of graphene crumpled balls in polyalkylene glycol base oil gradually decreases as the degree of wrinkle increases. The strongest tribological properties are achieved in graphene crumpled balls with medium wrinkle degree (the diameter of ～400 nm), leading to the lowest shearing resistance between graphene layers and then enhance lubrication performance. Moreover, MoS_2 QDs/graphene crumpled balls could extremely enhance the tribological performance of polyalkylene glycol at elevated temperature (150 °C). This is attributed to the synergistic lubrication effect between graphene and MoS_2 QDs

during the boundary friction region. In summary, we envision that the innovative self-dispersing crumpled balls possess immense potential for tribological applications under elevated temperature.

Keywords: self-dispersing MoS2 QDs/graphene crumpled balls, high temperature, tribological properties

Reproducible Molecular Simulations of Sliding on SDS Surfactant Films with Dtool and Dserver, a Flexible Ecosystem for Distributed Data Management

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3. John Innes Centre, United Kingdom

In our molecular dynamics simulations, we use *dtool* and *dserver*, a flexible ecosystem for both distributed and centralised data management, to systemmatically study the frictional response of adsorption films of the anionic surfactant sodium dodecyl sulfate. Making data **FAIR** - **f**indable, **a**ccessible, **i**nteroperable, **r**eproducible - has become an important building block in addressing science‘s replication crisis, but in the niche field of computational tribology, results are often not reproducible due to a lack of standardization and documentation. *dtool* is a lightweight data management tool that packages well-documented datasets; *dserver* makes such datasets **f**indable. Together, they facilitate scaling and analysis of our simulations: several hundred molecular dynamics runs of a sliding spherical asperity reveal two distinct friction regimes: at low loads, the films show Amonton's friction with a friction force that rises linearly with normal load, and at high loads, the friction force is independent of the load as long as no direct solid–solid contact occurs. The transition between these two regimes happens when a single molecular layer is confined in the gap between the sliding bodies. The friction force at high loads on a monolayer rises monotonically with film density. This monotonous increase of friction force is compatible with a traditional plowing model of sliding friction. At low loads, the friction coefficient reaches a minimum at the intermediate surface concentrations. We attribute this behavior to a competition between adhesive forces, repulsion of the compressed film, and the onset of plowing. The rigorous use of dtool and dserver make the pathway of how these results and conclusions came to be openly traceable step-by-step along a complex computational workflow and render our results fit for a world of FAIR data.

Keywords: molecular dynamics, FAIR data, reproducibility

Effects of Conformations of Adsorbed Films of Polymer Additives on the Formation of Lubricating Films during Sliding

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To improve the energy efficiency, the viscosity of lubricant oils has been decreased. Nevertheless, the use of low-viscosity oils has limitations in generating sufficient dynamic pressure to fully separate sliding surfaces in fluid lubrication. This issue has led to a rise in the number of lubrication systems operating in mixed and boundary lubrication regimes, resulting in increased friction and wear. To reduce the wear and friction in mixed and boundary lubrication regimes, various friction modified has been added into the lubricant oil. Polymer additives such as polyalkylmethacrylates (PAMAs) were found to be able to adsorb on sliding surfaces. The adsorbed films could separate the surfaces and thus protect the surfaces from direct contact. Understanding the formation mechanism of adsorbed films is essential to clarify their lubricating performance. However, due to the limitations of the measurement methods, the role of adsorbed films in reduction of wear during sliding is still unclear.

Previously, we have proposed a new method with vertical-objective-type ellipsometric microscopy (VEM) that enables ellipsometry to directly measure the thickness change of adsorbed films during the adsorption process and gap changes during sliding in-situ. In this study, by changing the concentration of PAMA additives in the lubricant oil, adsorbed films with different conformations were prepared. With the self-developed VEM, the effects of conformations of adsorbed films formed by PAMAs on the lubricating film formation were investigated.

Keywords: polymer additives, adsorption films, ellipsometry

INVITED:

In-situ Investigation of Lubricant Behaviour

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Every type of machinery with moving parts requires lubrication of one type or another. Most lubricants are formed of a base oil and a package of additives. Additives perform critical functions such as protecting surfaces from oxidation, wear, corrosion or modulating the rheology of the lubricant. Additives exploit fundamental physical and chemical processes, and their action can be studied in situ and in operando with specially designed techniques.

This talk will describe the latest developments in in-situ spectroscopy based on laser diagnostics techniques for lubricated contacts. Application to the investigation of velocity profiles, lubricant properties, and tribochemistry will be covered. The talk will show how advanced laser diagnostic techniques can be used to study and understand phenomena and local conditions under realistic conditions

Keywords: laser spectroscopy, lubricant flow, polymeric additives

ZDDP and MoDTC Interactions and Their Effect on Tribofilm Growth Revealed by in Situ Atomic Force Microscopy

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Zinc dialkyldithiophosphate (ZDDP) is known to form protective viscous tribofilm on rubbing area, preventing direct contact of machine parts and hence severe wear. Despite extensive literatures on performance of ZDDP-based lubricants, the mechanisms governing the tribofilm growth are not well understood, which limits the development of alternative environmentally anti-wear agents. The role of common coexisting additive, e.g., molybdenum dithiocarbamate (MoDTC) in a fully formulated oil, has also not been investigated during ZDDP tribofilm formation. In this study, single-asperity sliding contact with controlled and quantified loads is achieved using an atomistic force microscopy (AFM), in which the tribofilm forms on an area of few micrometers and its properties such as adhesion, hardness morphological and evolution with nanometer resolution have been measured concurrently. In addition to a thermal stress-activated model, our results show that the growth rate of ZDDP tribofilm is associated with the substrate material, which might be attributed to the molecular adsorption of ZDDP and its reaction products. MoDTC addition gives rise to the reduced tribofilm growth rate, and its negative suppressing effect is more evident as the concentration increases. TOF-SIMS analysis was carried out to show evolution and distribution of chemical species during rubbing. Additionally, macroscopic ball-on-disc tests were conducted and comparative analysis is carried out based on the results obtained from both macro/AFM friction tests.

Keywords: single-asperity sliding contact, ZDDP tribofilm, MoDTC

Performance and Mechanism Studies of Novel Polymers as Additives for Environmentally Friendly Lubricant

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Friction and wear accelerate the wear of key components in mechanical equipment, reducing their operational safety, reliability, and service life. Lubricants with excellent performance can provide sufficient lubrication for machinery, thereby reducing friction and wear. Friction improvers play an important role in improving the antifriction performance and fuel economy of engine oil. The widely used organic friction improvers currently meet environmental and energy requirements, but small molecule organic friction improvers usually have the disadvantage of fewer active adsorption sites and weaker ability to form adsorption molecular layers on metal surfaces.

In response to the current problems, three derivatives of polyether amine were synthesized using the "one-pot" method. Different end groups were introduced onto polyether amines. The tribological properties of these derivatives as lubricant additives were then discussed. Ball-plate reciprocating friction tests demonstrated that the addition of these new derivatives to base oils significantly reduced the coefficient of friction (up to 23%). Based on these findings, the anti-wear performance of the polyether amine derivatives was analyzed using white light interferometry, which revealed a wear rate reduction of up to 68% compared to that of the base oil. Water contact angle measurements and QCM tests provided supporting evidence for the mechanism of action of the polyether amine derivatives. Molecular dynamics simulations further validated the adsorption capacity of the three derivatives on metal substrates. Furthermore, the chemical composition of the wear surface was analyzed using energy dispersive spectroscopy, X-ray photoelectron spectroscopy, and Raman spectroscopy to gain a deeper understanding of the mechanism of action.Among them, ATPE-MA with carboxyl structure has the strongest adsorption capacity and optimal tribological performance on the iron surface.

Keywords: polymers, lubrication, adsorption energy

Electro-responsiveness of phosphorus-containing ashless lubricant additives

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Phosphorus-containing ashless lubricant additives are extensively used in various industrial applications, especially in the rapidly growing field of transportation electrification. Understanding their response under the influence of electric field is thus vital for predicting lubricant failure and potentially controlling lubricant performances. This work investigates how the application of an electric field can impact the performance of phosphorus-containing additives for lubricating steel/steel contacts in organic base fluids. The frictional properties of a range of phosphite and phosphate additives are evaluated using a ball-on-disk tribotester with an applied electric field. The effects of voltage on the additives' behavior and the tribochemical reactions at the interface are studied using microscopic and spectroscopic techniques. The nature of the interactions between the additives and rubbing surfaces is examined. The role of

supporting electrolyte is explored. Additionally, we conducted research on the impact of different ester-based oils on electric-field-controlled lubrication of electric responsive additive. This study contributes to our understanding on the mechanism of tribofilm evolution and consequent anti-wear protection in phosphorus-containing ashless lubricant under an electric field.

Keywords: phosphorus-containing lubricant additives, supporting electrolyte, electric field

Enhanced Lubrication Performance of PFPE with TMFS-Modified MoS2 under High-Temperature Conditions

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Perfluoropolyether (PFPE) is a superior high-temperature lubricant with distinctive molecular structure and properties, presenting challenges in dissolving other two-dimensional materials. As a representative two-dimensional material, MoS2 has emerged as a promising candidate for high-temperature lubricant additives. In this study, MoS2 achieved successful chemical grafting facilitated by Trimethoxy(1H,1H,2H,2H-perfluorodecyl) silane (TMFS). Raman and XPS revealed the intricate evolution of morphology and microstructure in MoS2-modified. TMFS modification not only enhanced the dispersion and stability of MoS2 in PFPE but also significantly improved the tribological performance of the lubrication system. Comparisons of different lubricant compositions under various conditions demonstrated the great enhancement effect by the addition of MoS2-modified on the high-temperature performance of PFPE.Compared to pure PFPE lubricant, the coefficient of friction (COF) decreases by 36.8%, and the wear rate decreases by 81.6%. This research provides profound insights into modified MoS2 and offers crucial academic references and guidance for designing high-performance, high-temperature lubrication systems in the future.

Keywords: high-temperature lubrication, perfluoropolyether, nanomaterials, chemical functionalization, dispersion

Relationship between Solubility of Additives in Base Oils and Friction Properties

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Organic friction modifiers reduce friction under boundary lubrication by adsorbing on the metal surface to form a boundary lubrication layer and protect the sliding surfaces.

In the friction reduction of boundary lubrication conditions, the "dissolved structure" of the friction modifier molecules in the base oil and the "adsorbed structure" on the surface are critical factors.
In this study, base oil/additive combinations with different solubilities were used to investigate the effect of solubility. Substrates with iron layers sputtered on the surface of silicon wafers were used in this study. The coefficient of friction of different combinations was measured by Atomic Force Microscopy (AFM) and the properties of adsorption layers were obtained by experimental methods such as contact angle measurements, and Neutron Reflectometry (NR). In order to evaluate the adsorption of additives at the molecular level, a series of molecular simulation experiments were conducted by Forcite in Material Studio to obtain adsorption energy profiles for different base oil/additive combinations. Furthermore, the solubilization structure of the additives in the base oil was also investigated by Dynamic Light Scattering (DLS) and Small Angle X-ray Scattering (SAXS).

This research focuses on the "dissolution" and "adsorption" of additives, which are the source of boundary lubrication layer formation, and examines whether the friction-reducing effects of additives can be summarized from a solubility-aware perspective, which is important for the design for low friction.

Keywords: organic friction modifiers, solubility, boundary lubrication layer

Track 1-III: Friction and Lubrication

KEYNOTE:

Multiscale Contact Mechanics Theory with Application to Adhesion

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Surface roughness has a big influence on the contact between solids instationary or sliding contact. Surface roughness often occurs over manydecades in length scale, e.g., from nm to the linear size of the objects, which makes ita hard problem for numerical (e.g. finite element) methods. I have developed an analytical contactmechanics theory which can take into account all relevant length scales. The only input for the theory is the surface roughness power spectra and the elastic or viscoelastic or elastoplastic properties of the solids. As application I will discuss leakage of seals, adhesion in wafer bonding and in spinning asteroids.

Keywords: contact-mechanics, adhesion, wafer-bonding

Influence of Probabilistic Roughness Parameters on the Contact Characteristics

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Studying the influence of roughness parameters on the characteristics of contact interaction of deformed bodies is a task of great practical and theoretical significance. For description of surface roughness, there are a number of methods, which includes deterministic, fractal and statistical. Each of them has its own advantages and disadvantages.

One of the most common models developed in the frame of the statistical approach is the Greenwood and Williamson model. This model represents roughness as a set of identical spheres with a given height distribution. To study the contact interaction of deformable bodies with rough surfaces based on this model, a number of assumptions are made, including the independence of asperities in contact and definite type of the asperities height distribution. Note that the first one is valid only for the low contact density, i.e. for the low nominal load.

In this work, a modernization of the Greenwood and Williamson model is constructed, taking into account the mutual influence of asperities. The resulting solution allows us to study the influence of roughness parameters (average curvature radius of asperities, average location density of them) on macro- and microscale contact characteristics (approach of the surfaces in contact, relative contact area, and contact pressure distribution at the individual contact spot). In addition, the influence of the type of the height distribution of asperities on the contact characteristics under consideration is analyzed.

The present work was supported by RSF (project No. 22-49-02010).

Keywords: roughness, mutual effect, elasticity

High-Speed Friction Behavior of Aircraft Tire Based on Thermo-Mechanical Coupling Method

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Severe heat generated by the hysteresis loss can be accumulated inside of the aircraft tire during the free rolling stage, which affects the performance and safety of aircraft. In this paper, verifying a thermo-mechanical coupling simulation method through experiments to predict the temperature field evolution and internal temperature distribution of natural rubber during high-speed rolling. The high-speed rolling performance of the aircraft tyre can be reflected by the disc-shaped specimen based on the similar working and contact conditions, which provides theoretical basis for the further application in aircraft tyre. The cyclic tensile test is conducted on dumbbell rubber specimen, and the results show that the temperature increases with the strain. The simulated temperature field distribution corresponds well with the test results, and the maximum error of the temperature rise data is within 4%. Rolling test is conducted on solid rubber wheels, the error between the simulated temperature rise curve and the test is within 1.2%, which proves that this method accurately predicts the temperature evolution process of the disc rubber wheel, and provides a basis for the study of aircraft tire heat generation under different conditions.

Keywords: aircraft tire, high-speed friction, thermal-mechanical coupling

Study on the Frictional Interface Interaction Based on Molecular Dynamics Simulation

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To elucidate the interactions between friction pairs at the atomic scale, molecular dynamics simulations were employed in this study to establish a tribological model between polymer nanocomposites and copper metal. By investigating the frictional wear performance of this system under various conditions including vacuum, high/low temperatures, different humidities, velocities, and loads, the dynamic changes of each atom during the friction process were visually observed. Analysis of changes in relative atomic concentrations, velocities, temperatures, and system energies allowed for the elucidation of the interaction mechanisms between the polymer matrix and nano-modifiers with the counterpart under different environments. Furthermore, by calculating the interaction energies between different materials, the influence mechanisms of material properties, external environments, and application conditions on friction and wear performance were revealed. This provides a theoretical basis for understanding the interactions between friction pairs at the atomic scale.

Keywords: molecular dynamics simulation, friction, wear

INVITED:

The Wheel-Rail Interface: Experimental Insights into an Open Tribological System

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The wheel-rail interface plays a crucial role in the safety and operational efficiency of rail transportation. This interface represents a typical open tribological system, highly susceptible to environmental and weather influences. The phenomenon known as "wet-rail" in the wheel-rail interface is characterized by a marked decrease in friction between train wheels and railway tracks due to the presence of water and other contaminants and materials. This contribution presents the latest insights into the mechanisms through which water acts as a trigger for low friction. It specifically highlights experimental findings that demonstrate the transient nature of this phenomenon in rolling contacts contaminated with water-particle suspensions. Additionally, this work underscores the potential risks associated with extremely low friction levels when top-of-rail lubricants are employed in conjunction with water contamination.

Keywords: wheel-rail interface, low friction, open tribology

Why Frictional Behavior is Difficult to Repeat?

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Just as the flapping of a butterfly's wings can potentially trigger a chain of events leading to a tornado on the other side of the world, minor deviations in experimental setup or conditions can amplify tribological behavior. In this study, we aim to illuminate the often-overlooked influences of two seemingly controllable and constant factors—surface profile and oscillation resulting from misalignment—on tribological experiments. Using a pin-on-disk tribometer, we meticulously controlled the variables of disk surface profile and misalignment. For surface profile control, rigorous standards were implemented to ensure that height variations on the 132 mm sliding track remained below 2 µm. Additionally, to mitigate oscillation caused by misalignment, the height difference after mounting was limited to less than 4 µm on the 132 mm sliding track. Our findings highlight that even minor differences in surface profile and misalignment significantly influence frictional outcomes. We discovered a complex interplay between surface topography and system properties, which collectively exhibit a strong correlation with frictional behavior and can predict areas of maximum wear.

Keywords: surface profile, waviness, oscillation, mechanical vibration, misalignment

Experimental Study on Friction Resistance of Earthworm Bionic Robot in Pipe

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This paper presents a robot that mimics the shape of earthworm. It is a robot that carries sensors and other cleaning tools to detect and clean pipes. The structure of this kind of pipe robot is introduced, the corresponding prototype is made, and the relevant experiments are carried out on the specially designed test platform. The robot can climb and clean in the circular and rectangular pipes. The various friction resistance of the bionic earthworm pipe cleaning robot during the pipe inspection and cleaning are discussed and the experimental results are described. This paper then focuses on the friction of these three aspects, firstly introduces the friction difference principle to analyze the influence of geometric deviation of pipeline robot on the movement of pipeline robot. Robots should move in industrial pipes, all of which have geometric deviations, either from the production process or from everyday use or operation. It is necessary to understand the effects of these geometric deviations on robot motion. Then the bristles (or bristles) from the bristles serve as carrying and cleaning elements, and they serve as an important part of the robot's crawling and cleaning. Look at the friction properties of the robot's bristles at different sizes on the surface of the pipe's inner diameter. When the inner diameter of the pipe is less than the outer diameter of the bristles, the operation and mechanical state of the bristles in the pipe with larger inner diameter are mainly due to the anisotropy of the friction force. Finally, the experiment of friction resistance between the robot and the pipe wall is analyzed, and the influence of the number of steel rings, the thickness of each ring and the self-locking mechanism on the sliding friction of the pipeline is studied.

Keywords: pipeline robot, brush, friction resistance, friction coefficient, earthworm bionics, steel ring

The Effect of Water Contamination on Friction Modification in the Wheel-Rail Contact

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Railway transportation presents an environmentally friendly way of transporting passengers and goods, and its energy efficiency can be further improved by modifying friction in the wheel-rail contact. High friction is the cause of wear and noise. On the other hand, a certain level of friction is necessary to ensure the vehicle's ability to brake. Therefore, TOR lubricants are applied, forming a lubricating layer on the rail and optimizing friction.
Up to today, TOR lubricants have been primarily tested in laboratory-clean conditions. However, the wheel-rail interface is an open contact, meaning different contaminants can be found on contact surfaces. Several studies showed that water (e.g. from the rain) acts as a lubricant and can lower friction by more than half. Now, the question arises – how will TOR lubricants perform in contaminated contact and whether they will cause low adhesion problems when combined with water?
Previously, researchers mainly used the time-tests approach to assess TOR products. However, the results of these tests can be easily biased by a slight change in ambient conditions. So, a novel benchmarking methodology based on a multiparameter approach was developed before further contamination testing.
In the presented paper, several commercial TOR products were tested under contaminated conditions. A novel benchmarking methodology was used to assess their performance. A tribometer MTM in the ball-on-disc configuration was employed to measure the traction coefficient. Water was applied via an electronic micropipette and peristaltic pump. Furthermore, a climate chamber was used to test the effect of air humidity.
The results showed that water influences TOR lubricant performance significantly. In several tests, a long-lasting period of very low traction coefficient occurred, showing that contamination poses a risk to TOR lubricants and may cause traction/braking problems on the actual track. The results can be used in TOR conditioning deployment and further product development.

Keywords: friction modification, top-of-rail, contamination

Track 2: Wear and Fatigue

KEYNOTE:

Revisiting Description of Surface Roughness of Worn Surfaces - By Human and By Machine

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This paper revisits an exploratory study on description of worn surfaces through human eyes made by the author around the turn of the century. The study showed that human could roughly rate surface roughness amplitude and describe various aspect of surface

features from photographs of worn surfaces by using a number of different words, which had some correlation with roughness amplitude. It also showed that some combination of texture parameters calculated from the photographs to describe brightness variation could also rate roughness amplitude just as the human could. The study is now extended to examine how machine learning can do what people observe and express geometrical features through observation by human eyes.

Keywords: surface roughness, human, machine learning

Understanding the Shear Localization and Shear Instability in Ultralow-Wear Polymers Crossing the Wide Pressure-Velocity Conditions

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Ultralow-wear polymers, consisting of polyetheretherketone/polytetrafluoroethylene (PEEK/PTFE), exhibit potential in addressing durability concerns within high-speed reciprocating sealing interfaces and low-temperature bearing retainers. Nevertheless, prior investigations have revealed that the remarkable properties of ultralow-wear polymers are susceptible to variations in operating conditions, notably under high pressure and high velocity circumstances. From a fracture mechanics perspective, the tribological deterioration of ultralow-wear polymers under high pressure-velocity conditions is primarily attributed to the transition from shear localization to shear instability near the sliding surfaces. In this study, we aim to understand this transition mechanism induced by changing pressure-velocity conditions. Tribological tests were performed on ultralow-wear PEEK/PTFE samples across a wide range of pressure-velocity values (0.06 to 12.0 MPa·m/s). To investigate the microstructural changes occurring on both the polymer and counterpart surfaces at different wear states, observations were conducted using cryo-sectioning, electron microscopy, and atomic force microscopy. Nanoindentation mapping tests were employed to probe the mechanical evolutions of the polymer's run-in and transfer films. The results turn out that the polymer's ultralow wear attributes stem from the mechanical reinforcement of polymer surface due to the shear localization. While subjected to high loads and velocities, adiabatic shear occurs within the polymer's subsurface thus resulting in the shear instability and ultralow wear failure. Utilizing continuum mechanics and shear transformation zone theory, we established the criteria for the transition of ultralow-wear polymers from shear localization to shear instability. Leveraging this insight, we then put forward a viable strategy aimed at improving the durability of ultralow-wear polymers operating under high pressure-velocity conditions.

Keywords: wear, shear localization, ultralow-wear polymer, PEEK, PTFE

INVITED:

The Tribological Behavior and Damage Mechanism of Bearing Materials under Unsteady Conditions

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Bearings are one of the most important key basic components of the machine, known as the "joint of high-end equipment". In the actual service process of bearings, with the change of working conditions, the bearing will experience unsteady services, such as rapid acceleration/deceleration, variable load, skid and so on. In this paper, the wear mechanism of bearing steel under different lubrication conditions is studied and the microstructure evolution of the surface material is also discussed. Under unsteady lubrication, the friction state of bearing materials changes sharply and the maintenance ability of tribological properties of lean lubrication depends on the resistance of the materials to thermal weakening. The failure assessment method of bearing material under unstable condition is raised. The variation rate of friction coefficient and the time of the lean and transition stages are proposed as the indicators of bearing early failure under unsteady lubrication. Meanwhile, the influence of rolling state on the damage mechanism of bearing steel is explored. Furthermore, the surface modification technologies of bearings are proposed to control the tribological behavior of the bearings, thus, the resistance of the materials to wear under the lean oil lubrication is increased and the reliability and life of the bearings are improved.

Keywords: bearing, tribological behavior, unsteady conditions

A Cross-Scale Study of the Mechanism of Wear Effects of Anisotropy in Nickel-Based Single Crystal Superalloys

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As a material that has been widely used in aerospace, the mechanical properties of nickel-based single crystal superalloys (NBSC superalloys) are susceptible to anisotropic characteristics. Multi-axis stress operating environments are prone to severe surface wear, and controlling that wear increases the likelihood of effectively extending component life. In this paper, the effect of anisotropic features on the wear resistance of different crystalline surfaces of NBSC superalloys at the macroscopic scale at room temperature is investigated, and it is found that the wear depths of the three conventional crystalline surfaces have a certain regularity, that is, the (100), (110), and (111) crystalline surfaces show 90°, 180° and 60° cycles, respectively. It was also confirmed that high temperatures have the same regularity of influence and the same anisotropy, but with a weakening. The anisotropic feature at room

temperature is more representative, so in combination with microscopic wear experiments at room temperature on different crystalline surfaces and orientations, it is found that the law of influence of the anisotropic feature on the wear depends on the angle between the slip system and the direction of wear. These findings are not only beneficial in providing informativeness for cross-scale analysis techniques, but also in assisting in the selection of the longest-lived grain orientation for NBSC superalloys.

Keywords nickel-based single-crystal superalloys; anisotropy; wear

Attempts to Enhance Hard/soft Seal Defence Against Particles Invasion: Model Construction and In-Situ Observation

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Downhole hard/soft (rubber/metal) dynamic seals are highly susceptible to invasion by hard particles from drilling fluids, which leads to premature failure. This poses a great challenge to sustained production. Therefore, work on techniques to control particle invasion was attempted. Focusing on adjusting the interfacial contact pressure to control the sizes of the invaded particles, an in-situ observational investigation was carried out. Through a combination of modelling and testing, it was found that an increase of compression forces would slow down particles invasion. And when the compression force reached a certain critical value, particles of a specific size would be rejected from the seal interface. This result was mainly realized by affecting the displacement of particles upon contact with the sealing surface. In addition, the exacerbation of the particles invasion phenomenon by the vibration environment prevailing downhole was also clarified, which was related to the fluctuation of the contact pressure at the seal interface. Based on the purpose of controlling particles invasion, this study not only revealed the mechanism of particles invasion, but also the theoretical models discussed in the work laid the foundation for prediction and seals structural innovations. The significance of this work would be to serve as a basis for decision-making on operational and structural parameters of seals in particle environment, as well as to provide important insights into the life and reliability of equipments downhole.

Keywords: seal, particle invasion, failure, wear

Cloud Maps Highlighting Dynamic Characteristics of Surface Signal to Improve Time-varying Wear Evaluation Accuracy

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This paper proposes a high accuracy time-varying wear evolution method with cloud maps highlighting dynamic characteristics of surface signal. Firstly, the cloud map method is established by arrangement of measured data, thus time-varying wear evolution process is visualized on a series of plane figures for preliminary qualitative analysis. Then, high accuracy recognition of time-varying wear states is realized by cloud map shape parameters, including kurtosis and 1-D kernel density function highlighting distribution information of surface signal. The relative recognition degree by cloud map shape parameters is higher than those of friction coefficient, Root-Mean-Square (RMS) deviation and fractal dimension. Finally, high accuracy time-varying wear life prediction is realized by cloud map size growing speed highlighting waviness information of surface signal. The relative prediction error is reduced from more than 20% to less than 10% compared with friction coefficient and roughness.

Keywords: cloud map, dynamic characteristics, surface signal, time-varying wear evolution process, wear evaluation accuracy

Cross-Scale Fretting Wear Characteristics of metal rubber under Thermal Mechanical Coupling

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Metal Rubber (MR), a crucial vibration damping material used in defense equipment, often faces the issue of a shorter-than-expected lifespan under high-temperature conditions, leading to early deformation, wear, and even breakage of metal wires, which significantly jeopardizes the safety of the equipment in service. In this study, metal wire micro-motion wear simulation was conducted using the umeshmotion subroutine. By introducing a micro-motion amplitude parameter for the regularization and recombination of dynamic and static metal wire wear marks, a micro-motion wear evolution model considering dynamic wear differences was developed, enabling accurate prediction of wear depth, area, and volume. Specifically, this study analyzed the impact of curvature radius on micro-motion wear for four typical internal curvatures of the metal wires, with a focus on developing a micro-motion wear evolution model for curved metal wires. Additionally, for high-temperature conditions of MR, a temperature function was introduced to describe the effects of material thermal expansion, high-temperature softening, and oxidation, leading to the development of a metal wire wear model suitable for high-temperature environments. Furthermore, using MR virtual fabrication technology, the study explored the curvature contact characteristics of MR under load through contact search and curvature classification algorithms. A cross-scale high-temperature numerical wear model for MR was

constructed using a multi-point spatial coupling method. The model's results were validated through micro-motion wear experiments and fatigue tests.

Keywords: metal rubber, fretting wear, contact search, thermal mechanical coupling, curvature

Revealing the Shear Band Origin of White Etching Area in Rolling Contact Fatigue of Bearing Steel

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White etching area (WEA) has become a big challenge for bearing failure under rolling contact fatigue (RCF). Despite of the extensive investigations, the origin of the WEA has not yet been well understood. This work elucidates the WEA origin from a new perspective that WEA is essentially the shear band (SB) induced by plastic strain localization. Firstly, RCF and quasi-static compression tests were conducted to generate WEAs and SBs. Secondly, the SB was compared with the WEA in terms of shear localization, microstructures, formation mechanism and crack development. Thirdly, the RCF model was developed based on crystal plasticity theory coupled with phase field damage and cohesive zone. The results showed that the WEA can be categorized as deformed and transformed WEAs depending on whether phase transformation occurs. The deformed WEA consists of nanocrystalline, while the transformed WEA consists of well-developed equiaxed grains of austenite phase, which indicates the phase transformation from ferrite to austenite. The large micro shear strain in the WEA provides the driving force for mechanically controlled austenite phase transformation. The modelling result of SB development are in good agreement with the WEA experimental observations. The inhomogeneity and scatter in WEA’s distribution are due to the influence of the crystal orientation. The shear band center, which has the largest strain and the lowest stress, is where microcracks initiate. This suggest that cracks are developed during the WEA formation, rather than crack faces induced WEA (crack initiation prior to WEA) as it is previously reported.

Keywords: rolling contact fatigue (RCF), white etching area (WEA), shear band, strain localization, crystal plasticity

Track 3-I: Coatings and Surfaces Engineering

KEYNOTE

Precise Control of Particle Transport, Deposition and Removal in Current and Additive Semiconductor Manufacturing

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The control of particle transport, deposition and removal plays a key role in current semiconductor manufacturing in the removal of particles in post CMP process or from various structures such as vias. This particle control plays a much greater role in additive manufacturing of electronics. This control relies on the fundamental understanding of all the forces that will affect the particles in liquids or on the surface of a substrate and the parameters that will enable us to control these forces such the adhesion force, particle charge, electrostatic field, convection, direct forces applied through contact with one or two surfaces.

The first part of the presentation will cover the fundamentals of particle removal from surfaces as it applies to post-CMP cleaning and the effect of the adhesion force, and the removal forces that can be harnessed to remove the particles through the application of forces directly or indirectly. This will include the effect of chemistry and particle deformation in decreasing or increasing the adhesion force. High-frequency acoustic streaming and brush cleaning will be addressed. The second part of the talk will address the use of particle transport and deposition to additively manufacture electronics without etching, vacuum deposition, or chemical reactions. This is done through the precise direct assembly of nanoscale particles or other nanomaterials at room temperature and atmospheric pressure onto a substrate with nanoscale precision. The technology enables the additive manufacturing of passive and active components at the nano and microscale, utilizing inorganic semiconductors, metals, and dielectric nanoparticles.

Keywords particle control, post-CMP, additive manufacturing

Multi-Scale Debonding Behaviors of Precision Glass Molding Interface

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Precision glass molding (PGM), a hot-forming replicative optics fabrication method, is extensively used for producing small-to-medium-sized aspherical lenses, microstructures, and freeform optics. Compared to traditional grinding and polishing techniques, PGM is more time- and cost-efficient, environmentally friendly, and particularly suitable for high-volume production. Despite these advantages, adhesion or sticking between glass and molds remains a significant obstacle, potentially degrading the high-precision surface quality and shortening the lifespan of molds. To address the glass/mold adhesion problem, it is crucial to understand the multiscale debonding behaviors and consequences during the separation of the glass/mold interface. We employ a probe tack test procedure to investigate the macroscale debonding behaviors of a typical glass molding interface. Additionally, the microscale surface morphology of the molded glass after debonding is statistically characterized. Experimental results show that debonding behaviors are highly dependent on temperature and separation velocity. As temperature increases or separation velocity decreases, the macroscale debonding behavior shifts from interfacial fracture to cohesive bulk deformation. These temperature and rate-dependent debonding behaviors can be unified by the reduced crack velocity along the interface. Moreover, the glass surfaces after debonding are covered with numerous randomly distributed micrometer-scale cavities. As temperature increases, both the maximum depth and the area fraction of these microcavities significantly increase. These microcavities likely result from localized deformation at gas-trapping spots during the separation of the adhesive glass/mold interface. For interfacial fracture cases, cavities mainly propagate as cracks along the interface, developing into shallow, disc-like shapes. In contrast, for cohesive cases, cavities tend to grow within the bulk. Ultimately, both the macroscale mechanical behaviors and the growth bifurcation of microcavities are governed by the competition between the strain energy release rate and the viscoelastic complex modulus.

Keywords interfacial debonding, precision glass molding, viscoelasticity

Enhancing Current-Carrying Prediction with Spatial Frequency Analysis

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Electrical contact interfaces, crucial in devices such as connectors, switches, and conductive slip rings, significantly influence current-carrying capabilities. This study introduces the spatial frequency method, utilizing parameters like gain factor, spectral index, and cutoff frequency, for an in-depth characterization of surface morphology. Analyzing through a correlation matrix, we discovered a strong link between the gain factor and surface roughness, with a correlation coefficient of 0.9, indicating its direct impact on the load-bearing capacity of rough surfaces. Remarkably, the correlation between roughness and load-bearing stability is as high as 0.98, suggesting that excluding current-carrying performance, assessing roughness alone can accurately predict surface stability under pressure. However, when focusing on current stability, the relevance of roughness diminishes to a correlation of 0.78. The study highlights the importance of the ratio of high to low spatial frequency components in influencing

current-carrying performance, with a notable correlation of 0.59, underscoring its significance. Employing multiple linear regression, predictions using the spatial frequency method for current-carrying performance yielded an R^2 of 0.827, surpassing the roughness-based prediction, which scored only 0.613. This disparity arises because roughness merely quantifies the statistical deviation of surface heights, whereas the stability of current-carrying and load-bearing capacities is intricately tied to the curvature of micro-protrusions on the surface. Our research provides a refined, more accurate approach for predicting current stability on electrical contact surfaces, promising to improve the reliability of electrical transmission devices.

Keywords electrical transmission, surface morphology, spatial frequency method

Characterization of Three-Dimensional Roughness of Aviation Bearing Surface and Evaluation of Its Influence on Lubrication Performance

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The ongoing evolution in aviation engines leans towards an enhanced thrust-weight ratio. To enhance the thrust-weight ratio of aviation engines, it is inevitable that the working conditions of the main shaft bearings of aviation engines will become more demanding, thereby increasing the possibility of lubrication failure in the main shaft bearings of aviation engines. Therefore, it is of great importance to conduct research on anti-surface abrasion and anti-oil cutoff of main shaft bearings of aviation engines considering surface roughness, in order to improve the reliability and extend the service life of main shaft bearings of aviation engines, which is crucial for the development and progress of aviation engines and the aviation industry. In this paper, the formation process and detection methods of three-dimensional surface roughness of aviation bearings are studied, for exploring the methods of numerical simulation of three-dimensional surface roughness of aviation bearings. Based on this study, experimental research is compared and verified with numerical simulation to study the influence of three-dimensional roughness parameters of aviation bearings on lubrication performance and measurement of lubricant film thickness. The results show that the numerical simulation method proposed in this paper can accurately represent the structural characteristics of the real surface of aviation bearings, achieve precise substitution between simulated surfaces and real surfaces, and provide a more concise and effective method for studying the intrinsic relationship between macroscopic performance and microscopic morphology of aviation bearing surfaces. The research results of numerical simulation surfaces on lubrication and oil film thickness measurement match well with experimental results, obtaining conclusions highly consistent with experimental results, indicating that the method has significant practical value.

Keywords oil cut-off, three-dimensional, roughness, numerical, simulations, lubrication, film thickness measurement

Nanoscale Coating Wear Measurement Approach Based on Raman Signal

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For gaining fundamental insight into coating wear mechanisms and increasing operational efficiency and automation degree of equipment in important application fields of coating techniques, it is of great importance to developing novel wear measurement techniques enabling nanoscale studies of coating wear in the running process, but this remains a significant challenge. Here, a facile strategy is reported to achieve accurate coating thickness quantification at nanoscale level, which is based on a bilayer structure: a top target layer of a-C:H (hydrogenated amorphous carbon) film is considered as a light attenuating and anti-wear layer while underlayer of silicon serves as Raman-sensing layer. Through constructing the relationship between the thickness of a-C:H and Raman intensity of attenuated silicon signal, the coating thickness quantification method is established and successfully applied to quantify coating wear in the friction process. This approach can effectively avoid remarkable errors caused by tribo-induced effects in the interface regions, demonstrating its advantage in error tolerance. Details about these tribo-induced effects are also elucidated by a combination of Raman spectroscopy, optical profilometer, EELS, and TEM. In particular, the proposed approach enables the possibility of measuring coating wear with oil film on top, which breaks an important limitation of existed wear measurement methods, i.e., incapable of applying in oil-lubricated conditions. This approach can be used to quantify the wear condition of diverse target coatings and has the potential of online wear monitoring when combining a compact laser excitation and detection system.

Keywords coating, wear measurement, Raman

Surface-Interface Characteristics and Tribological Performances of In Situ Grown CrN and CrAlN Coatings by Cathodic Arc Ion Plating

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To improve the tribological performance of hot work molds at working temperatures, a cathodic arc ion plating (CAIP) technique was used to in situ grow CrN and CrAlN coatings on AISI H13 steel. The characterization processes of obtained coatings were performed using a field emission scanning electron microscopy (FE-SEM), energy

disperse spectroscope (EDS), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and nanoindentation techniques. The tribological performances of CrN and CrAlN coatings were evaluated using a ball-on-disc wear tester, and the wear mechanisms were consequently discussed in detail. The results show that the grown CrN and CrAlN coatings primarily are composed of CrN and (Cr, Al)N phases, respectively, exhibiting the in situ grown columnar-grained structures. The nanohardness and elastic modulus of CrAlN coating are 23.89 and 295.60 GPa, respectively, higher than those of CrN coating. The average COF and wear rate of CrAlN coating are lower than those of CrN coating, indicating that the CrAlN possesses the more outstanding friction reduction and wear resistance compared with the CrN coating, which is attributed to the formation of Cr and Al oxides during the friction process.

Keywords CrN coating, CrAlN coating, mechanical property, coefficient of friction (COF), wear mechanism

Synergistically Enhancing Wear-Resisting Property by Infiltrating Silicon Nitride Fibers with TPU/PEG through Sizing Technology

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Recently reported silicon nitride fibers(Si3N4 Fiber) have attracted considerable attention for aerospace applications due to their high-temperature resistance and wave permeability, however, the properties of the composite material are directly determined by the properties of the prefabricated materials. The poor molding efficiency and poor performance of the prefabricated materials stem from the low wear-resisting property of Si_3N_4 Fiber. Herein, we developed a sizing agent capable of significantly improving the wear-resisting property of silicon nitride fibers by modifying thermoplastic polyurethane (TPU) using polyethylene glycol (PEG) with acetone as a solvent. Silicon nitride Fiber@Thermoplastic Polyurethane/Polyethylene Glycol (Fiber@TPU/PEG) was prepared by sizing technique and silicon nitride fiber with Fiber@TPU was used as a control. The results demonstrated that TPU/PEG could fully infiltrate the Si_3N_4 Fiber, evenly distributed on the inner and outer surfaces of the fiber, and formed a good interfacial relationship with the monofilament. Fiber@TPU/PEG-2.5wt% exhibited better protonema bunching than Si_3N_4 Fiber when the PEG concentration was increased to 2.5 wt%. Additionally, the wear-resisting property of Fiber@TPU/PEG-2.5wt% was observed to be greater than Si3N4 Fiber and the COF value of Fiber@TPU/PEG-2.5wt% was 61.82% lower than that of Si_3N_4 Fiber. Consequently, this method was promising for improving the friction and mechanical properties of ceramic fiber-reinforced composites.

Keywords silicon nitride fiber, sizing agent, wear-resisting property

The Effect of Duty Cycle and Nitrogen Flow Rate on the Mechanical Properties of (V,Mo)N Coatings Deposited by High-power Pulsed Magnetron Sputtering

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(V,Mo)N is regarded as a promising coating material for tribological applications, having high hardness and ductility deriving from its extraordinary metal-nitrogen bonding environment. However, the toughness enhancement of (V,Mo)N coatings deposited by dc-unbalanced magnetron sputtering (dc-UBMS) was not as significant as the theoretical predictions, which may be attributed to the insufficient energy delivery in forming nitride bonding in the dc-UBMS system, thereby leading to an inadequate coating quality. The objective of this study was to investigate the effect of duty cycle and nitrogen flow rate on the mechanical properties of (V,Mo)N coatings deposited by high-power pulsed magnetron sputtering (HPPMS). Four sets of (V,Mo)N coatings were deposited by HPPMS with different duty cycles, 5% and 3%, and various nitrogen flow rates, 6.0 and 12.0 sccm. The results showed that the N/Metal ratio increased from 0.70 to 0.96 with increasing nitrogen flow rate. The lattice parameter of the coatings linearly increased with the N/Metal ratio. X-ray diffraction revealed that the (200) texture coefficient gradually increased with the deposition duration. For the coating deposited with 6 sccm nitrogen flow rate and 3% duty cycle, multi-phase microstructure was observed. This finding was confirmed by glancing incident XRD and transmission electron microscopy analysis, indicating a phase separation from (V,Mo)N to (V-rich,Mo)N and (V,Mo-rich)N. The coatings hardness decreased from 28.4 to 19.3 GPa with increasing nitrogen content, which was possibly due to the decrease of nitrogen-vacancy hardening effect. The resultant fracture toughness of (V,Mo)N coatings ranged from 36.1 to 43.7 J/m^2, which was significantly higher than VN and (V,Mo)N coatings deposited by dc-UBMS. The high fracture toughness of (V,Mo)N coatings is consistent with the theoretical predictions, suggesting that the sufficient formation energy provided by the HPPMS process is crucial to achieving the desired quality of (V,Mo)N coatings.

Keywords (V,Mo)N coatings, fracture toughness, high-power pulsed magnetron sputtering

Comparison of Tool Life and Wear Resistance of Four Designed Coatings

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As an effective way to improve surface properties, coating technology has been widely used in the modern cutting tool industry. In recent years, hundreds of coatings have been developed. Match between coating material and workpiece material is more and more important for industrial application.. In this study, four kinds of CVD coated tool samples were prepared by designing the thickness of each layer of the CVD coating (TiN-Al_2O_3-TiCN). The difference between these four kinds of coating tool samples is that the thickness of TiN layer and Al_2O_3 is different. Moreover, four coated tools were tested by AISI 1045 steel turning. Cutting force, tool life and tool wear mechanism were obtained. The experimental results show that the Al_2O_3 layer is too brittle, the existence of TiN layer can effectively protect the Al_2O_3 layer, which greatly improves the coating life. Meanwhile, it is found that the coefficient of friction of TiN layer is higher than that of Al_2O_3 layer. However, the existence of TiN on the coating surface greatly improve the life of the coated cutting tools.

Keywords CVD coating tools, designed coating, cutting experiment, tool life

Track 4: Tribo-chemistry and Lubricants

KEYNOTE:

Polymer Micelles, Worms, and Hollow Spheres under Confinement and Shear: Surface Forces, Friction, and Nanomechanics

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Understanding polymer-mediated surface forces and friction is critically important to colloidal stability, biological processes, and industrial applications. Interfacial polymer layers can be carefully orchestrated through chemical synthesis and self-assembly, leading to controlled geometries and sophisticated structural hierarchy at the interface (e.g. brushes, surface aggregates, or loops and trails [1-5]).
Using a surface force apparatus (SFA) [6], we have measured interactions mediated by positively charged polymer nanoassemblies of different geometries and dimensions, including small and large spherical polymer micelles (~30 and 200 nm in diameter, respectively), cylindrical/worm micelles (~25 nm in diameter and 200 nm in length), and polymersomes (hollow spheres ~200 nm in diameter), self-assembled from (poly(glycerol monomethacrylate) + quaternized poly(2-(dimethylamino)ethyl methacrylate))-poly(2-hydroxypropyl methacrylate). We find that the polymer worms formed a loosely packed surface layer protruding into the solution, giving rise to a long-range repulsion. The hollow polymer spheres adsorbed weakly on the surface and were expelled out the confining surfaces.

Remarkably, the charged polymer spheres remained robustly adsorbed on the surface under high pressures, mediating extremely effective lubrication, with a friction coefficient μ<~10^{-4}. We develop an analytical model, combining 1) the electrical double layer, 2) confined liquid droplets, and 3) de Gennes' scaling arguments for polymers under severe confinement, to describe the surface force data at long, intermediate, and short range, respectively (Fig. 1). This also yields a Young's modulus of ~15-19 MPa for the confined polymer spherical micelles. These unprecedented results enable a discussion of the correlation between the geometry and surface charge density of the polymer assemblies, their interfacial conformation, and the surface forces and friction they mediate.

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Keywords: Surface forces, friction, surface force apparatus, polymers at interfaces, nanomechnics

Effect of Electric Fields on the Decomposition of Nanoconfined Lubricant Additives

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The increasing demands in electric vehicles (EV) has propelled advancements in lubricant technology for new operational environments under electric fields (EFs). Past research in investigating the effect of EFs on lubricant additives' performance are terminologized as "Triboelectrochemistry" [1]. However, it has been pointed out that the change in lubricating effect at electrified interface behave differently for bulk liquid-solid interfacial systems and nanoconfined systems. The triboelectrochemistry mechanism at molecular scale during tribofilm formation are not well understood.

Therefore, in this study, we perform nonequilibrium molecular dynamics (NEMD) simulations with a reactive force field (ReaxFF) [2] to study the effect of EFs on tributyl phosphate (TNBP) lubricant additives, in between two iron oxide surfaces (Fe_3O_4), under nanoconfined and sliding conditions. Meanwhile, two charge equilibration methods implemented in NEMD are also investigated and compared, known as QEq [3] and QTPIE [4]. These findings provide an atomistic understanding of the effect of EFs on lubricant additives' behaviours during the redox reactions. Results also suggest the potential discussions on influence on adsorption process before chemical reactions.

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Keywords: Molecular Dynamics, Electric Fields, Additive Decomposition

In-situ AFM Observation of ZDDP-Derived Tribo-Film Formation Process in Nitrogen Environment

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In recent years, the trend of reducing the viscosity of lubricant has been advancing to reduce viscous drag under hydrodynamic lubrication. As reducing lubricant viscosity, the improvement of friction and wear properties by lubricant additives becomes more crucial under boundary lubrication.
Zinc dialkyl dithiophosphate (ZDDP) is widely used as anti-wear and extreme additives. ZDDP undergoes chemical reactions to generates tribofilm on the sliding surface. The tribofilm exhibits wear resistance and anti-seizure properties by regulating metal direct contacts. Since the tribofilm derived from ZDDP is mainly composed of phosphorus acid, oxygen is necessary for its formation process, but the detailed mechanism of tribofilm formation has not been elucidated. Atomic Force Microscope (AFM) is a device capable of acquiring nanometer-scale shapes by detecting interactions between the surface and the tip of the probe. It enables measurements in high-temperature oil. Especially, in-situ AFM observation is a method of acquiring shapes while sliding, allowing contact only at single asperity. In this study, to investigate the effects of oxygen on ZDDP tribofilm formation, we conduct sliding tests in nitrogen and air atmosphere using in-situ AFM observation and macro-friction tests, and X-ray photo spectroscopy(XPS) to identify the chemical composition of ZDDP tribofilm in nitrogen and air atmosphere.
As a result, we confirmed tribofilm formation in nitrogen and air conditions using in-situ AFM and macro friction tests. Additionally, the growth rate of tribofilm in nitrogen condition was slower than that in air condition. Furthermore, tribofilm formed in nitrogen condition exhibited lower oxygen concentration compared to those formed in

air condition, with little change in phosphorus concentration and a higher proportion of C-O bonds. It is considered that oxygen in the atmosphere acts on ZDDP to promote its decomposition, thereby accelerating the formation of the ZDDP tribofilm.

Keywords: Atomic Force Microscope, Zinc dialkyl dithiophosphate, Nitrogen

Potassium Borate/graphene Nanocomposite Lubricant Additive with Anti-friction/wear and Anti-corrosion Functions for Marine Diesel Engine Burning Low Sulfur Fuel

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To suppress the corrosion and wear of cylinder liner of marine diesel engine burning low sulfur fuel, potassium borate/graphene lubricant additive was prepared by plasma assisted ball milling. Tribological tests were conducted by simulating operating condition of diesel engine to evaluate the anti-friction/wear and anti-corrosion properties of potassium borate/graphene additive. The effect of additive on cylinder liner corrosion and wear was verified by bench test of diesel engine. The results of tribological tests indicated tribochemical reaction occurred on the surface of the cylinder liner-piston ring and generated a tribochemical film composed of graphene, FeO, Fe_2O_3, Fe_3O_4, B_2O_3 and Fe_2B with anti-friction/wear and anti-corrosion properties. Bench test shown that potassium borate/graphene additive had good anti-friction/wear and anti-corrosion functions, and reduced fuel consumption and exhaust emissions of the engine.

Keywords: Potassium borate/graphene lubricant additive, Anti-friction/wear and anti-corrosion, Marine diesel engine, Low sulfur fuel

Formation and Tribological Properties Analysis of Tribofilm on Piston Ring and Cylinder Liner

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Tribofilm plays an important role in the wear resistance and lubrication performance of the piston ring cylinder liner interface of the internal combustion engine. This study analyses ZDDP additive lubricant performance and the tribofilm distribution on the surface of piston ring and cylinder liner under different loads and temperatures based

on the real working conditions. Tribofilm formation and wear mechanism on the liner at the Top dead center (TDC)、bottom dead center(BDC) and maximum burst pressure point was characterized by Scanning electron microscope(SEM) and Energy dispersive X-ray spectrometer(EDS). This study reveals that the tribofilm thickness and distribution on the cylinder liner strongly rely on the internal combustion engine operating conditions, thus influence the wear mechanism of liner and ring surface. The findings presented in this paper confirm that ZDDP tribofilm distribution plays a pivotal role in reducing wear, the wear amount can be reduced by 68.6%, but have slight effect on friction-reducing. Additionally, it is noticed that at bottom dead center, there is no tribofilm grow on the surface because of low load and temperature despite of under the boundary lubrication conditions.
Moreover, the tribofilm thickness and lamellar structure at the cylinder and ring were further investigated by Transmission Electron Microscopy (TEM), High-Angle Annular Dark-Field Scanning (HAADF) and Energy Dispersive X-ray Microscopy (STEM-EDX). Under the condition of top dead center, the distribution thickness of the tribofilm on the cylinder liner surface is uneven, ranging from 90nm to 470nm while the tribofilm on piston ring only ranges from 6nm to 16nm. The reason for the large difference in thickness is further explained, which is important for the design of cylinder liner and piston ring.

Keywords: Wear, tribofilms, piston ring and cylinder liner

INVITED

Lubrication Response of Ionic Liquid Water-Based System Induced by Multiple Interactions and Their Interfacial Tribochemical Behavior

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Water-based lubrication has caught wide attention for the advantages of superior cleaning performance, environmental sustainability and saving resources, etc. Nevertheless, water-based lubrication has inherent defects of severe corrosion and poor interfacial film formation, resulting in the limitation for its practical engineering applications. In this work, we innovatively designed and prepared a series of the functionalized structure of ionic liquids (ILs) to develop them into water-based lubrication systems that can meet engineering application requirements, achieving an optimized balance of solubility, high performance, corrosion prevention, and green environmental protection. The interfacial behavior and tribochemical mechanism of IL water-based lubrication systems at engineered metal interfaces are importantly investigated. The functional ILs lubrication additives in this work can significantly enhance the tribological performance of aqueous systems under harsh conditions, providing a theoretical basis for its development in the engineering field.

Keywords: ionic liquid, water-based lubricants, interfacial tribochemistry

Key of The Interfacial Bonding Reaction on Friction Surfaces: A Theoretical Answer to What The Activation Volume Is and How to Compute

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Activation volume emerges as a pivotal concept within the realm of nanotribology, playing a decisive role in shaping the response of interfacial bond formation/breaking reaction rates to applied mechanical force. Currently, activation volume primarily functions as a fitting parameter in reaction-rate theory, presenting a formidable challenge in fully grasping its physical connotations and theoretical computation. In this study, we introduce the innovative concept of inherent stress difference between initial and transition states, originating from the displacement of reacting atoms. Through this introduction, we unveil a universal formula for activation volume. This formula distinctly elucidates the physical significance of activation volume, representing the volume change from initial to transition states. Subsequently, our first-principles calculations of a dehydration bonding reaction system at silica/silica interface successfully validate the proposed activation volume formula across a spectrum of reactions. In summary, this work provides a lucid physical depiction of activation volume and its computational methodology, making a substantial contribution to the foundational understanding of mechanochemical reactions and advancing the field.

Keywords: Interfacial bond, tribochemistry, nanoscale wear, first-principles

Coupling Molecular Dynamics and Fluid Dynamics for Multiscale Fluid in Tribology

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Molecular design is becoming increasingly important for developing environmentally friendly lubricants in the field of green tribology. Grease is a kind of complex fluid, which is consisted by thickener molecules forming reverse micelle in base oil and applied in green tribology such as contact area in bearing in wind turbine or in motor in electric vehicle. Viscosity index improver is a polymer also used in base oil to improve temperature dependence of viscosity. Small molecules such as extreme pressure (EP) agents have polar group in the molecule, so they make large aggregate in oil environment in some case, and tuning the size may be essential for controlling the

surface protecting properties in variant sliding conditions. These functional fluids may be named multiscale fluid, since they are consisted by functional solute such as thickener, polymer, or EP agents in oil solvent. In this presentation we show our multi-physics numerical simulation approach to investigate the dynamics of solute molecules by Brownian dynamics treated by Langevin equation and solvent flow by lattice Boltzmann method. We simulate the motion of solutes in confined spaces and bulk flow. To simulate chemical feature of realistic solute molecules, several models are implemented in the simulator, such as bead-spring model, charged particle model, polar particle model and united atom model. In each case, the Brownian motion of the solute molecules makes very complex velocity field in the whole solution in slow sliding speed. This complexity is crucial for understanding the lubricant's function and goes beyond simple fluid dynamics due to the low Reynolds number involved. We will discuss the physics of multiscale fluids and highlight their applications, such as in viscosity index improvers.

Keywords: Molecular Simulation, Fluid Dynamics, Multiscale Fluid

Dispersion Stability and Tribological Behavior of Nanocomposite Supramolecular Gel Lubricants and Molecular Dynamic Simulation

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Nanoparticles have been well studied as lubrication additives duo to their excellent anti-friction and anti-wear performances. However, its poor dispersion stability in lubricating oil limited their application. To address this problem, diverse of nanoparticles with different morphology, component and size were introduced to supramolecular gels to fabricate a new lubricant system (Nano-Gel) and their chemical, rheological, tribological properties and lubricant mechanism were systematically investigated. Molecular Dynamics showed that gelators with hydroxyl groups adsorbed onto the surface of nanoparticles at the interaction of H-bonding, electrostatic, Van der Waals, which improved the dispersion stability of nanoparticles in lubricants. Besides, the intricate networks of supramolecular gels also have spatial confinement to nanoparticles which further increase their dispersion stability in lubricants. Compared with supramolecular gels, the combination of Nano-Gels showed good anti-friction and anti-wear properties. And the friction coefficient decreased by 35%-50% for different nanoparticles as lubricant additives. The wear volumes of Nano-Gels with different nanoparticles as additives reduced by 85-98%. Additionally, the lubrication mechanism showed that Nano-Gels with mechanical responsive could release base oils and nanoparticles at high shear stress. And they would transfer to the surface of frictional pairs and form tribo-films to increase their tribological properties. The rheological properties have shown that Nano-Gels would self-repair from sol to gel at lower shear stress which restrain nanoparticles aggregating and oils creeping. The soft-nano gel

composites provide effective solutions to the application of nanoparticles in lubricating oil, which have great values to prolong the life of mechanisms.

Keywords: Nanoparticles, Supramolecular gels, Mechanism of dispersion stability, Tribological performance

Effect of Compressive Stress on Tribofilm Formation of Zinc Dialkyl Dithophosphates

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Zinc dialkyl dithiophosphates (ZDDPs) are additives that are well known for their excellent antiwear and antioxidation performance. They are used widely in various industries such as automotive, manufacturing, construction, mining, and agriculture. Although there has been an interest in finding alternative antiwear additives to replace ZDDPs, the mechanisms of ZDDP at the molecular level remain unclear.

ZDDPs protect rubbing surfaces by rapidly forming a thick, phosphorus-rich tribofilm which can prevent the substrates from wearing. Previous studies have shown that ZDDPs can form tribofilm under elastohydrodynamic (EHD) lubrication contacts and it was found that the rate of tribofilm formation increases exponentially with temperature and applied shear stress. The rate is also affected by the alkyl chain structure attached to the ZDDPs.

This study uses the in-situ spacer layer interferometric method (SLIM) on an extreme-traction machine (ETM) to examine the effect of compressive stress on the ZDDP tribofilm growth in steel-steel, ball-on-disc full film EHD contacts. A 4-oil blending method is used to allow independent control of the shear stress, compressive stress, and lambda ratio in the contact. Performances of a primary type ZDDP and a secondary type ZDDP are tested at a fixed lambda ratio. As expected, the rate of tribofilm formation of primary ZDDP is lower than that of secondary ZDDP. It was found that higher compressive stress has either no effect or slightly increases the rate when the applied shear stress is low.

Keywords: ZDDP, tribofilm, mechanisms

Using Molecular Simulations to Predict The Tribology Behavior of Lubricant Additives and Guide The Formulation Design of Lubricant for Titanium Alloy Cutting Fluid

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To efficiently design appropriate lubricant for titanium alloy, molecular simulation method for predicting lubrication properties was proposed. Six kinds of lubricant additives (Oleic acid, OA; Ricinoleic acid, RA; Glyceryl tripalmitate Palmitolein, GTM; Glyceryl tripalmitate Trioleate, GTL; Glyceryl tripalmitate Ricinolein, GRN and Alcohol ether phosphate, AEP) were chosen for prediction. The adsorption configurations of these additives were calculated. It was found that AEP could form chemisorbed film, while the other additives formed lubricating film by physical adsorption. In aqueous medium, AEPE was ionized, and the oxygen without hydrogen ion could form Ti-O-P bond with the pentacoordinate titanium. The unionized AEP could form hydrogen bonds with the dicoordinated oxygen. The adsorption capacity of other five additives was further compared. It was indicated that GRN, GTL and GTM showed similar and higher chemical activity. When adsorbed on titanium alloy, the adsorption energies of GRN, GTL and GTM were higher. So they were presumed to be more likely to form stable lubricating films. Aqueous medium improved the adsorption capacity of these three unsaturated fatty acids by increasing the chemical activity of the ester group at the intermediate position. So it was inferred that they were also more suitable for use as additives in aqueous medium. To verify the validity of this predicted method, corresponding tribological experiments were also carried out. The experimental results were in good agreement with the predicted results. By combining above molecular simulation method with experimental investigation, a water-based cutting fluid (QC-3801) was designed and prepared. The permeability and lubricity of QC-3801 were investigated by tapping torque test and cutting test. Comparing with commercial titanium alloy cutting fluid, QC-3801 was associated with a 16.9% reduction in average torque value, a 23.3% reduction in the increase value of temperature and a 21.6% increase in tool life.

Keywords: Titanium alloy, prediction of tribological properties, molecular simulations

Track 5: Biotribology and Biomimetics

KEYNOTE:

Bio-Inspired Lubrication with Synovial Fluid Constituents and Hydrated Polymer Hydrogels

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Natural synovial joints have attracted many scientists and engineers with their low friction nature during our daily activities. Sliding surfaces of natural synovial joints are covered with soft, porous and highly hydrated articular cartilage and lubricated with synovial fluid which contains a lot of biological molecules including proteins,

phospholipids (PL) and hyaluronan (HA). Many previous studies have been conducted to clarify the detailed lubrication mechanism of our synovial joints. Resent achievements are emphasizing the importance of the boundary lubrication mechanism with synovial fluid constituents while the contribution of hydrated and permeable nature of cartilage tissue have been also highlighted. In this study, highly hydrated polymer hydrogel is used as an analog of the articular cartilage tissue and the lubrication effect of water-based lubricants with synovial fluid constituents is evaluated on it to explore the feasibility of the bio-inspired lubrication system consists of biological macromolecules and a highly hydrated polymer hydrogel.
Results indicated that HA increased the viscosity of the lubricant and reduced friction by increasing the theoretical fluid film thickness. In addition, HA could reduce friction even under the thin film condition with the theoretical film thickness less than 1 mm, probably because large HA molecules were trapped between porous hydrogel surface and the glass counterface and reduced shear resistance. By mixing HA with PL, the friction coefficient under the thin film condition could be reduced further to around 0.01. However, if protein molecules existed in the lubricant, they formed sticky adsorbed and denatured protein film on sliding surfaces and shuttered the lubrication effect of HA/PL complexes. To utilize the excellent lubricating function of HA/PL mixture even in the biological environment containing proteins, novel copolymerized hydrogels with anti-protein adsorption function were developed in this study.

Keywords: hydrogel, hyaluronan, phospholipids

Wall Shear Gradient Dependent Thrombosis and Thrombolysis Studied in Blood-On-A-Chip with Stenotic, Branched, and Valvular Constructions

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Thrombosis is the leading cause of death, while the effect of the shear flow on the thrombosis and thrombolysis in vascular constructions has not been thoroughly understood, and one of the challenges is to observe the origination of thrombus with a controlled flow field. In this work, we use blood-on-a-chip technology to mimic the flow conditions in coronary artery stenosis, neonatal aortic arch, and deep venous valve. The flow field is measured by the microparticle image velocimeter (μPIV). In the experiment, we find that the thrombus often originates at the constructions of stenosis, bifurcation, and the entrance of valve, where the flow stream lines change suddenly, and the maximum wall shear rate gradient appears. Subsequently, ultrasound-assisted thrombolysis (UAT) is conducted on the chip to assess the impact of ultrasound on thrombolysis under varying flow conditions. The study reveals that UAT enhances the thrombolytic rate by 40% in the coronary stenosis chip and by 10% in the deep venous valves chip. This enhancement is attributed to the disruption of crosslinked fibrin fibers by ultrasound, leading to increased urokinase diffusion within the thrombus and accumulation of plasminogen on the fibrinogen α chain. Moreover, the acceleration of the dissolution rate of thrombi in the venous valve chip by ultrasound is not as significant as that in the coronary stenosis chip. Using the blood-on-a-chip technology, the effect of the wall shear rate gradients on the formation of the thrombus and the differential impact of ultrasound on thrombolysis under various flow conditions have been illustrated, which emphasizing the valuable role of the blood-on-a-chip technology in exploring thrombosis and thrombolysis mechanisms.

Keywords: blood-on-a-chip, coronary artery, neonatal aortic arch, deep venous valve, ultrasound-assisted thrombolysis

Delaying Total Knee Replacement: New Implants for Young Osteoarthritis Patients

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Knee osteoarthritis (OA) presents a formidable challenge in the realm of musculoskeletal pathology, particularly affecting the adult population. Characterised by the gradual deterioration of articular cartilage, this chronic disease lacks a definitive therapeutic intervention. The progression of OA is intricately intertwined with the biomechanical loading conditions experienced by the knee joint. Consequently, a comprehensive understanding of these biomechanical factors is essential in formulating effective treatment procedures.

In clinical practice, the management of knee OA often commences with conservative, non-invasive approaches aimed at symptom alleviation and disease progression mitigation, thereby postponing the necessity for surgical interventions, including knee arthroplasty.

For younger cohorts afflicted by knee OA, the consideration of surgical options, notably knee replacement surgery, typically remains a last resort due to concerns regarding prosthetic longevity and the inherent challenges associated with tissue regeneration. Despite the widespread success observed with orthopaedic prostheses in restoring functionality and alleviating discomfort among OA patients, their applicability to younger individuals with localised cartilaginous defects remains suboptimal.

Against this backdrop, ongoing research endeavours at Auckland University of Technology have been dedicated to pioneering innovative implant solutions tailored specifically to the unique needs of younger knee OA patients. These advancements seek to bridge the gap between conservative management strategies and invasive surgical interventions. Noteworthy developments include load-sharing implants designed to mitigate excessive joint loads, thereby minimising stress on compromised cartilage. Additionally, novel implant designs aim to address tissue degeneration by implementing regenerative approaches that preserve healthy tissue, ultimately delaying the requirement for total joint replacement.

By offering patient-specific solutions that minimise the necessity for extensive joint modification, these novel implants represent a paradigm shift in knee OA management. They hold significant promise for early-onset knee OA in active individuals, facilitating the preservation of mobility and quality of life, while deferring more invasive treatment options.

Keyword: Articular cartilage degeneration; Knee osteoarthritis; Patient-specific implants.

Improved Hydration Lubrication of UHMWPE by Polyelectrolyte-embedded Modification for Long-lasting Artificial Joints

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Total knee replacement is an effective remedy for severe osteoarthritis which is a disease bothering hundreds of millions of people in the world. Due to the good biocompatibility, chemical stability and self-lubricating performance, ultra-high molecular weight polyethylene (UHMWPE) has been one of the most popular materials to produce artificial joints. However, compared with articular cartilage, UHMWPE has relatively poor tribology properties of friction and wear, leading to a short service life of only 15-20 years for the replacement. In this work, hydrophilic monomer 3-sulfopropyl methacrylate potassium salt (SPMK) was successfully grafted onto the UHMWPE powders, which was verified by a series of characterizations. Then the modified powders were hot-pressed into homogeneous bulk material with a surface showing larger negative charge density and smaller water contact angle than the pristine UHMWPE, enabling it better hydration lubrication and thus lower friction coefficient and less wear rate. In addition, the enhanced tribology performance could be maintained persistently because the embedded polyelectrolyte would be exposed when the surface was sheared off. This overall modification provides a promising method for the preparation of highly hydrated, long-lasting artificial joints.

Keywords: UHMWPE, hydration lubrication, artificial joints

Friction of Articular Cartilage Surface Lubricated with Synovial Fluid Constituents in Contact with Glass and Hydrogel

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The objective of this study is to determine the effect of different sliding counterface on the frictional exerted on articular cartilage surface lubricated with synovial fluid constituents. Angularly reciprocating tests were conducted on glass-cartilage and hydrogel-cartilage interfaces over a wide range of sliding velocities and extremely low contact loads by Nano tribometer. The contact pair was lubricated with different lubricants containing proteins, hyaluronic acid, and phospholipids as representative synovial fluid constituents to evaluate the lubrication ability of each constituent. Results of the friction test indicated that the coefficient of friction (COF) of cartilage-on-hydrogel sliding pair is significantly lower than the cartilage-on-glass sliding pair. The effect of proteins, hyaluronic acid, and phospholipids on friction coefficient was also depending on the counterface material.

Keywords: articular cartilage, hydrogel, synovial fluid

INVITED:

Improving Wheel/rail Contact Tribology: Case Studies in Going from the Lab to the Field

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Recently the railway industry has become more open to innovation and change in the way it deals with the issues that it faces in terms of wheel/rail interface management which is essential in terms of ensuring a network can be run in a safe and efficient manner. As researchers, it is important that we can deliver for the railway industry and find a route to take our ideas that are successfully proven in the laboratory to implementation in the field to support infrastructure owners and train operators in improving the performance of a network.

This paper gives an overview of work in three areas where initial laboratory tests of an idea were scaled up through full-scale tests before being taken to the field. They show how the transition from fundamental research at a low Technology Readiness Level (TRL) can be translated to higher TRLs and implemented on track to ensure benefit for infrastructure owners and train operators. They have addressed different areas of concern for the railway industry, but all relate to the wheel/rail interface:

1. Laser Cladding of Rail to reduce plastic flow, wear and rolling contact fatigue (RCF)
2. New Conductive Traction Enhancing to overcome issues of isolation leading to track circuit disruption
3. TOR Friction Management – to enable intermediate friction in the wheel/rail contact to be achieved to reduce damage, energy consumption and noise

Keywords: wheel/rail interface, laser cladding, friction management

Construction and Application of The Dynamic Swallowing Model Based on Medical Image Data

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Dysphagia is a common condition in older adults. One of the most common treatments is swallowing exercises, and combined with thickening foods. However, the mechanism of swallowing is still not fully understood since the process of swallowing is a complex interaction among organs and the food bolus. Simulation is a non-invasive method of observation, and can directly observe the movement of the bolus in the oral and pharyngeal cavity. Therefore, this study constructs the model of swallowing movement based on medical data to explore the swallowing mechanism. This model combines computed tomography (CT) and TV fluorescence swallowing study (VFSS) image data from the healthy volunteer. All organs and food boluses are modeled using the Finite Element Method (FEM) and smooth particle hydrodynamics (SPH), respectively. The effectiveness of the swallowing dynamics model was quantitatively assessed by the brightness of the epiglottis area. On this basis, different swallowing symptoms was simulated by adjusting the angular velocity of the epiglottis. The results showed that the probability of aspiration could be increased with the reduction of angular velocity of the epiglottic. Moreover, the rotation of the epiglottis appears to increase lingual palatal pressure, thereby assisting food swallowing. These results will provide better insight into the rehabilitative exercises and the development of food for special medical purpose.

Keywords: Dysphagia, VFSS, Finite element method, Effectiveness evaluation, Epiglottis rotation

Novel Biomimetic Synthetic Injectable Macromolecular Materials for Efficient Lubrication Treatment of Osteoarthritis

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The emergence of injectable joint lubricants has provided a new treatment option for patients with osteoarthritis (OA). These synthetic injectable macromolecular materials can effectively improve the lubrication performance of joint surfaces, reduce joint wear, and alleviate pain. In this study, we targeted natural sugar-based biopolymer chitosan for modification, and chemically modified its side chains through amide bond reactions and free radical-initiated polymerization strategies. By grafting natural peptides and hydrophilic monomers onto the main chain of chitosan molecules, we prepared bottle-brush type joint lubricants that exhibit excellent lubrication and antimicrobial properties. Additionally, using chitosan nanoparticles as cores, we loaded drug molecules such as

diclofenac sodium and aspirin, which have therapeutic effects on arthritis, and modified the surface of the nanoparticles with hydrophilic small molecules to prepare particle-type biolubricants with drug-loading therapy and lubrication functions. Different types of joint lubricants demonstrated extremely low friction coefficients in tribological tests, animal experiments and cytotoxicity tests showed that the prepared joint lubricants have good biocompatibility and antimicrobial properties. These biolubricants provide a new and timely strategy for the treatment of OA.

Keywords: Osteoarthritis treatment, synthetic biomacromolecule, lubrication

Design, Preparation and Application of Near-Infrared Responsive Gecko-Inspired Bionic Surface

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The bionic surfaces based on gecko toe arrays have excellent adhesion and easy desorption properties, which make them demonstrate unique value in aerospace, bio-medical, gripper and soft robotics fields. In this presentation, we successful fabricate near-infrared responsive gecko-inspired bionic surface (NIR-GS), which has both excellent infrared-responsive and dynamic attachment-detachment characteristics. The NIR-GS is formed by the combination of infrared responsive driving hydrogel layer and strong adhesive bionic surface through the surface modification strategy of free radical polymerization. And under the 808 nm near-infrared light irradiating, the temperature of driving hydrogel layer can be increases from 17.9 °C to 107 °C within 30s, and the curling angle can be curled by 0 ° to 180°, similar to the folded state. Another microstructure gecko-inspired adhesive bionic surface can withstand a maximum shear force of 22.4 N/cm^{-2}. Through the experiments, the correlation law of materials ratio, preparation parameters and microstructure evolution in the heterogeneous interface bonding process will affect infrared responsive and adhesion characteristics of NIR-GS. Finally, the NIR-GS was structurally optimized to prepare a four-arm gripper that could grasp/release only by unilateral irradiation. And the gripper grasps an object in about 120 s and release it in about 60 s. This work can provide solution for the requirement of adhesive bionic surfaces to response external stimuli, in addition, it may also show technological ideas and technical support for designing, fabricating and functional regulation of multi functions and structures bionic surfaces.

Keywords: Bionic surface, Heterogeneous interface combination, Flexible arm gripper

Track 6 Nanotribology and Superlubricity

KEYNOTE

Biotribology – How Nature Does It

Jacob Klein
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Lubrication in living organisms is essential for their well-being. Over evolutionary times nature has optimized its lubrication mechanisms, to provide a reduction of friction across sliding tissues that is more effective than between any man-made surfaces. Understanding and making use of this will not only help common pathologies such as osteoarthritis and dry-eye syndrome, but can point the way to creating better-lubricated materials crucial for advanced biomedical devices. This talk reviews recent progress in biotribology and looks ahead to how nature's optimal lubrication solutions may be teased out and exploited.

KEYNOTE

Hydrogen Induces Ultra-Low Friction in Friction Systems Using Carbon-Based Coatings

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In the friction system involving hydrogen-containing carbon nitride coating and silicon nitride, we observe exceptionally stable friction with a friction coefficient of approximately 0.01 or less at elevated temperatures in an air environment. Under these conditions, a tribofilm several nanometers thick, primarily composed of carbon and believed to exhibit orientation, forms on the surface of the silicon nitride. The presence of hydrogen termination, derived from water molecules in the atmosphere, in conjunction with high temperature, is crucial for the formation of this tribofilm.
Conversely, even in low humidity environments where low friction is not observed with hydrogen-free carbon nitride coatings, the hydrogen-containing carbon nitride exhibits remarkably stable low friction due to the formation of the aforementioned tribofilm. This finding clearly indicates the significance of hydrogen within the carbon nitride coating.
Furthermore, in low humidity conditions, when a hydrogen-free carbon nitride coating is rubbed, introducing hydrogen gas into the atmosphere results in the formation of the tribofilm, which leads to extremely stable low friction.
Based on the various results obtained thus far, I would like to present the pivotal role that hydrogen plays in achieving ultra-low friction through the formation of a nanometer-scale tribofilm in friction systems utilizing carbon nitride coatings.

Keywords: ultra-low friction, nanointerface, carbon-based coatings

Hydration Layer Structure Modulates Superlubrication

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Water-based lubricants provide lubrication of rubbing surfaces in many technical, biological, and physiological applications. The structure of hydrated ion layers adsorbed on solid surfaces that determine the lubricating properties of aqueous lubricants is thought to be invariable in hydration lubrication. However, we prove that the ion surface coverage dictates the roughness of the hydration layer and its lubricating properties, especially under subnanometer confinement. We characterize different hydration layer structures on surfaces lubricated by aqueous trivalent electrolytes. Two superlubrication regimes are observed with friction coefficients of 0.0001 and 0.001, depending on the structure and thickness of the hydration layer. Each regime exhibits a distinct energy dissipation pathway and a different dependence to the hydration layer structure. Our analysis supports the idea of an intimate relationship between the dynamic structure of a boundary lubricant film and its tribological properties and offers a framework to study such relationship at the molecular level.

Keywords water-based superlubricity, hydration effect, ion adsorption, hydration layer structure, confined viscosity

New Superlubricity Systems of Highly Concentrated Solutions and Ionic Liquid Analogues

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Lubricating materials have become a research focus in the field of tribology due to their ability to save energy and reduce emissions by reducing friction and wear (i.e., improve machine performance/extend lifespan). Among them, superlubricating materials with almost ideal lubrication performances ($\mu < 0.01$) have become a hot topic in friction research. Compared to the harsh conditions (e.g., vacuum/inert gas atmosphere, micrometer size, incommensurable contact, and absolute surface rigidity) required for solid superlubricating materials, liquid superlubricating materials can achieve relatively stable superlubricity under atmospheric environments, macroscopic scales, and conventional flat surfaces. Though there are quite a lot of liquid superlubricity systems (e.g., typical acid/alcohol-based, hydrated alkali metal ions, ionic liquids, and

solid/liquid coupling materials), they all possess the following commonalities: 1) ultra-low shear resistance sliding interfaces due to weak interactions between molecules and ions; 2) adsorption film/tribochemical film/transfer film formed by strong interaction between liquid materials and friction pairs. Therefore, based on the above two understandings, new macroscopic liquid superlubricity systems are constructed with highly concentrated aqueous solutions (e.g., graphene/concentrated KOH, MgO/LiTFSI, and $ZnCl_2$ concentrated solutions) and ionic liquid analogues (e.g., ChCl/$MgCl_2$•6H_2O, ChCl/triethanolamine, unequal-sized CDs additives/ChCl+Gly, and unequal-sized PMMA additives/$ZnCl_2$+EG). These studies have deepened the understanding of the formation mechanism of low shear sliding interfaces in the new liquid superlubricity systems, laying a foundation for promoting the application of liquid superlubricating materials.

Keywords liquid superlubricity; highly concentrated solutions; ionic liquid analogues

Probing Microstructure and Nanofriction of Confined Ionic Liquids Using Colloid Probe AFM

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Ionic liquids (ILs) are room-temperature molten organic salts that consist of cations and anions and they were initially discovered as high performance synthetic lubricants in 2001. There has been experimental and theoretical evidence suggesting that the ion structures of near-surface ILs are peculiar, leading to significantly different nanofrictional behavior from the bulk. Atomic force microscopy (AFM) provides a good measure to investigate the microstructuring and frictional phenomena of ILs at the nanoscale, in which, the confined ILs between the AFM probe and the supporting solid substrate is subjected to a normal load. The microstructure of the near-surface ILs are synergistically influenced by the complex characteristics of the IL–solid interface, i.e., the solid surface features, the ILs nature and the external environment, resulting in completely different nanofrictional behavior. Therefore, the resulting nanofriction differs at varying IL–solid interfaces, without rules to follow, difficult to quantitatively control and predict, which becomes a bottleneck for optimizing and screening ILs-based lubricants. This work uses colloid probe atomic force microscopy (CP-AFM) to mimic the solid surface features to study in situ changes of the microstructure and the associating nanofriction of confined ILs. And the interaction of ILs with the solid surface is further quantified, which can be derived as force field parameters in the coarse-grained molecular dynamics simulation to predict the diffusion of the confined ILs. It is expected to guide the building of structure–property relationship to effectively design and screen ILs-based lubricants.

Keywords AFM; colloid probe; ionic liquid; nanofriction; microstructure; quantify

KEYNOTE

Design of Macroscale Solid Superlubrication Towards Engineering

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Superlubricity is a frontier subject in tribology research. From a theoretical perspective, it refers to the phenomenon where the frictional force between objects in relative motion approaches zero; From an engineering perspective, it refers to the reduction of friction coefficient by 1-2 orders of magnitude compared to traditional lubricants, reaching the level of 0.001 or below. The breakthrough of superlubricity technology is expected to promote the revolutionary progress of industrial technological civilization, but there are still many challenges in obtaining macroscale superlubricity performance. Based on the three superlubricity principles of hydrogen passivation of amorphous carbon films, incommensurate structrual superlubricity and molecular rolling, this report provides some innovative research ideas such as the designs of medium-range ordered structure, heterostructure and self-curling rolling lubrication, and the relevant research progresses are introduced.

Keywords superlubricity, macroscale, solid lubrication

INVITED

Unveiling the Layered Structure of Sulfobetaine Polymer Brushes through Bimodal Atomic Force Microscopy

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Many zwitterionic polymer brushes exhibit highly stimuli-responsive properties stemming from the strong dipole and electrostatic interaction of their building blocks. Here, we showed how a combination of two atomic force microscopy (AFM) modes can reveal the layered structure of poly(sulfobetaine methacrylate) brushes synthesized by surface-initiated atom transfer radical polymerization. Due to polydispersity and anti-polyelectrolyte effect, a diffused layer emerges on top of a condensed layer of the brush as a function of salt concentration. The amplitude-modulation mode of the AFM, owing to the tip's dynamic motion, can only probe the more stable condensed layer near the substrate, whereas the force spectroscopic mode with its high sensitivity can accurately detect the diffused layer and hence determine the total brush thickness. Infrared (IR) spectroscopy and quartz crystal microbalance (QCM) monitoring revealed the strong ion-screening effect and higher brush hydration propensity of multivalent

ions. Different cations and anions also showed different effects on the structure and tribomechanical properties of the zwitterionic PSBMA brushes.

Keywords AFM, zwitterionic polymer brushes, tribomechanical properties

Disparate External Electric Field Effect on the Adsorption and Shear Behavior of Monovalent and Trivalent Ions in Electrolyte Solution

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Hydrated ions exhibit excellent lubrication performance on the charged solid surface, due to the high load-bearing capacity and extremely low shear strength. Although charged friction pairs such as mica and PTFE have been commonly used in ion lubrication research, in actual working conditions, friction pairs are sometimes at low charge density and as an alternative external electric field is needed. In this work, we used the electrochemical module of atomic force microscopy (EC-AFM) to regulate the charge density on the surface of the friction pair and found that the lubrication behavior of multivalent ions was significantly different from that of monovalent ions. After the AFM in-situ variable potential force curve analysis and the double layer Poisson-Boltzmann and its derivations analysis, we developed a systematic and quantitative model to explain the different frictional behaviors of solutions. The effect of applied voltage， solution with different concentrations and ion compositions on the surface electrical properties, Stern layer structure, and ions segregation near surfaces are revealed. The result provides a theoretical basis for surface charge adjustable ion lubrication, and expands the application prospects of ion lubrication.

Keywords electrochemistry; lon valency; adsorption

Effect of Surface Oxidation on the Adsorption and Friction Properties of Oiliness Additives Evaluated by Atomic Force Microscopy

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2. Kobe Steel, Ltd, Japan

To comprehend the friction properties of sliding surfaces, exploring the adsorption tendencies of lubricant additives onto these surfaces becomes imperative. This adsorption characteristics are influenced not only by the type of metals and additives used but also by the condition of the sliding surface. Previous research has shown the significant impact of oxidation on metal surfaces, which in turn changes the adsorption

characteristics of additives, consequently affecting friction properties. In this study, nanotribological tests were performed on metal surfaces immersed in lubricant using atomic force microscopy. To investigate the influence of surface oxidation on friction properties, the oxidized metal surface was previously worn by a point-probe cantilever, thereby exposing the pure metal surface in the lubricant environment. Subsequently, lubricant with additives was dropped to both the oxidized and pure metal surface areas, followed by friction testing in each zone to ascertain any discernible differences in friction properties arising from surface oxidation.

Keywords surface oxidation, nanotribology, oiliness additive

Symposium 2: Triboelectric Nanogenerators for Energy and Sensors

KEYNOTE

Explore and Utilize The Human Body's Triboelectrification for Energy Harvesting and Sensing

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The human body does many physical movements that contain a large amount of information representing a person's: emotions, physical condition, moods, etc. When doing these movements, interactions with surroundings such as cloth, socks, shoes, doors, tables, etc., generate triboelectric charges on the human body due to the skin's high positive charge affinity. By analyzing the changes in the triboelectric charges on the human body, and the interaction of the charge with other devices, we can gain much information about the human body and realize interactions with devices. Results from our lab have shown that the generated triboelectric charges could be an energy source for powering small electronics, a signal source for human-computer interaction, and digital security. Potential application in biomedical applications is expected in the near future.

Keywords: the human body, triboelectrification, sensors, human-computer interaction, digital security

Micro-Nano Electromechanical System Based on Piezoelectric Microfluidics and Triboelectric Self-Sensing

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This article mainly develops a self-sensing piezoelectric micropump based on the triboelectric nanogenerator, which constructs an integrated driving-sensing-detection microfluidic system, and utilizes active microfluidic method to achieve point-of-care testing (POCT) technology innovation. According to 'Global Point of Care Testing Market Outlook 2022', the global POCT market scale has reached $30 billion. This article focuses on the development direction of digitalization, intelligence, miniaturization, and integration of microfluidic technology. Based on the piezoelectric micropump, the triboelectric nanogeneration technology is integrated, in which the integrated triboelectric nanogeneration unit is used to realize the real-time sensing and closed-loop control of the flowrate of piezoelectric micropump. The multidisciplinary research on the coupling mechanism, fusion design method, and adaptive control strategy of the triboelectric self-sensing unit and piezoelectric micropump is carried out to solve the mathematical mapping problem between the driving signal, flowrate, and self-sensing signal, as well as the optimal control problem of the complex nonlinear electromechanical coupling system, so as to construct the design-modeling theory system of the self-sensing piezoelectric micropump, which can solve the bottleneck of quantitative, controllable, accurate, and efficient transportation of microfluidics closely related to the application of advanced microfluidic equipment, laying a theoretical foundation for its application in future frontier fields and major engineering.

Keywords: triboelectric nanogenerator, self-sensing, piezoelectric microfluidic, friction, sensor, MEMS

Super-Low Friction Electrification Behavior and Mechanism of The PTFE Films Under Liquid Lubrication

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The novel proposal of Wang's triboelectric nanogenerator (TENG) has inspired extensive efforts to explore energy harvesting devices from the human living environment for the upcoming low-carbon society. The inevitable friction and wear problems of the tribolayer materials become one of the biggest obstacles for attaining high-performance TENGs. To achieve super-low friction electrification of the TENGs, the tribological and electrical behaviors of the sliding-mode TENGs based on the polytetrafluoroethylene (PTFE) films and metallic balls under liquid lubrication conditions were investigated by using a customized testing platform with a ball-on-flat configuration. Specifically, the average friction coefficient of the PTFE films running against a steel ball decreased to 0.027 under a pure silicone oil lubrication condition. It was further decreased to 0.016 when lubricated by silicone oil with the doping of graphene nanosheets at a mass fraction of 0.005 wt%. Most interestingly, a super-low

friction coefficient of 0.008 was achieved under graphene-doped silicone oil lubrication with the optimized high load of 10 N and high sliding speed of 1000 mm/s. The corresponding wear rate of the PTFE film was drastically decreased to 8.19 × 10−5 mm3/Nm, which was approximately half of that lubricated by pure silicone oil. Thus, it was claimed that the ultra-low wear rate of the PTFE film was achieved together with the super-low friction behavior. Simultaneously, the output short-circuit current and open-circuit voltage were enhanced by 6.8 times and 3.0 times, respectively, compared to the dry friction condition. The excellent triboelectrical performances of the PTFE films sliding against steel balls are attributed to the synergistic lubricating effects of the silicone oil and graphene nanosheets. The current research provides valuable insights into obtaining superlubricity of the lubricated-TENGs and paving the way for the design of high-performance superlubric TENGs.

Keywords: triboelectric nanogenerator, liquid lubrication, PTFE, super-low triboelectrification

Self-Powered Sensor System for UAVs Based on Triboelectric Nanogenerator

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At present, unmanned aerial vehicles (UAVs) are widely studied by scholars at home and abroad as an important part of low-altitude economy. With the wide application of UAVs in various industries, new requirements have been put forward for UAV sensing systems. Considering the duration of the UAV in flight, externalisation of the UAV with conventional commercial sensors requires additional energy supply to the sensors, which indirectly limits the duration of the UAV. Triboelectric nanogenerator has the property of converting mechanical energy into electrical energy, which provides a new idea for self-powered sensing in UAVs. At the same time, combined with the UAV's detection of the external environment as well as its own state, we attribute it to external sensing and internal sensing. The external sensing mainly consists of the wind speed sensor, two different structures of wind speed sensor are designed, and the sensor structure and signal acquisition system are optimised and upgraded according to the working conditions of the UAV. On the other hand, in combination with the internal sensing of the UAV specifically including: acceleration of the UAV during the cruise phase, vibration condition of the motor part and online monitoring of the rotor speed of the UAV, the X and Y axis acceleration detection of the UAV in the cruise state, the vibration of the motor part of the UAV in advance warning and the closed-loop rotor speed on-line detection of the rotor speed of the UAV, respectively. The above work is combined with the actual flight conditions of the UAV and the corresponding structural design and signal processing, and finally the UAV was carried out by the above sensing system, and good results were achieved.

Keywords: self-powered system, UAV, triboelectric nanogenerator

Track 8 Aerospace and Ocean Tribology

KEYNOTE

Tribology of Carbon-Based Coatings for Lightweight Components under Demanding Conditions: High Humidity, Temperature, and Electrical Current

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Diamond-like carbon (DLC) coatings, such as amorphous carbon (a-C) and hydrogenated amorphous carbon (a-C), provide low coefficients of friction against aluminum, titanium, and magnesium alloys. These coatings reduce material transfer and adhesion, enhancing the wear performance of components made from these materials. However, optimizing DLC applications for different environmental conditions requires further investigation. This presentation examines the stability of DLCs in humid atmospheres and discusses the role of silicon and fluorine as stabilizing agents. It also addresses the effects of these coatings on the efficiency of minimum quantity lubrication machining of aluminum and titanium alloys. Additionally, the presentation will focus on the high-temperature performance of tetrahedral amorphous carbon (ta-C) and tungsten-, titanium- doped amorphous carbon coatings. It will analyze the tribological behaviour of these coatings at the microstructural and atomistic levels, utilizing friction and wear maps. As the aerospace industry progresses towards the integration of more electric aircraft (MEA), assessing the performance of these coatings under electrical conditions becomes important. The presentation will cover experiments that measure wear and friction of DLCs under various electrical currents, with a focus on mechanisms such as pitting, oxidation, and graphene formation on wear tracks. Overall, these investigations aim to provide a base for enhancing the manufacturing, and utilization of these coatings in aerospace components subjected to demanding environments.

Keywords: carbon-based coatings, friction, wear

KEYNOTE

Superlubrication Microcapsules

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Superlubricity is vitally desirable for the high efficiency, strong stability, long lifetime, and environmental protection in the service of engineering applications, and solid-

liquid coupling microcapsule develops a novel method to realize the ultra-low friction for composite components without requiring external lubricants. Herein, the macroscale superlubricity (friction coefficient of 0.0062) with very short running-in period (< 20 s) was firstly achieved on the polymer-based composite surface at ambient conditions by combining superlubrication theory and microcapsule technology, in which the prepared polytetrafluoroethylene @ polymethyl methacrylate (PTFE@PMMA) nanocapsules and poly alpha olefin/organic molybdenum @ polyimide (PAO/MODTC@PI) microcapsules served as matrix and filler, respectively. Comparative experimental and numerical analysis corroborate that the force-thermal coupling action at the frictional interface promoted the rupture PAO/MODTC@PI microcapsules and the decomposition of MODTC to form the lubricating oil film of PAO and the boundary adsorption tribofilm mainly composed of organic carbon chain molecules (R2N), which prevented the original asperities from direct contact and provided an ultralow shear strength. Furthermore, the micro-amount oil (< 0.02 μL) released by microcapsules facilitated a more reliable superlubrication state due to the reduced adhesive meniscus effect from liquid bridge compared with that by traditional drip lubrication. These findings provided fundamental insights into the nature of tribological mechanisms and suggested a new strategy to achieve the superlubrication for composites in engineering.

Keywords: superlubricity, microcapsules

Improved Tribological Characteristics of Pure Graphite in liquid Nitrogen Resulting from Cryogenic Mechanical Properties

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In this study, with the application background of the shaft-end graphite seal rings of liquid rocket turbopumps, cryogenic tribological behaviors of pure graphite in liquid nitrogen were tested on a self-developed tribometer and reproduced by molecular dynamic simulations. As a brittle material, tribological performance of pure graphite, cooled by liquid nitrogen, exhibits unexpected improvements in friction and wear characteristics compared with room-temperature conditions. The hardness results exhibit that the toughness becomes much better in liquid nitrogen. Molecular dynamic simulations are conducted to reveal the underlying mechanism and reproduce the flake-like wear debris. The cooling of liquid nitrogen could suppress the thermal vibration of atoms, leading to a decrease in atomic distance and an increase in atomic interaction. Macroscopically, the cryogenic mechanical properties were improved significantly, resulting in the observed abnormal tribological behaviors.

Keywords: cryogenic tribological behaviors, pure graphite, liquid nitrogen, molecular dynamic simulations

Molecular Dynamics Simulation and Characterization of Metal Migration and Friction Behavior at The Interface of Antimony-Graphite Immersed with C/Sb20% at High Temperature and High Pressure

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The research commenced with the synthesis of antimony-impregnated graphite composites, designated as C/Sb20%, incorporating 20% by weight of antimony. These specimens were subjected to a battery of tests employing Rtec MFT 5000, a state-of-the-art high-temperature, high-velocity friction testing apparatus. Employing a suite of sophisticated analytical tools, including EDS, TEM, and XRD, this investigation provides a detailed examination of the C/Sb20% samples, focusing on their surface morphology, microstructure, elemental composition, and lattice parameters. Furthermore, through the deployment of molecular dynamics simulations, this paper elaborates on the construction of both planar and spherical models of the tungsten carbide (WC) structure alongside a comprehensive structural model of C/Sb20%. Leveraging the canonical ensemble (NVT) and a diverse array of potential functions, including Morse and embedded atom model (EAM)/alloy potentials, the study delves into the wear dynamics and sliding friction phenomena at the interface of the C/Sb20% friction pairs. Notably, findings from the simulations reveal a dramatic decline in antimony concentration within the C/Sb20% samples, plummeting from an initial 19.6% to 6.89% over an experimental period of 4000 seconds, signaling a substantial depletion of antimony. Concurrently, the emergence of Sb_2O_3 and Sb_2O_5 oxides was observed, indicating oxidative phenomena. Further elucidation from FIB-TEM analysis confirmed that the antimony lattice within the C/Sb20% consistently exhibited a face-centered cubic (FCC) configuration. Integrating insights from molecular dynamics simulations with SEM analyses conducted before and after experimentation, this study unveils the extraordinary activity and "softening" of antimony flake structures under extreme conditions. This transformation, from flake to agglomerated forms, coupled with sliding friction, leads to the disruption of the graphite's internal structure, facilitating the continuous efflux of antimony and, consequently, diminishing the structural integrity of the graphite. This degradation not only compromises the graphite's mechanical properties but also escalates the risk of secondary wear through the formation of metallic oxides.

Keywords: friction, graphite, molecular dynamics

KEYNOTE

Study on The Preparation and Lubricated Performance of Bionic Lignum Vitae Composite Materials for Water-lubricated Bearing

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The water-lubricated bearing is one of the most important constituents of the propulsion system, and significantly affects safe operation. However, due to the low viscosity of the water, the lubricated performance of the water-lubricated bearing materials is poor especially under harsh working conditions. Lignum vitae have been used as water-lubricated bearing material at the earliest and is proved to have good self-lubricated property, but its application is limited by resource scarcity. In this case, Lignum vitae is used as the bionic objects to improve the lubricated performance of the water-lubricated bearing materials. Firstly, three representative kinds of wood have been used to study the influence factors on the lubricated performance of wood through a series of experiments. According to the experimental results, the mechanical properties and the extractives are considered to be the main factors affecting lubricated performance. After that, four different kinds of Lignum vitae-modified materials have been developed and the previous guess has been verified through a series of experiments. At last, the bionic functional units are extracted according to the above study. Three different kinds of bionic fibers including thermoplastic polyurethanes (TPU) fibers, liquid polydimethylsiloxane (PDMS) prepolymer/TPU core-shell fibers and solidified PDMS/TPU core-shell fibers are designed and the bionic samples are manufactured further. The lubricated performance experimental results indicate that the bionic samples present far better lubricated performance than the Lignum vitae under dry frictional and heavy-load working conditions. In specific the PDMS/TPU fibrous membranes bionic samples achieves the maximum reduction of 73.0% and 98.7% in friction coefficient and wear volume, respectively under dry frictional conditions, and 60.3% in wear volume under heavy-load water-lubricated conditions compared with the Lignum vitae. This study aims to provide a novel route to improve the lubricated performance of water-lubricated bearing materials.

Keywords: water-lubricated bearing, lignum vitae, lubricated performance

Study on Dynamics of Cavitation Collapse and Cavitation Erosion Mechanism

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Cavitation refers to the process of cavitation expansion and collapse in the liquid or at the liquid-solid interface when the local pressure of the liquid is reduced to the critical value of its saturated vapor pressure. Cavitation is the direct manifestation of material damage and destruction. Polymer materials have the advantages of low density, high strength and toughness, corrosion resistance and excellent self-lubricating properties, and are used as friction pair materials for water-lubricated bearing in water environment. However, cavitation erosion damage occurs on the surface of polymer materials under long-term service, and the cavitation erosion resistance of different polymer materials is also very different. The collapse dynamic process of a single cavity was simulated from the microscopic atomic scale, and the collapse mechanism of the microscopic cavity was revealed. It was found that the higher the impact velocity, the shorter the cavitation collapse time and the higher the jet velocity. Secondary water hammer impact will be formed after cavitation collapse and jet formation. When the velocity of water molecules is 3.5km/s, the impact pressure reaches 25GPa. In addition, the cavitation damage mechanism of different polymer materials was revealed by hydrodynamic simulation and vibration cavitation test.

Keywords: cavitation, polymer, friction pair

Effect of Particle Type and Size in Water on The Performance of Surface Texturing in Friction and Wear Reduction

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Water as a lubricant offers several advantages, including being non-polluting, widely available, and energy-saving. However, in river and ocean environments, water inevitably contains various types and sizes of particles or dust. The presence of surface textures could enhance the tribological performance of the system. Unfortunately, most studies in this field only focus on the tribological properties of surface textures in water lubrication, neglecting the influence of particles in water. Consequently, this study investigates the tribological behavior of tungsten carbide-textured samples with different types and sizes of particles. To examine the influence of particle type, three different particles (silica, alumina, and diamond) were selected for experimentation due to their varying hardness. The study also explores the interaction between texture size (depth of 15 μm) and particle size (5 and 25 μm). The experimental results indicate that surface textures effectively reduce the friction coefficient and wear rate for samples containing different types and sizes of particles. Softer particles are more prone to being crushed, allowing them to enter the friction interface and fill the textures more easily. Additionally, smaller particles (5 μm) have a greater tendency to enter the friction interface and facilitate rolling compared to larger particles (25 μm), leading to increased three-body abrasion.When the particle size is 5 μm or smaller than the texture depth (15 μm), the textures are successful in trapping the particles, thereby reducing abrasive wear. However, the depth of the texture becomes shallower, compromising the friction-reducing efficiency of the texture. Conversely, when the particle size is 25 μm or larger than the texture depth of 15 μm, the particles become embedded in the texture, resulting

in impact wear. This study offers novel insights into reducing friction and wear in samples containing water with varying types and sizes of particles.

Keywords: particle, surface texturing, water lubrication

Experimental and Numerical Study on Oil Leakage Flow Characteristics of Carbon Seal in Bearing Chamber

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Leakage of lubricating oil from carbon seal system of bearing chamber caused by insufficient seal pressure from compressor and excessive oil supply pressure of bearing chamber has an important effect on operational stability of aero-engine. Based on air-bleeding oil-sealing mode, an experimental device was designed and built to simulate structure and working environment of the carbon seal system in bearing chamber of an actual aero-engine. A numerical solution model of the carbon seal system was also established to investigate lubricating oil leakage flow characteristics. Evolution process of the oil leakage flow was visually observed. Effects of rotor speed and oil temperature on the critical oil-sealing pressure difference were further studied. Leakage flow mechanism of oil through the carbon seal system in bearing chamber was revealed. Results show that with gradual decrease of sealing pressure difference, the lubricating oil leaked initially from bottom of carbon seal ring, and in turn underwent four processes, i.e., infiltration and backflow, increased infiltration, droplet-like leakage and fluid-like leakage. Value of sealing pressure difference corresponding to that the droplet-like leakage occurred was considered as critical oil-sealing pressure difference of carbon seal system in bearing chamber. As rotor speed decreased from 12500r/min to 4000r/min, lower centrifugal force of oil in respond to lower rotor speed made seal clearance to be filled with more oil, resulting in the increasing critical oil-sealing pressure difference from 4.1 KPa to 29.28 KPa. With decreasing lubricating oil temperature from 121℃ to 40℃ progressively, density and dynamic viscosity of the oil increased, gravity and viscous acting on the oil increased, accumulation of the oil in seal clearance also increased, which further led to increase of the pressure difference from 4.96KPa to 29.28 KPa.

Keywords: carbon seal, leakage flow, critical oil-sealing pressure difference

New Findings Regarding High-Temperature Materials

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The urgent challenge of reducing CO2 and climate-damaging emissions in the transport sector necessitates exploring alternatives, particularly in the utility vehicle domain. This study delves into the thermal management of heavy-duty commercial vehicles, focusing on flap systems crucial for emission control and wear-resistant brake systems. Employing cobalt-based materials, Tribaloy T-400 and T-800, in an oscillating friction wear tribometer with a high-temperature test chamber, the research evaluates their tribological behavior in the temperature range of 600 °C and above. The findings showcase improved tribological performance, with glaze layers forming at higher temperatures demonstrating wear-protective effects. Significantly, heat treatment at 600 °C and 800 °C emerges as a key factor influencing wear characteristics. T-800 pairings exhibit a notable reduction in wear, irrespective of the manufacturing process. Introducing the concept of "self-healing" of glaze layers through targeted transient temperature control, the study reveals potential advancements in reducing wear by up to 99 % and improving friction by up to 35 %. Considering manufacturing processes and material choices, the research provides industry-wide recommendations for optimizing real systems, emphasizing temperature, manufacturing processes, and material selection as key influencing factors.

The findings from the studies carried out can now be used to derive specific recommendations for action across all industries with the aim of optimizing state-of-the-art real systems. The focus should be on the technical usability of the influencing factors found - temperature, manufacturing process and material selection.

Keywords: tribotesting, glaze layer, high-temperature wear

A Novel Tribometer for Aircraft Engine Nozzle Actuation System under Heavy Load and High Temperature

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The aircraft engine thrust vectoring nozzle, pivotal for adjusting the exhaust jet's exit area and direction, significantly enhances aircraft maneuverability. The actuation system's primary wear components, including cam-roller, spherical pair, and pin, operate under the extreme conditions of high temperature and heavy load, necessitating reliability over tens of thousands of cycle movements. The conventional pin-on-disc tribometer prescribed by the ASTM G99 standard, while useful for evaluating the wear characteristics of components at equivalent loads and temperatures, fails to replicate the wear coupling effects between different moving pairs at the system level. A novel system-level tribometer designed for the aircraft engine nozzle actuation system is presented, featuring an integrated motion-loading module, a heating and cooling module, a fixture module, and a control and data acquisition module. This design facilitates the precise replication of motion under heavy load and stable temperature control of different zones. Initial testing has revealed the phenomenon of roller sticking, characterized by alternating sliding/rolling motions to be caused by severe abrasive wear between the roller's inner surface and the liner, identifying failure mechanisms beyond mere surface wear. The innovation of employing a system-level tribometer over traditional component-level assessments offers a comprehensive evaluation of complex motion couplings and failure mechanisms in real-world scenarios.

Keywords: tribometer, heavy-load, high-temperature, extreme condition, nozzle

Track 9 Industrial Tribology and Instruments

KEYNOTE

Innovation Management for Tribological Solutions

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Machines have advanced remarkably in just two hundred years, freeing people from hard labor and providing us with convenience and comfort. In the future, machines will be able to do more and more with their intelligence, freeing mankind from mechanical labor, including clerical work. We can expect to see a world in which working hours are reduced and people can enjoy both labor and leisure. For the time being, there will be three tasks for humans: product innovation to create new products and services, process innovation to have machines perform the mass production of those products and services, and operations where humans perform the parts that machines cannot yet perform. Tribology has supported the development of machines through improving their durability, reducing energy loss due to friction, and reducing machine noise and vibration. Tribology will play an increasingly important role in the pursuit of human happiness by accelerating mechanical civilization while preserving the global environment for future generations. For example, innovations in life expectancy prediction and repair are needed for machines to be able to diagnose their own remaining life span and repair themselves. For now, fortunately or unfortunately, AI is unable to innovate, so humans will need to innovate. Innovation based on the creative thinking skills of engineers is the key to essentially solving tribological problems. We would like to introduce an example of organizational efforts to generate innovation. In order to draw out the creativity of engineers, we defined the concept of "digital twin with emphasis on the real," and made all engineers in the company aware of it. This is the process of creating solutions that break through stereotypes by looking inside real phenomena, grasping them in detail, and creating models to understand the essence of

what is not visible in the actual thing alone.

Keywords: innovation, management

Wear Debris Image Segmentation Algorithm Based on Wavelet Modulation and Morphological Contour Analysis for Gear Wear Online Monitoring

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To solve the problems of imaged wear debris and bubble separation of reflected ferrogram captured by direct-reflection Online Visual Ferrograph (OLVF) for gear wear online monitoring, a low frequency nonlinear threshold function is derivated by using hyperbolic tangent function. Meanwhile, two characteristic arguments of length-width ratio and elliptic similarity index are presented, which can be employed to distinguish in-focus bubble images from the reflected ferrogram. On the basis of the nonlinear threshold function and characteristic arguments, a wear debris image segmentation algorithm based on wavelet modulation and morphological contour analysis of strong bubble interference is proposed. In order to realize the effective segmentation of wear debris image of direct-reflection OLVF reflected ferrogram, the in-focus bubble images in the reflected ferrogram need to be recognized precisely and the out-of-focus bubble impression have to be suppressed effectively. Then, wear debris images can be obtained from the reflected ferrogram correctly by using this current one. Comparing with the segmentation effects of wear debris images processed by other algorithms, the results show that the complete segmentation of wear debris images in the reflected ferrogram can be achieved more accurately by identifying in-focus bubble and modulating out-of-focus bubble with the proposed algorithm. Finally, an online monitoring experimental measurement is carried out to characterize the fast-changing of gear wear in the full useful life by extracting the index of debris concentration. Results show that the effects of strong bubble interference on the vilidity of wear debris image segmentation of reflected ferrogram during the sampling periods of direct-reflection OLVF can be eliminated by this current algorithm, and the abnormal wear fault of gear failure is accurately detected. Accordingly, it has been further verified that this proposed algorithm for gear wear online monitoring is applied to extracting the visual characteristics of wear debris in in-use lubricants.

Keywords: direct-reflection OLVF, in-focus bubble, out-of-focus bubble, reflected ferrogram, wear debris segmentation

Effect of Grid-Like Array Wettability Surface on Bearing Lubrication Performance under Limited Lubricant Supply

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Rolling bearings are precision components in mechanical equipment, which play a supporting, load-bearing, and friction-reducing role for rotating parts. In industries, ultra-precision machining is used to improve surface quality, such as raceways of the inner ring and outer ring. However, starved lubrication is commonplace when bearing running at high speeds, heavy load, and huge slip ratio, which can lead to severe friction and wear, regardless of the quality of the surface. In this case, some thoughtfully designed surfaces were manufactured to overcome the harsh operating conditions. For example, micro-dimple film induced by the surface texture was used to help improve the slider performance of a sliding bearing [1].
Making the best use of the available lubricant in a bearing can improve the bearing performance. This paper utilizes grid-like array wettability (GAW) surfaces to enhance lubrication behavior under limited lubricant supply. Scattered oil pools are designed to improve oil supply through grid array wettability, which helps alleviate excessive viscous force and enhance lubrication efficiency. Additionally, the microcirculation effect of the patterns aids in reducing starvation in the bearing. The impact of the novel surface pattern on lubrication is assessed using a multi-point-contact EHL film thickness test rig under limited lubricant supply. Findings indicate that the GAW surface improves lubricant replenishment and increases the lubricating film thickness. Additionally, equipping a shaft with four bearings featuring the GAW surface leads to a reduction in the overall rotating torque.

Keywords: rolling bearings, microcirculation effect, replenishment

Airborne Particles Emitted From Vehicle Disc Brakes

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Airborne particles emitted from vehicle brakes make up a significant portion of non-exhaust particle emissions in urban areas. This study investigated the effect of braking conditions on the airborne particles emitted from vehicle disc brakes using Low metallic, semi-metallic, and non-asbestos organic brake materials and grey cast ion as the brake contact pairs. Results show that the coefficient of friction and specific wear rate decrease with increasing contact pressure and sliding rate. Particle number size distribution has a single peak around 100 nm for all brake materials. Generally, total particle number and total particle mass emissions increase with increasing sliding rate and contact pressure. Both sliding rate and contact pressure can significantly affect the TPN and TPM emissions. There is no particular trend for geometric mean diameter (GMD) with sliding rate and contact pressure.

Keywords: brake wear particle emissions, disc brakes, brake materials

KEYNOTE

Tribotronic Components: A Revolution Transforming Machine Elements into Cyber-Physical Systems

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This presentation explores the development of actively controlled tribological elements (tribotronics) and considers the potential of tribotronics as part of a revolution machine element design for the future. It presents a “state of the art” assessment of some devices that can be considered to be “tribotronic” which are in common use now, as well as reviewing some recent progress in research in tribotronics. It also presents a “perspective” on the future challenges and likely developments in the subject of tribotronics, including an overview of the likely challenges to be faced, and the integration of tribotronics with developments in other fields of digital technology including Industry 4.0 and the “Internet of Things”. It is concluded that tribotronics is likely to contribute significantly to transforming the design of the components and machines of the present day into the cyber-physical systems in the future.

Keywords: tribotechnology, tribotronics, active tribology

Research on The Tool Adhesive Wear Behavior During High-Speed Milling of Aluminum Alloy

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The ADC12 aluminum alloy has been widely used in aerospace, ship and automotive fields by its high specific strength, excellent die casting performance and wear resistance. However, it is easy to produce adhesion during milling, which aggravates tool wear and reduces tool life. Firstly, through the high-speed milling experiment of uncoated carbide tool, It shows that the adhesion and peeling are the main tool wear morphology. Then, a finite element model was established based on the improved J-C constitutive equation for high-speed milling aluminum alloy. The simulation results show that F_x cutting force plays a dominant role during milling process. With the increase of cutting speed and feed, the tool-chip interface temperature increases firstly and then decreases, which is related to the friction angle, the tool-chip contact length and the friction force on rake face. Next, the influence of thermo-mechanical coupling effect on tool wear behavior was discussed. It is found that the main tool wear morphology is peeling on the cutting edge and stable adhesion on the tool surface. Finally, the accurate tool wear simulation models were established for peeling and adhesion. Combining with the tool wear rate equation and the energy spectrum results on tool face, the mechanism of peeling and adhesion was explained by considering the thermo-mechanical coupling effect. The tool wear simulation results show that, in the process of chip formation, the tool-chip interface temperature increases gradually, but the shear stress shows a trend of first increasing and then decreasing. Local high temperature at the tool-chip interface results in adhesion, oxidation and abrasive wear of adhesion layer on the tool surface. The alternating stress causes the cutting edge to crack and peeling, thus the adhesion-peeling wear was generated on the cutting edge.

Keywords: high-speed milling, tool adhesive wear, thermo-mechanical coupling effect

Effect of Coulomb Friction of the Auxiliary Sealing Ring on Dynamic Characteristics of Gas Face Seals

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The remarkable nonlinearity of the gas face seal system is partly due to the complex friction states between the auxiliary seal and the contact pair. An advanced double mass axial vibration model is established to study the comprehensive effect of the O-ring during transient operation. The transition law between static friction and sliding friction of the O-ring during disturbed operation is explored, and the forced response patterns under different O-ring friction states are clearly distinguished. The influence of dynamic characteristics of the support system and external excitation on the central film thickness variation is analyzed in sliding friction state. Two dynamic performance indicators, peak value for film thickness impact and variation of disturbance center position of film thickness, are defined. The dynamic performance under the combined action of stator impact disturbance and rotor forced excitation is studied. The results show that due to the sudden change in the O-ring friction state, there is a rapidly attenuating high-frequency component in the time-varying curve of film thickness. As the O-ring friction increases, the axial disturbance of the seal system gradually transfers from the supporting spring to the O-ring. If the buffering and friction effects of the O-ring are not considered, the stable state of the seal may be misjudged under conditions such as excitation overload.

Keywords: gas face seal, double mass kinematic model, coulomb friction, impact disturbance, transient response

The Influence of Cooling Condition on The Heat Transfer of High-Speed Mechanical Seal with Textured Side-Wall

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When operating at high speed, the mechanical seal produces a large amount of frictional heat on the seal face. If the heat is not dissipated in time, it could lead to the thermal failure of the seal face. In the field of tribology research, the technology of textured surface is a method to enhance the heat dissipation rate. Numerical analysis is carried out based on the SST k-ω turbulence model and the energy equation with viscous dissipation term, and the results are validated by the experimental data published in the reference. In a wide range of rotational speeds, cooling medium with varied Pr numbers is employed to confirm the performance of textured side-wall in heat transfer enhancement. The shape of the seal chamber is also changed to provide guidance for the design of the cooling channel. The results show that a larger Pr number increases the heat transfer enhancement of the textures; it is advisable to utilize a cooling channel that gradually decreases in size; and the flushing should not be perpendicular to the stator; additionally, it is important to ensure that the cooling channel is not too narrow. By means of appropriate design, the maximum temperature of seal face can be reduced by over 40°C at 20,000rpm.

Keywords: high-speed mechanical seal, Pr number, shape of seal chamber, direction of textures, heat transfer enhancement

Relationship Between Fine Wear Particle Matter Emission and Wear Loss For oriented-CNT-Reinforced Styrene-Butadiene Rubber

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As a new additive, carbon nanotubes (CNTs) have been widely investigated and utilised in industries since their invention CNTs have been incorporated in rubber to improve its matrix performance and extend its industry applications such as tire and belt. Owing to its one-dimensional property, CNTs are also fabricated to be oriented in the rubber to further promote its tribological performance. When CNT-reinforced rubbers are worn, the wear particle matters (WPMs) are emitted, which inevitably include CNTs. Particle matter that includes CNTs has greater toxicity to induce granulomas, pulmonary

fibrosis, and even lung tumours and has been ranked as the 2B and third level in the list of carcinogens. Hence, the use of CNTs in the rubber is a wide concern for the respiratory health risk. This study explored the relationship between fine wear particle matters (WPMs) and wear loss for oriented-CNT-reinforced styrene-butadiene rubber (SBR) using a self-developed test rig. WPMs per unit worn mass (UWM) were defined for evaluation. The results show that CNTs-z/SBR emits more WPM 3.0 and WPM 5.0 per UWM owing to its superior wear resistance. Hence, a greater worn mass results in larger amounts of WPMs, but lesser WPM3.0 and WPM5.0 emissions per UWM. Water lubrication and lower COF promote WPM3.0 emissions per UWM. Considerable load and velocity result in a decrease in the WPM3.0 and WPM5.0 emissions per UWM.

Keywords: styrene-butadiene rubber, oriented CNTs, wear particle matter, worn mass, water lubrication

September 16, 2024

Track 1-I: Friction and Lubrication

KEYNOTE:

Towards the Prediction of Lubricated Contacts by Machine Learning

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The prediction of lubricated tribo-contacts is crucial for optimizing mechanical system performance, but it remains complex and computationally intensive. Artificial Intelligence (AI) and Machine Learning (ML) techniques offer efficient and accurate solutions. This presentation explores ML algorithms, particularly artificial neural networks, for modeling lubricated tribo-contact behavior. One focus is on elastohydrodynamically lubricated (EHL) contacts, where ML algorithms trained on extensive experimental data efficiently capture complex patterns using input parameters like lubricant properties and operating conditions. Another aspect discusses physics-informed ML, like physics-informed neural networks (PINNs), for hydrodynamically lubricated (HL) contacts. By integrating known physical laws such as the Reynolds equation, PINN produces accurate and interpretable models.

Keywords: machine learning, artificial intelligence, hydrodynamics, elastohydrodynamics

INVITED:

In-Situ SEM Observation of POM Friction Interfaces and Friction Force Estimation by Convolutional Neural Network

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Polyacetal resin (POM) is increasingly utilized as a tribomaterial in various applications, such as gears. However, there remain numerous uncertainties surrounding its friction mechanism. Unlike metals, POM is believed to be significantly influenced by adhesion to the opposing surface and wear in terms of friction. However, as these phenomena typically occur at scales smaller than micro, observing them via optical microscopy presents is quite difficult. We have pioneered the development of a device enabling in-situ observation of friction interfaces directly, employing scanning electron microscopy (SEM) with a microtribometer and electron-transmitting membranes. In this study, we examined the friction interface of POM using SEM. Additionally, friction forces were estimated from the obtained SEM images utilizing a convolutional neural network (CNN), which is a type of AI analysis. We used silicon nitride membranes as the electron-transmitting membrane and POM pins. A load is less than 10 mN. From the in-situ SEM observations, it was observed that in the absence of an adhesion layer on the opposing surface, friction was notably high. Wear debris were only formed from the peeling of the adhesion layers. It was revealed that rolled wear debris were generated only when there is an appropriate gap. Furthermore, we identified the existence of friction through a free layer sandwiched between the electron-transmitting membrane and the surface of POM. It was apparent that frictional forces could be estimated from the obtained friction interface images using CNN. We have been trying to explain where in the images CNN relies on to estimate friction forces using gradient-weighted class activation mapping (Grad-CAM).

Keywords: POM, wear, SEM

Tribo-Informatics: Tribology Research with Enabling Technologies in the AI Era

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Tribology focuses on the phenomena of friction, wear, and lubrication. The wide application of friction has significantly improved productivity and the quality of life. The friction process involves a variety of phenomena, including mechanics, electricity, thermology, optics, and magnetics. The inherently interdisciplinary characteristic of tribology is becoming increasingly apparent along with the development of foundational disciplines. The progress of artificial intelligence has driven forward the

capabilities for calculating, designing, simulating, and validating tribological systems. Nonetheless, tribology's complex and interdisciplinary nature leads to challenges in integrating informatics with tribology. This research aims to explain tribo-informatics as a new interdisciplinary field that combines tribology with informatics. The five major categories of tribo-system information are input, system intrinsic, output, tribological, and derived state information. The tribological research has four key categories: tribological condition monitoring, behavior prediction, system optimization, and mechanism analysis. Traditional information processing methods and advanced machine learning methods, such as linear regression models, Gaussian regression models, support vector machines, and random forests, can play essential roles in these studies. The application of AI in different fields of tribology research, including component tribology and intelligent tribology, will be highlighted. Several case studies will also be provided to showcase the application of tribo-informatics. The utilization of information technology can significantly lower the system's information entropy and compress the research timeline in the field of tribology.

Keywords: tribo-informatics, artificial intelligence, information technology

Fast Prediction of Simulated One-Dimensional Model Functions Based on Machine Learning and DFT Theory

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The generalised functional theory (DFT) method is increasingly being used to analyse friction and lubrication at surface interfaces, based on the idea that electron density is informative and predictive of the physicochemical phenomena underlying friction and lubrication. The Schrödinger equation is solved according to the KS-DFT principle of one-dimensional smoothing of N non-interacting isospin fermions under the action of an external potential. The potential is expressed in a parametric form (e.g. Gaussian potential model) and the Schrödinger equation is solved using numerical methods, in particular the Numerov method with the hit-and-miss method, to obtain the wave function $\psi(x)$ of the system. Machine learning ridge regression, random forest and decision tree models are then used to analyse and predict the potential energy and electron density data using randomly generated parameters, and to make predictions for random parameters using increasing ridge regression aj coefficients. The random forest model is optimal without the aj coefficients, and the model is improved by introducing the aj coefficients. The random forest model is still optimal. Based on the theory of the DFT equation, the data model of a one-dimensional box is simulated. With the help of machine learning models, bypassing the complex Numerov and targeting methods, fast simulation of potential energy and electron density is realised.

Keywords: machine learning, DFT, predictive density functions

A Study on the Evaluation of Prediction Performance of Friction Coefficient from Speckle Patterns Using Machine Learning

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Predicting the friction coefficient is important for the maintenance of machine components. This helps to detect machine failures before they occur during operation. Various methods have been devised to understand friction behavior, but in real sliding environments they often encounter obstacles such as environmental noise and difficulties in signal separation. Furthermore, these methods do not provide direct information about surface conditions.

The laser speckle method is an easy way to provide information about a surface. Speckle patterns are formed when a laser beam reflects off a material surface, and these patterns contain information on the roughness of the reflected surface. There is a possibility to predict the friction coefficient based on the geometry information of the friction surface provided from speckle patterns. This is because surface roughness effects on the friction coefficient. The purpose of this study is to explore ways to predict the friction coefficient using speckle pattern.

Machine learning, particularly through fully connected neural networks, has shown promise in deciphering complex tribological properties by identifying relationships among variables to enhance prediction accuracy. Furthermore, combining multiple networks and applying time series analysis can further enhance accuracy.

In this study, we used a homemade tribometer to simultaneously measure the friction coefficient and capture speckle patterns. We trained a convolutional neural network (CNN) with datasets collected over five 30-minute sessions to predict the friction coefficient from these patterns. Comparing the prediction accuracy of friction coefficients after training the model on 1, 2, and 5 datasets, the coefficient of determination increased from -0.03 to +0.06, suggesting that the prediction performance improves with the number of datasets and that friction prediction is possible. Furthermore, when a network combining CNN and time series prediction was used for training, the prediction accuracy of the friction coefficient was further improved.

Keywords: laser speckle, machine learning, surface texturing

KEYNOTE:

Research on Lubrication of High Speed Bearing

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As the major equipment is developing towards high speed and heavy load, higher requirements are placed on the rolling bearing, which serves as an important support. At high speeds, the distribution and migration of lubricating oil in the bearing, thermal effects, shear thinning, and interfacial slippage become important factors affecting lubrication performance. However, the current research on elastohydrodynamic lubrication is mostly concentrated in the range of line speed below 5 m/s, and research above 5 m/s is very rare. Moreover, there is little concern for the oil supply conditions in the bearing and the urgent need for in-depth research on the high-speed lubrication mechanism. To this end, a newly developed ball-ring contact high-speed oil film thickness measurement system is developed, which more realistically simulates the contact between steel balls and raceways in ball bearings. The film thickness measurement results under the traction rolling mode up to 52 m/s is presented; a point contact layered-slip lubrication model that considers interfacial slippage and thermal effects is established, and the mechanism of oil film thickness change and slippage in the contact zone at high speeds are explored; finally a lubricant distribution measurement method based on laser-induced fluorescence intensity is proposed, and the law of lubricant distribution and migration in the bearing are presented, it is found that the capillarity number can effectively characterize the lubricant flow pattern and oil starvation degree.

Influence of Lubrication Characteristics in High-Speed Rotating Bearings

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In order to improve motor efficiency of electric vehicles, the oil cooling of motors is being considered. The lubricants viscosity is becoming lower to improve cooling performance, but the operating environment is more severe for bearings and gears lubrication. In addition, motors rotate at higher speeds than conventional engines, which can change the lubrication condition of bearings and make them more susceptible to damage. In this study, we investigated the effects of lubricant viscosity, coefficient of traction, and coefficient of friction on the heat generation characteristics of high-speed rotating bearings under various test conditions. Tests were conducted using an evaluation device with a combination of four bearings at speeds up to 20,000 rpm. The Bearings were deep groove ball type, 6008 and bearing temperatures were measured on the outer ring. The lubricant was a circulating spray system. The test start temperature

was set at 50°C and the bearings were lubricated with 50°C circulated lubricating oil. The test results showed that the heat generation of the bearing was strongly influenced by the kinematic viscosity of the lubricating oil, and that the lower the kinematic viscosity, the lower the heat generation. The coefficient of friction and coefficient of traction were not significantly affected. This can be attributed to the agitation loss and cooling performance of the lubricant. Therefore, reducing lubricant viscosity may reduce heat generation and prevent seizure, but lower viscosity also carries the risk of fatigue damage. The wear characteristics of the bearings will also be reported in the presentation.

Keywords: lubricants, high-speed bearings, heat generations

The Influence of Roughness on the Peeling of Rolling Bearings

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Rolling bearings, as commonly used rotary bearing components, are widely used in various applications including automotive gearboxes. With the continuous improvement of energy conservation and environmental protection awareness in human society, the demand for energy conservation and emission reduction in automobiles is rapidly increasing, including the promotion of technologies such as reducing lubricant viscosity and fuel supply to reduce friction losses. However, the use of these technologies can easily cause a negative impact on the lubrication status of bearings, leading to an increase in the peeling (micro cracks) of rolling bearings in the market. This study focuses on the influence of roughness on the peeling, by using steel balls with different roughness levels for durability testing. The results show that peeling only occurs under specific lubrication conditions and roughness levels. At the same time, by observing the microstructure of the metal, it is found that the peeling has typical features that is different from no abnormalities and wear.

Keywords: peeling, roughness, oil film parameter

Fundamental Experiments on Electrical Corrosion in Oil Lubricated Radial Ball Bearings

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Electrical corrosion occurs in rolling elements and the raceway when a voltage difference is given between the outer and inner rings of bearings, and it causes severe damage to rotational machinery. In recent years, electrical corrosion has been focused on as one of the common damages of ball bearings in electric vehicles, and electric motors. However, it cannot be said that the mechanism of the electrical corrosion inside bearings has not been clarified yet. The purpose of this study is to make clear the formation process of electrical corrosion. For this purpose, a series of bearing tests were performed under various operating conditions.
Electrical corrosions were reproduced by applying a voltage difference between the inner and the outer rings to the test bearing. Radial ball bearings (6202) were tested with rotational speeds of 1800 and 3600min^{-1}. The axial load of 44N and three kinds of radial loads from 0 to 200N with an increment of 100N were applied. Poly-α-olefin was used as a lubricant and it was recirculated with a flow rate of 1.3ml/min using a roller pump. The bearing tests were conducted using a DC power supply with a current of 6A. After the bearing tests, the lubricant, the balls, and the inner rings were observed.
As a result, there were two states in increasing vibration acceleration. In the first state, the vibration moderately increased with time, and only a running track was observed. In the second state, the vibration rapidly increased and clear damage, so-called "ridge-mark" was able to be observed. The first state in the rotational speed of 3600min^{-1} was greatly shorter than that in the rotational speed of 1800min^{-1}, despite the same electrical conditions. It was suggested that the difference in film parameters affected the duration of the first state.

Keywords: electrical corrosion; radial ball bearing; oil lubrication

Thermodynamic Characterization and Experimental Study of Double-Row Angular Contact Automotive Wheel Hub Bearings

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The thermodynamic characteristics of double-row angular contact wheel bearings are of great significance for bearing fault diagnosis and structure optimization design. In this paper, firstly, the load distribution and kinematic parameters of the bearing are obtained by establishing a thermal-force coupling model of the wheel bearing, and the contact load distribution, friction power consumption distribution and temperature distribution of the wheel bearing are analyzed; secondly, a box-type encapsulated fiber-optic grating temperature sensor is designed to realize the analysis of the influence of different rotational speeds, axial loads and radial loads on the axial and circumferential temperature distribution of the wheel bearing by arranging 12 fiber-optic measuring points. By arranging 12 fiber optic measuring points, the axial and circumferential

temperatures of wheel bearings were analyzed by different speeds and radial loads. The results show that the temperature difference between axial and circumferential directions of wheel bearings is not negligible under the effect of combined loads, and the rotational speed, axial load and radial load all affect the temperature rise and temperature distribution of the bearings, and the degree of influence is in the order of rotational speed > axial load > radial load.

Keywords: double-row angular contact wheel bearing, thermal coupling, fiber grating sensor, non-uniform temperature field analysis

INVITED:

Ball Bearing Cage Structure on Lubricant Distribution, Lubrication and Friction

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As a crucial component of rolling bearings, the cage not only separates the rolling elements but also redistributes lubricant. The replenishment of the rolling track is closely related to lubricant distribution induced by the cage design. Therefore, this study aims to investigate how different cage structures affect lubricant distribution and corresponding friction and lubrication. An optical ball-on-disc apparatus is employed to visualize the lubricant reservoirs and lubricating contacts. Comparisons of EHL lubrication states with and without cages are given. Results show that cages remarkably enlarge lubricant reservoirs, leading to enhanced lubrication states from staved contacts to fully flooded ones. The cage parameters on the friction between the rolling element and the cage are quantitatively measured. Moreover, textures are imposed on the inner surface of the cage to guide the lubricant flow and redistribution, which affects both the friction and the lubrication state. CFD simulations are conducted to validate the lubricant distributions. The results are beneficial to understanding the mechanisms of cages on bearings lubrication and helpful to cage design.

Keywords: cage, lubricant distribution, elastohydrodynamic lubrication, ball bearing

Quantitative Study of The Flow Patterns and Transport Mechanism of Lubricant Oil in A Ball Bearing

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The lubrication of rolling bearings is significantly impacted by inadequate oil replenishment at the inlet of the rolling point contact zone. However, determining the actual volume of lubricating oil supply to the contact regions of rolling bearings remains challenging. To address this, we conducted a quantitative study combining novel laser-induced fluorescence (LIF) experiments with computational fluid dynamics (CFD) simulations. These experiments and simulations focused on air-oil flow both within rolling bearings and around rolling contact regions. It was found that most of the oil adhering to component surfaces does not directly contribute to lubricating the contact regions. Instead, flow patterns emerge and evolve around the rolling contact zones, transitioning from single-tail flow to butterfly and tunnel flows. The oil film migrates in the form of oil ridges. The recovery of this migrated oil film is limited by the spreading time and the initial average location of the oil ridges. Consequently, oil film migration cannot be eliminated, leading to the formation of decayed areas along the rolling point contact track. This decay causes a significant reduction in the thickness of the oil layer, which weakens oil replenishment and leads to insufficient oil supply at the inlet. It is further demonstrated that flow pattern evolution and oil layer migration occur as the capillary number (Ca) increases. There is a quantitative relationship between the degree of oil layer decay and the capillary number (Ca). These findings may provide insights into the lubrication mechanisms of rolling bearings and the associated challenges posed by oil replenishment.

Keywords: flow pattern, transport mechanism, capillary number

Experimental Investigation of the Oil Supply Layer in A Model Rolling Bearing

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The major oil supply for the rolling bearing contact is provided by the lubricating oil reservoir and the oil ridges, however the regularity of their changes has not been thoroughly investigated. In this study, the laser induced fluorescence technique was adopted to determine the film distribution of the oil reservoir and the layer thickness of the oil ridges on the free surface. It clearly depicts the changes of the oil reservoir and reveals the mechanism of the oil migration surrounding the contact region under various driving actions. The results may give a new perspective and a fuller understanding of the lubricating oil supply by revealing additional information about oil supply surrounding the contact region.

Keywords: ball bearings, film thickness, starvation

Predictions of Friction and Wear in Ball Bearings Based on A 3D Point Contact Mixed EHL Model

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Ship gas turbine bearings are subjected to heavy loads and intricate interface micro-morphologies, predominantly operate in a mixed lubrication regime. Excessive asperity relative sliding can cause wear at contact points.In this paper, a numerical solution procedure is developed for the predictions of transient friction and wear in the marine ball bearings based on the 3D point contact mixed lubrication simulation. The obtained results indicate that as the amount of bearing material removed increases, the actual area of wear marks produced is larger than the elliptical contact area. In addition, It is observed that the conditions of heavy load and low material hardness usually lead to significantly increased maximum wear depth. In the meantime, the maximum wear of the inner raceway is on both sides.

Keywords: ball bearings, 3D point contact mixed EHL, sinusoidal surface roughness, wear

Investigation on the Skidding Characteristics and Cage Motion Stability of High-Speed Cylindrical Roller Bearing

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Addressing the issues of skidding damage and cage fracture in high-speed cylindrical roller bearings, studies focus on the skidding characteristics and cage motion stability. Based on the dynamics theory and experiments, aimed at elucidating the influence mechanism of bearing operational conditions and structural parameters on the skidding characteristics and the cage motion stability. The critical rotational speed corresponding to the bearing skidding inflection point (maximum skidding rate) was found, and the theoretical discrimination method for the occurrence of skidding was proposed. On the other hand, according to the motion characteristics of the cage mass center, the cage motion states were classified and the critical conditions for cage motion state conversion were determined. It is discovered that the cage force which maintains the motion characteristics of the cage mass center is different under different cage motion states. In addition, the variation of motion state of rolling elements directly affects the force between cage and rolling elements, which indirectly changes the cage motion

state. Further, it is proposed that the traction coefficient between the rolling elements and the raceway is the fundamental factor determining the cage motion state.

Keywords: skidding, cage stability, traction coefficient

Track 1-II: Friction and Lubrication

KEYNOTE:

Study on Elastohydrodynamic Lubrication with Electric Field Using Optical Interference Method

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An electrical potential difference may develop between the races and the rolling elements of rolling bearings when they run in electric vehicles, wind power generation equipment and other electric machines. Lubricating greases can form an oil film between the bearing race and rolling elements. If the electrical potential difference reaches its specific threshold, it can rupture the oil film and a momentary surge in current occurs. This results in damage to the rolling elements and raceway surfaces. With increasing exposure to electrical conditions, the risk of bearing failure due to electric erosion becomes significant concerns. To better understand how lubrication interacts with electric discharge in rolling bearings, an optical ball-on-disc tribometer was used to measure film thickness under elastohydrodynamic lubrication (EHL) with electric discharge from DC or AC power. Lithium-based grease was used in the experiments. The base oil is a mixture of polyalphaolefin oil (PAO10) and diester oil (diisodecyl adipate) with lithium 12-hydroxy stearate as the thickener. The results reveals that electrical potential difference between the surfaces separated by the lubrication film leads to a reduction in film thickness and friction, which can be attributed to the generation of Joule heating. Two types of discharge were found. One was the sporadic discharge with white light in the contact region, and the other was discharge with purple light, which occurs out of the contact region. Both discharges can induce surface erosion. It was clearly shown that the coating on the surface of the glass disc is entirely destroyed. In addition, grease was also investigated with a conductive additive, a double trifluoro-sulfonate ionic liquid. It was found that incorporating this ionic liquid into the grease can decrease the energy during discharge, thus to mitigate bearing electric erosion.

Keywords: EHL, electric filed, discharge

INVITED:

Development and Characterization of TEMPO-based High-Performance Organic Friction Modifiers

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High-performance organic friction modifiers (OFMs) added to lubricating oils are crucial for reducing energy loss and carbon footprint. We have proposed the use of N-(2,2,6,6-tetramethyl-1-oxyl-4-piperidinyl)dodecaneamide, referred to as C_{12}Amide-TEMPO, as a new type of OFMs. This molecule features a head group comprising a rigid six-membered ring sandwiched by an amide group and a terminal free oxygen radical.

Pin-on-disk tests conducted under pure sliding conditions demonstrated that C_{12}Amide-TEMPO outperforms the conventional OFMs of glyceryl monooleate (GMO) and stearic acid, particularly for load-carrying capacity, wear reduction, and stability of friction over time. Further tests under rolling and sliding conditions using a mini traction machine showed that C_{12}Amide-TEMPO generally surpasses stearic acid not only in the boundary but also in the mixed lubrication regime, and it remains effective up to 3 GPa at the slide-to-roll ratio of 50%. Additionally, pin-on-disk tests confirmed that C_{12}Amide-TEMPO outperforms C_{12}Amino-TEMPO and C_{12}Ester-TEMPO, where an amino and ester group replace the amide group in C_{12}Amide-TEMPO, respectively, highlighting the critical role of the amide group.

Quantum mechanical calculations and molecular dynamics simulations revealed that C_{12}Amide-TEMPO can form effective boundary films on iron oxide surfaces with a unique double-layer structure: a strong surface adsorption layer owing to the chemical interactions of the amide oxygen and free radical with iron oxide surfaces, and an upper layer owing to the interlayer hydrogen-bonding between the amide hydrogen and free radical or between the amide hydrogen and oxygen. Moreover, intralayer hydrogen-bonding in each of the two layers is also possible. As a result, the boundary films exhibit not only strong surface adsorption but also self-healing properties, contributing to the high tribological performance of C_{12}Amide-TEMPO.

These findings are expected to provide new insights for the optimal molecular design of OFMs.

Keywords: boundary lubrication, friction and wear, surface adsorption, molecular simulation

Gaseous Lubrication of Steel/Steel Rubbing Contacts

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A wide range of systems are operating with gases or in gaseous environments, such as gas fuel engines, gas refrigerators, gas pumps, inerted analytical instruments. In these systems, the interactions between gases and the rubbing surfaces plays a critical role in determining tribological performance. Such interactions can involve the adsorption of gaseous molecules and/or their chemical reaction with the surfaces. For example, molecular oxygen can lead to the formation of metal oxides, while ammonia and hydrocarbons may form protective tribofilms.
This presentation describes the use of an HPR tribometer coupled with a gas flow control system to evaluate the tribological performance of steel/steel contact rubbing in various gaseous atmospheres, including compressed air, inert gases, ammonia, carbon oxides and select hydrocarbons. The obtained results, along with post-test analysis revealed significant differences in tribological performance and their underlying mechanisms. Additionally, the flow control system allows rapid switching of rubbing atmospheres, enabling us to investigate the tribofilm formation and loss kinetics.

Keywords: gaseous lubrication, steel/steel contact, tribofilm

Fabrication of Flexible and Transparent Metal Mesh Electrodes Using Surface Energy-Directed Assembly Process for Touch Screen Panels and Heaters

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Transparent conductive electrodes (TCEs) are indispensable components of various optoelectronic devices such as displays, touch screen panels, solar cells, and smart windows. To date, the fabrication processes for metal mesh-based TCEs are either costly or having limited resolution and throughput. Here, a two-step surface energy-directed assembly (SEDA) process to efficiently fabricate high resolution silver meshes is introduced. The two-step SEDA process turns from assembly on a functionalized substrate with hydrophilic mesh patterns into assembly on a functionalized substrate with stripe patterns. During the SEDA process, a three-phase contact line pins on the hydrophilic pattern regions while recedes on the hydrophobic non-pattern regions, ensuring that the assembly process can be achieved with excellent selectivity. The necessity of using the two-step SEDA process rather than a one-step SEDA process is demonstrated by both experimental results and theoretical analysis. Utilizing the two-step SEDA process, silver meshes with a line width down to 2 μm are assembled on both rigid and flexible substrates. The thickness of the silver meshes can be tuned by varying the withdraw speed and the assembly times. The assembled silver meshes exhibit excellent optoelectronic properties (sheet resistance of 1.79 Ω/□, optical transmittance of ≈92%, and a FoM value of 2465) as well as excellent mechanical stability. The applications of the assembled silver meshes in touch screen panels and thermal heaters are demonstrated, implying the potential of using the two-step SEDA process for the fabrication of TCEs for optoelectronic applications.

Keywords: directed assembly, surface energy, flexible and transparent electrodes

Interfacial Friction Behavior of the Energetic HMX Crystal

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The interfacial friction behavior of the energetic HMX crystal has been studied. The experimental results show that the friction behavior of energetic HMX crystal is strongly related to contact stress, friction direction, and crystal plane. In addition, we focused on studying the correlation between friction temperature rise and work done by friction, providing a linear mapping relationship between the two, discussing the efficiency of work heat conversion and its micro structural mechanism, and developing a friction temperature rise simulation model based on friction interface hotspots, which provides important information for studying the safety of energetic crystals and energetic materials under various friction conditions.

Keywords: friction behavior, energetic crystal, mechanics

KEYNOTE:

Carbon-based Solid Lubricants: An Overview

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Solid lubrication is an excellent option to reduce friction and wear in dry sliding conditions and as a secondary source of protection in fluid-lubricated systems. Considering the most used solid lubricants, carbon-based ones are among the most versatile ones for tribological use. The reasons include availability and the innate capability of these materials to adopt various nanostructures. The crystalline ordering of carbon has been identified as the main factor governing its tribological behaviour. This work presents and discusses the most significant findings from an ongoing research program aimed at developing carbon-based solid lubricants. In this sense, several carbon-based materials with diverse levels of nanostructural order are being studied: crystalline graphite (GR), turbostratic 2D graphite, plasma functionalized multilayer graphene (MLG), vertically aligned carbon nanotubes (CNT) and novel carbide-derived carbon (CDC) produced from B4C-Cr3C2 solid-state reactions. Initially, we present a brief description of the processing route for obtaining these materials, followed by their microstructural characterization and a synthesis of the most

relevant aspects of tribological evaluation. Dry sliding tests in reciprocating motion were employed, but with different tribo-pair geometries, specimens and counter-body materials, varied surface topography, and diverse routes to add the solid lubricants to the contact (vacuum impregnation of sintered steels, drop-casting, self-lubricating composite and vertically aligned films). Results provide a holistic view of the nature of the tribolayers formed by these materials. Finally, a new µRaman analysis technique quantifying the point and line defects of the carbon present in the tribolayers is used to correlate the lubrication and degradation mechanism of carbonaceous solid lubricants with their initial nanostructure and testing conditions. This technique enabled new insights into the nature of tribolayers produced by carbon-based solid lubricants

Keywords: carbon nanostructures, solid lubrication, defects quantification

Experimental Insights into Film Thickness and Friction of Textured Surfaces in Hydrodynamic Wedge and Parallel Gaps

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The effect of surface texture on hydrodynamic lubrication has been extensively studied for possible application to wedge gap bearing configurations or other cases with nominally parallel surfaces. Much of the progress has been made by theoretical treatment of the problem, with only a small contribution from experiments involving in-situ measurement of film thickness and friction. The aim of the contribution is to provide an experimental insight into the processes occurring in the hydrodynamic lubrication of textured surfaces in parallel and wedge gap situations. The light-induced fluorescence technique was used to measure film thickness in a pin-on-disc configuration. The contribution of surface texture to load carrying is different in the two situations. Lubrication mechanism and the effect of deviations from ideal parallel configurations are discussed. Experimental data with controlled gap parameters are an important step towards improving numerical modelling.

Keywords: hydrodynamic lubrication, surface texturing, film thickness

Surface Texturing for Tribosystem Optimisation: A Homogenized Mass-Conserving Approach

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Combatting friction, wear and failure mechanisms instigated by inadequate lubrication and severe operating conditions is essential when revamping the performance and lifecycle of tribo-contacts. In addition to formulating lubricants, applying surface coatings and modifying material properties, texturing lubricated surfaces is another practice often pursued to enhance the tribological performance of tribosystems. Being the crux of a plethora of studies, texture configurations have proven to be influential in alleviating friction-induced effects, behaving as lubricant reservoirs in starved regimes, ensnaring wear debris and reducing the contact area exposed to continuous shearing.
Various fluid-solid interactions often materialise in the vicinity of interfaces that operate in mixed-lubrication conditions, such as structural deformation, inter-asperity cavitation and thermal gradients promoted by viscous dissipation and asperity-asperity interactions. Simulation modelling techniques have played a major role in establishing a comprehensive understanding of such processes to optimise lubrication performances. Despite the extensive utilisation of stochastic and deterministic models for the mathematical description of mixed-lubrication conditions, their performances often deteriorate due to the loss of local information or exigency for dense computational meshes.
With an aim of overcoming the aforementioned limitations, the current contribution proposes a mixed-thermohydrodynamic lubrication model based on the two-scale homogenization approach. Hydrodynamic behaviour is described via the homogenized generalised Reynolds equation with the (p-Θ) mass-conserving cavitation model, for which hydrodynamic pressure and film fraction are calculated at the micro- and macro-scales. Furthermore, under the aegis of experimental investigations, the simulation framework showcases the significance of admitting thermal effects for evaluating surface texturing via the coupled thermal solutions of the lubricant film and bounding bodies. The conceived numerical simulations elucidate how the integration of curvilinear-based modelling can further enhance the homogenization of lubrication problems, hence paving a new pathway for unified modelling of a variety of bearing systems.

Keywords: thermal mixed-lubrication, cavitation, numerical simulation

Study on Lubrication and Wear Reduction of Textured Drill Bearing

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Drill bit is the key tool to break rock and form hole directly in the process of oil and gas exploration and development. Its working performance and service life directly affect the drilling rate and drilling cost, and the drill bearing is one of the most vulnerable parts of the whole drill bit. The traditional process optimization is to improve the anti-wear performance of drill bearing from the aspects of structural parameters, surface strengthening, composite coating, etc., but it is still difficult to meet the

increasing drilling demand. Biomimetic surface texture technology has attracted more and more scholars' attention due to its lubrication and wear reduction effect. This technology has been introduced into the design of drill bearing structure, and combined with laser ablation technology, surface texture is arranged in drill bearing machining to explore a new idea of improving the tribological properties of the contact surface and improving the bit life. A theoretical lubrication model of textured plain bearing was established, and theoretical simulation experiments, unit experiments and bench experiments were carried out to compare the changes of tribological performance indexes such as oil film thickness, bearing capacity, friction coefficient, wear amount and wear morphology with or without texture, and evaluate the effect of textured bit bearing technology on improving bearing life. The study preliminarily verified the feasibility of textured bit lubrication and wear reduction, and obtained that the textured parameters with good lubrication and wear reduction effect can extend the life of the bit bearing by more than 50%, which provides an important theoretical and experimental basis for the textured optimization design of the bit bearing.

Keywords: surface texture, drill sliding bearing, lubrication and wear reduction, laser processing

Effect of Groove Parameters on Tribological Performances of Battery Grid Continuous Casting Mold

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The battery grid plays a role in collecting current and is widely used in the field of new energy batteries. The battery grid continuous casting manufacturing system is an environmentally friendly, energy-saving, and low-cost battery grid manufacturing equipment. The core equipment of the machine consists of a moving mold and fixed mold, and the moving mold surface is designed with rectangular grooves to reduce friction between the moving and fixed molds. Therefore, choosing the rectangular groove parameters is crucial for the above friction-reducing design. For this, an elastic hydrodynamic lubrication model of the mold was established. Based on this model, effects of rectangular groove size and tilt angle on the tribological performances of the mold is investigated, and then optimized based on the discrete difference evolutionary algorithm. The results show that increasing width, length and depth of groove results in changes in the friction coefficient and film pressure of the continuous casting mold.

Keywords: battery grid, EHL, groove

INVITED:

The Synergetic Effect of Surface Texturing and ZDDP Additive Subject to Starved Lubrication Condition

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In order to provide some insights into the application of surface textures under boundary lubrication in additive-contained oils, the synergetic effects of microscale surface texturing and anti-wear additive ZDDP (zinc dialkyldithiophosphate) subject to starved lubrication conditions was studied. The experiments were performed on reciprocating ball-on-disk friction in base oil with and without ZDDP. Textured and texture-free surfaces in the oils with and without ZDDP additive were tested until an abrupt rising of friction coefficient was detected. The results showed that the magnitude of friction coefficient before terminating each test was almost same for various tests, while the endurance time in different test conditions was significantly different. The textured surface exhibited longer endurance time than the texture-free surface, especially when the ZDDP additive was used. The mechanism was discussed based on the experimental results.

Keywords: surface textures, ZDDP additive, boundary lubrication, starved oil lubrication

Study on the Synergistic Effect of Laser Shock Peening and Surface Texture on the Friction and Wear Behaviour of Piston Ring Cylinder Liner Pair

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Aiming at the abrasive wear and adhesive wear loss of the piston ring-cylinder liner pair of gas storage tank compressors, a new method of utilizing laser shock peening and surface texture synergy to enhance the lubrication and wear resistance of PTFE/42CrMo piston ring-cylinder liner pair was innovatively proposed. The 42CrMo cylinder liner specimens were firstly shock peened by laser process parameters with pulse energy of 5J, spot diameter of 3mm, pulse width of 10ns, and lap rate of 50%. Then, laser-ablated homogeneous circular craters with a diameter of about 800 μm, a depth of 100 μm, and an area ratio of 20% on the surface of the shock-peened 42CrMo specimens. Based on the UMT high-frequency linear reciprocating module, the unit friction and wear tests of PTFE/42CrMo piston ring and cylinder liner pairs were carried out under the simulated load of 200N, frequency of 5Hz, and the infiltration of ISO VG 32 lubricating oil with a solid-phase dust particle size of 10-20 μm, and a mass fraction of about 1%. The coefficient of friction, wear amount and wear pattern characteristics were used as evaluation indexes to comprehensively analyze the

tribological performance of the paired pairs of pairs with only surface texture processing, only laser shock peening and the synergistic effect of the two. The results show that the synergistic effect of laser shock peening and surface texture can reduce the friction coefficient of PTFE/42CrMo piston ring and cylinder liner pairs by 50%, and increase the wear resistance by 43%, which is mainly attributed to the synergistic effect of the texture capturing and storing abrasive particles and the laser peening to reduce the adherent wear. This study provides an innovative solution for improving piston ring-cylinder liner pairs' lubrication and wear resistance under the complex media conditions of gas storage tank compressors.

Keywords: PTFE/42CrMo friction substitutes, laser shock peening, surface texturing, synergistic effect, friction performance

Study on the Effect of Laser Processing Edge-Raised Microtexture on the Water Lubrication Performance of UHMWPE

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When processing concave microtextures on the surface of ultra-high molecular weight polyethylene (UHMWPE) with a CO_2 laser, convex structures form at the edges of the concave textures due to the melting of the material. In order to investigate the effect of laser processing edge-raised microtextures on the water lubrication performance of UHMWPE, six different arrangements of rectangular textures were designed on the surface of flat circular UHMWPE specimens, and were processed using the same laser parameters. The friction coefficients and water film thicknesses of the specimens at different rotational speeds and loads were tested by conducting disk-to-disk water lubrication tests. The influence of the microtexture arrangements on the lubrication performance of laser processing edge-raised microtextured UHMWPE specimens were analyzed. The results show that as the load increases, the friction coefficients and the water film thicknesses of the specimens gradually decrease. As the rotational speed increases from 30 r/min to 300 r/min, the friction coefficients of the specimens decrease and the water film thickness increases. The anti-friction properties of UHMWPE can be effectively improved by surface laser processing edge-raised rectangular microtextures, and the lubrication performance of the rectangular long microtexture with inwardly opening is the best.

Keywords: micro-texture, water lubrication, laser processing

Optimization of Surface Texture Distribution on the Thrust Bearing based on the Flat-Headed Chevron

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This study developed a numerical optimization model for the texture distribution in thrust bearings, employing the flat-headed chevron and circular dimple, and utilizing a mass-conserving cavitation boundary. A hybrid of the genetic algorithm and sequential quadratic programming algorithm is utilized. The results indicate the highest load-carrying capacity can be obtained by optimizing the texture distribution based on the flat-headed chevron. The primary mechanism is that the optimal distribution can efficiently harness the collective effect of texture, thereby effectively building up pressure. The optimal distributions of the flat-headed chevron and circular dimples exhibit asymmetric chevron and herringbone shapes, respectively. Furthermore, verification experiments show that the optimal distribution can shift the transition point to a lower rotation speed and higher normal load.

Keywords: optimization, texture, distribution, cavitation, load-carrying capacity

Friction and Wear Properties of Aluminum Alloy During Ultra-Low Temperature Forming

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Ultra-low temperature forming, as a transformative technology different from conventional cold and hot forming, holds great promise in manufacturing thin-walled aluminum alloy parts. However, the lack of understanding of friction and wear inhibits the applications of ultra-low temperature forming simulation in engineering practice. This study unveils the friction and wear characteristics of aluminum alloy during ultra-low temperature forming using a dedicated cryogenic strip drawing tribometer (CSDT). The findings demonstrated that the ultra-low temperature environment has significant advantages in reducing the friction coefficient and wear rate of aluminum alloy. CSDT can well evaluate the friction and wear properties of aluminum alloy.

Keywords: aluminum alloy, ultra-low temperature, friction

Track 1-III: Friction and Lubrication

KEYNOTE:

Investigation of Frictional Resistance in Sliding Contact Between Undulating

Surfaces and Third-Body Particles

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A model system of sliding contact between rough surfaces with third-body particles is experimentally studied. The experiment is designed to isolate the direct contact between first bodies so that friction resistance is induced completely by the interactions between the third-body particle and the wavy surfaces of the rubbers.
In dry contact of s single particle, the particle exhibits pure rolling during the sliding of the first bodies. In this scenario, the normal and tangential forces fluctuate more prominently with larger particles, but the overall macroscopic friction resistance for overcoming sliding doesn't vary with the particle size. Interestingly, this friction resistance is notably affected by the initial alignment of the surface waviness concerning the particle's position, represented by the phase shift between the two waviness patterns of the elastic bodies. The minimum friction resistance occurs when the particle is initially positioned in the valley of the lower surface waviness and contacts the peak of the upper waviness.
Under lubricated conditions, a starkly different behavior is observed. The low local friction at the interface due to the lubrication facilitates the rapid movement of the particle into the valley of the surface waviness upon compression. This abrupt displacement causes the particle to settle into a stable position, necessitating substantial force to push it further. This process is similar to the well-known Prandtl-Tomlinson model. In this lubricated scenario, the macroscopic friction resistance remains consistent, independent of the initial alignment of waviness, consistently maintaining the highest level observed in dry contact. Consequently, it can be concluded that lubrication increases the macroscopic friction resistance.

Keywords: third-body particle, friction, contact mechanics

INVITED:

Research on the Influence of Particle Crushing Behavior on Wheel-Rail Adhesion and Damage During Sanding Process

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Sanding is generally adopted in the railway to enhance the degraded adhesion to ensure the safe and efficient operation of trains. During enhancing wheel/rail adhesion, sanding could also lead to the deterioration of wheel-rail wear and damage. This study aims at investigating the crushing strength, ultimate particle size and wheel-rail damage caused by the particle crushing process through uniaxial crushing tests and elastic-plastic contact analysis of silica sand and alumina particle with various particle size. Also,

experiments were conducted on wheel-rail twin disc machine to study the effect of abrasive wear caused by crushed particles on enhancing adhesion and wheel-rail damage. Results indicate that the applied sand particles would be fractured into micro fragements in the inlet zone of wheel/rail contact during sanding. The size distribution of those particles that finally entered into in the contact interface concentrated around the ultimatize size of sand. The adhesion enhancement by sanding was determined by the ploughing of crushed fragments in the wheel-rail contact and the improvement of adhesion coefficient highly depended on the contents of acting particles. Although the crushing process of initial sand particles had no visible promotion on improving adhesion, this process dominated in inducing severe wheel/rail wear and damage problems. With the increase in the particle size, the crushing strength became stronger and would cause more serious wheel-rail surface damage during the crushing process. The maximum particle size range for silica sand and alumina was 6.5-13 μm and 17-24 μm. With the same particle size conditions, the crushing strength of alumina was about 1.6 times higher than that of silica sand. That is, the wheel-rail surface damage during the crushing process of alumina particles was more serious than that of silica sand.

Keywords: sanding, wheel-rail adhesion, adhesion enhancing particle crushing

Optimization of the Influence of the Friction Effect on the End Face of the Material in the Hopkinson Pressure Rod Experiment

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Split Hopkinson Compression Bar (SHPB) is a technology widely used to study the dynamic compressive mechanical properties of engineering materials at high strain rates. In the SHPB test, the contact interface between the specimen and the pressure bar will produce the end face friction effect, which will inevitably affect the stress state inside the specimen, which may cause it to deviate from the ideal one-dimensional stress state, and the maintenance of the one-dimensional stress state is one of the basic prerequisites to ensure the accuracy of the SHPB test results. Therefore, lubricants are usually added to the end face of the material to reduce the influence of friction, and in this experiment, the three lubrication conditions of molybdenum disulfide lubrication, oil lubrication and water lubrication are compared and analyzed with dry friction under different strain rates and different temperatures of the material, and an effective data optimization method is established.

Keywords: hopkinson press bar friction lubrication

Calculation Method of Friction Coefficient Based on Computer Vision Image Recognition

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The surface morphology change during friction is a stochastic disorder process, To better characterize the friction surface topography, Image recognition based on computer vision, By introducing a large number of surface regular morphology measured by 3D profilometer as the basic data model to learn the basic determination rules of surface orientation, Thus, the surface orientation distribution of the input friction morphology surface to be measured under the existing model is given based on the image recognition; Of the different surface orientation distributions. From the similarity between friction force-time relationship curve and the orientation and time relationship of friction surface, a relation of friction coefficient, orientation distribution and time based on statistical law is derived.

Keywords: friction, coefficient of friction, computer vision

Influence of Torque Control on the Dynamic Behavior of Wheel-Rail Adhesion Instability Under Traction Conditions

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Wheel-rail adhesion is a crucial factor for train traction and braking. During the locomotive traction process, the wheel-rail adhesion instability can lead to wheel slip and rail abrasion. Therefore, it is important to study the dynamic behavior of wheel-rail adhesion instability to improve the safety and stability of train operations. Currently, the existing testing machine controls the creepage by adjusting the rotational speed of the wheel and rail. However, this control of creepage is relatively constant, which cannot simulate the dynamic behavior of wheel-rail adhesion instability behavior.
To solve this problem, a novel wheel-rail adhesion testing machine based on the mechanical closed system was designed. The analysis of wheel-rail adhesion instability behavior in traction conditions can be realized by controlling the motor torque to adjust the creepage using this machine. The critical points of wheel-rail adhesion instability under different rotational speeds and axle loads, and the influence of various torque increments on the behavior of wheel-rail adhesion instability beyond the critical points were investigated.
The results show that: When the torque increased at equal intervals, the creepage initially increased steadily. Then, when the torque exceeded the critical point, the creepage rapidly rose which indicated that the wheel-rail adhesion instability behavior occurred. Meanwhile, the torque increments had an impact on adhesion instability behavior. When the torque increment was small, the creepage increased first, then

decreased, and finally remained stable. At this time, a new stable state occurred at the wheel-rail interface; However, when the torque increment exceeded a certain value, the creepage increased exponentially, leading to abrasions on the wheel-rail samples. In addition, with the axle load and rotational speed increased, the critical point of wheel-rail torque shifted right, and the creepage fluctuated more significantly. The results can provide a basis for the adhesion control and utilization of wheel-rail adhesion.

Keywords: wheel-rail adhesion instability, torque control, traction condition

INVITED:

Nonlinear Dynamic Analysis of a Hydrodynamic Air Bearing with Spiral Groove Used in High-Speed Micro Compressor

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Mechanical ventilators are critical medical devices for treating patients with respiratory diseases. The compressor, which supplies source gas for ventilators, is the choke point. Centrifugal type compressors supported by air lubricated bearings have become the preferred choice for their high efficiency, compact structure and low noise. However, their applications are limited due to the instability problem, which will cause sub-synchronous vibrations of the rotor bearing system at high speeds. This study analyzed the nonlinear dynamics characteristics of a high-speed micro rotor supported by hydrodynamic air bearings with spiral grooves. A mathematical model with considering the bearing dynamic Reynolds equation and the five degrees of freedom rotor motion is developed. The finite element method combined with the Runge-Kutta method is employed simultaneously to obtain the nonlinear trajectory of the compressor rotor. The stability performance of the rotor bearing system is evaluated by the frequency spectrum obtained from the fast Fourier transform analysis on the calculated trajectory. The validity of the theoretical analysis is verified by the experiments on the built micro compressor prototype. The influences of bearing clearance, groove depth, groove angle, groove axial and circumferential width on the dynamic performance of the rotor bearing system are analyzed. The results show that bearing clearance has a considerable influence on the bearing stability performance, followed by groove depth, then groove axial and circumferential width, finally the groove angle. With the increment of bearing clearance, the bearing stability performance deteriorated drastically. A 2 μm shift from 6 μm to 8μm can cause the instability of the rotor bearing system. There are optimal values for the depth, axial and circumferential width of the spiral grooves, which are 7 μm, 4 mm and 0.5 in this study. The study can provide valuable reference for the design and application of spiral-grooved air lubricated bearings.

Keywords: hydrodynamic air bearing, stability, spiral groove, micro compressor

Research on the Inherent Mechanism of Velocity Distribution Law of the High-Pressure Aerostatic Thrust Bearing

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It is necessary to consider the gas inertia in the design process of high-pressure aerostatic thrust bearings, which is apparently different from the bearings with low air supply pressures. Based on the simplified one-dimensional flow model established for the channel gap, the first-order nonlinear ordinary differential equation about Mach number is obtained and the one-dimensional approximate solutions for Mach number distribution in channel gap are acquired using the Runge-Kutta method. The differences between the one-dimensional approximate solutions and the Fluent 2D numerical solutions based on fully structured grids are discussed. It is demonstrated that the velocity distribution of airflow is in a mixed flow state with the height of gas film being 0.3mm, that is, subsonic-supersonic-subsonic, and finally accelerated to supersonic speed. It is also demonstrated that the one-dimensional approximate solutions may effectively predict the acceleration process of Mach number of the airflow in the contraction section of the bearing, and it may also qualitatively analyze the changes of Mach number of the airflow in the channel gap well enough. The inherent mechanisms behind the changes in Mach number of the airflow are described as follows. On the one hand, the deceleration of supersonic airflow is due to the fact that the obstruction effect of friction on supersonic flow begins to exceed the acceleration effect of area expansion on that. On the other hand, the acceleration of subsonic airflow is due to the fact that the acceleration effect of friction on subsonic flow begins to outweigh the deceleration effect of area expansion on that. In the preceding two situations, the total driving potential is similarly greater than zero. Therefore, the combination of one-dimensional approximate solutions and two-dimensional numerical solutions is an effective method to study the inherent mechanism of the velocity distribution of airflow in high-pressure aerostatic thrust bearings.

Keywords: high-pressure aerostatic thrust bearing, velocity distribution, one-dimensional approximate solutions, two-dimensional numerical solutions, driving potential

Multi-Physics Coupling in Lubricated Piston-Liner Systems: Modeling and Analysis

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The piston-cylinder liner system, essential for converting combustion thermal energy into mechanical energy in engines, typically operates under high temperatures, pressures, and poor lubrication. It involves multiple disciplines such as multibody dynamics, contact mechanics, heat transfer, and tribology. Significant research has been conducted in this area. However, limitations still exist in the study of the thermo-tribo-dynamic coupling model and characteristics of piston-liner systems. Traditional multibody dynamic models that use the floating coordinate approach require trigonometric calculations, which reduce computational efficiency. Furthermore, lubrication models often rely on local coordinate descriptions, necessitating coordinate conversions that limit the models' generality.
To address these issues, we propose a new 3-D multi-physics coupling model for lubricated piston-liner systems. The sub-models for mixed lubrication, spatial multibody dynamics, and heat transfer are established and fully coupled on a unified absolute coordinate frame. The coupling model is discretized and solved using the unified spatial and temporal discrete methods. Then, we validated the model through bench testing on a high-speed, four-cylinder automotive engine, confirming its accuracy.
Our findings indicate that piston slap vibrations primarily propagate along two paths to the outer surface of engine thrust side. The middle surface of the engine thrust side shows slightly lower vibration intensity compared to the upper, with energy concentrated in the 2500-5000Hz frequency band. The model also observes the presence of two distinct locations with the lowest local film thickness on either side of the piston's central axis, consequently yielding elevated local oil film pressures. This observation provides a reasonable explanation for the occurrence of wear and failure in the piston skirt on both sides.

Keywords: lubricated piston-liner system, mixed lubrication, multi-physics coupling, piston slap, multi-body dynamics

Friction Reduction and Improve Seizure Resistance of Engine Bearing by a-C:H:Si Coated Journal

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For a carbon-neutral society, friction reduction, which causes energy loss in automobiles, is extremely important. In engines utilizing alternative fuels such as hydrogen, which have been developed in recent years, since the majority rely on existing engine systems, the development of friction reduction methods is considered necessary to further enhance fuel efficiency. Among the engine components that generate friction, the ultimate friction reduction between the crankshaft and plain bearings is required. Engine bearings are generally used in the fluid lubrication to EHL

(Elasto-Hydrodynamic Lubrication) regime, and it is necessary to create friction reduction technology within this regime.
Therefore, we focused on DLC (Diamond-like Carbon), which has been reported to reduce friction in the EHL regime in recent years. In general, achieving friction reduction with fluid lubrication often results in reduced seizure resistance. However, DLC has high adhesion resistance to aluminum of the aluminum alloy plain bearings used in this study, thus, experimental verification was conducted to investigate the possibility of achieving friction reduction without reducing seizure resistance. Based on the above, three types of DLC were coated only on the crankshaft journal section, and the uncoated steel journal was used as a benchmark for the individual evaluation of the journal bearing section. The experiment utilized an engine bearing test rig, using general purpose gasoline engine oil as the lubricant.
As a result, friction reduction in the EHL regime was confirmed only with the a-C:H:Si-coated journal, achieving a maximum friction reduction effect of 15%.
Also, in the case of a-C:H:Si coated journal, no seizure occurred despite applying load up to the limit of the test rig, and an improvement of at least 12% in seizure resistance was achieved.

Keywords: friction, DLC, plain bearing

Study on the Influence of New and Old J55/D Rod Tube Mixed Mode on Wear Performance of Rod Pump

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In order to explore the effect of mixing old and new J55 tubing and D rod on the wear performance of rod pump. The UMT friction and wear testing machine is used to carry out tests on pure oil, oil sand (sand mass fraction is Unit experimental study on rod and tube wear rules of different J55 tubing/D-grade oil rod mixed modes (J55 new /D old, J55 new /D new, J55 old /D old) under medium conditions, oil water sand (water mass fraction 55%, sand mass fraction 0.02%). The surface wear morphology was characterized by scanning electron microscopy (SEM, EDS) and white light interferometer. The test results show that the wear resistance of the mixed pair with old rod and tube is the worst among the three kinds of mixed pair. There is a Fe2O3 friction protection layer on the surface of the mixed pair, which reduces the direct contact of the material. It has the best wear resistance under the condition of pure oil and oil sand lubrication medium, and is the best choice. This study provides data support for the analysis and evaluation of the wear performance of J55 tubing and D rod under the mixed use of old and new.

Keywords: rod pump, mix old and new, J55 tubing /D rod, friction and wear, lubricating medium

INVITED:

Numerical and Experimental Investigations on Tribological Characteristics of Sliding Bearings in the PTO System

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The Power take off system (PTO system) is commonly used in commercial heavy trucks. The purpose of this PTO system is to transfer the power of the main bearing system to other mechanical structures in the heavy truck. Due to its special structure, the bearing of the PTO system has serious unbalanced-load phenomenon in the working process, and the bearing edge is easy to wear and fail. In this paper, based on the analysis of a type of PTO system, and considering the thermal coupling and journal misalignment, a tribo-dynamics model of multi-bearing coupling multi-degree-of-freedom is established. The tribological characteristics of this system under unbalanced-load conditions are investigated. The results show that due to the influence of unbalanced-load, the bearing closest to the input gear plays the main supporting role. And its friction temperature rise is also the largest. The friction temperature rise of the bearing is concentrated at the bearing edge. In addition, wireless temperature measurement experiments are carried out for the PTO system. The numerical results are in good agreement with the experimental results.

Keywords: PTO system, unbalanced-load, wireless temperature measurement

Prediction of Lubricating Oil Flow Around Piston Rings in Automotive Engines Using Computational Fluid Dynamics

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Although lower piston ring tension is effective in reducing friction loss in automobile engines, lubricating oil consumption (LOC) tends to increase, and prediction methods such as 1D model calculation have been proposed to predict LOC. To improve the accuracy, it is important to understand the dynamic behavior of the piston and the behavior of the lubricating oil around the piston. Therefore, in this study, oil flow simulation by CFD was conducted focusing on the 3rd land among the piston parts, and the calculation results were verified by visualizing the lubricant flow in an actual engine using the photochromism method. To predict the oil flow around the 3rd land, an external force term was added to the Navier-Stokes equation to account for the inertia

force acting on the fluid. The effect of the inertia force acting due to the vertical movement of the piston on the oil behavior was evaluated under different engine operating conditions.
As an experimental approach, visualization of oil film behavior around the OCR was performed using an actual engine equipped with a visual window. To visualize the oil film, a photochromism method was used in which engine oil mixed with a photochromic dye was illuminated with a UV laser to color a portion of the oil film. The behavior of the colored lubricant oil was photographed by a high-speed camera and compared with the calculation results to clarify the validity of the calculations.

Keywords: friction loss reduction, lubricating oil consumption (LOC), computational fluid dynamics

Research on Dynamic Stiffness and Damping Characteristics of Lubricating Oil Film in Sliding Bearings

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When the working state of sliding bearings changes, it is easy to cause bearing wear, abnormal shaft vibration, and reduce bearing life. Once the rotor bearing system, as a core component, is damaged, it will cause huge economic losses. In extreme working conditions, the radial sliding support system is required to have sufficient adaptability. Therefore, it is particularly important to study the dynamic characteristics of the rotor bearing system under time-varying working conditions. This article focuses on the online monitoring and health management requirements of high-end sliding bearings in aviation transmission systems, and establishes a multi parameter dynamic model for this type of sliding bearing. Under given boundary and initial conditions, the Reynolds equation and NS equation are combined to solve the oil film pressure in the dynamic and static pressure region. Considering the decrease in lubricating oil viscosity caused by temperature rise and the thermal deformation of the bearing, the detailed flow situation of lubricating oil under fluid solid thermal coupling conditions is obtained. Finally, the theoretical calculation of the dynamic stiffness and damping characteristics of the bearing is achieved using the perturbation method. The results show that setting the orifice at 30 °, 180 °, and 270 ° can increase the back pressure of the bearing, During the stable operation of the bearings, all three bearing shells reach a floating state, achieving optimal performance; The forward rotation transfer of bearing shells affects axial pressure, oil film thickness, oil film force, as well as the stiffness and damping coefficient of bearing shells and bearings; The rotation angle of the tile affects the distribution of pressure. The larger the rotation angle of the tile, the significantly

reduced stiffness and damping characteristics of the oil film, leading to bearing instability.

Keywords: sliding bearings, dynamic stiffness and damping, fluid solid thermal coupling

Influences of Surface Material, Lubricant and Oil Contamination on the Low-Speed Tribological Performance of Slipper Pairs in Swashplate-Type Axial Piston Motors

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Swashplate-type axial piston motors are widely used under severe conditions because they are able to operating reliable and efficient at high pressure and various ranges of speed. However, the reliability and efficiency of the motor are relatively low at low speed because of insufficient lubrication. The contact between the slipper and swashplate is of critical importance because the insufficient lubrication from this pair causes rapid wear and high friction loss, which significantly reduces motor reliability and efficiency. The influences of surface material, lubricant and contamination on the low-speed tribological performance of slipper pairs are studied. Disc-on-disc testing is conducted to investigate the friction and wear behaviors of the slipper-swashplate contact. Three types of test conditions are carried out to examine the characteristics of friction and wear including (a) boundary lubrication, (b) dry friction, (c) oil contamination. A confocal laser scanning microscope, probe-type contour test and energy dispersive spectroscopy are used to examine the surface of test pieces. The results indicate that most of the upper test pieces are subject to eccentric wear. The material match of manganese brass and alloy tool steel have the best tribological performance with lower wear and friction than other material match. In addition, surface treatment of silvering and nitriding are adverse to the working performance of motor at low speed. The combination of these two surface treatments will lead to an increase in the static friction coefficient, especially when the two surfaces start to move relative to each other. The phenomenon will lead to a lower working efficiency of the motor or even a failure to start-up. This study contributes to the development of high performance fluid power components with high reliability and efficiency.

Keywords: swashplate-type axial piston motor, slipper pair, disc-on-disc test

Numerical and Experimental Investigation of Patterned Liquid Film Thickness in the Surface Energy-Directed Assembly Process

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Patterned metal oxide thin films constitute crucial components of numerous electronic devices. Conventional fabrication process of patterned metal oxide films exhibits high manufacturing cost due to requirements for expensive vacuum system. In contrast, surface energy-directed assembly (SEDA) process which utilizes contact line friction to drag liquids from certain solution and then forms solid film in specific regions of substrate by post process is vacuum-free, addictive in nature and low-cost, demonstrating extensive applicability in cutting-edge electronic devices. Here, a lubrication-theory-based model is developed to reveal parametric dependence of entrained liquid film thickness during SEDA process. A precursor film is assumed in the dry substrate regions and a two-term disjoining pressure relevant to local wetting property is utilized to characterize the motion of three phase contact line with finite contact angle. In addition, a full-curvature correction is adopted to improve accuracy under large slope conditions. Numerical results shows a power-law dependence of maximum film thickness on nondimensional capillary number, which is consistent in trend with experimental results. The power-law dependence can be identified into two region: when capillary number is lower than about 10-3, the exponents associated with capillary number are remarkably smaller than previous researches, which is attributed to lateral and longitudinal confinement of the liquid; when capillary number is higher than about 10-3, the exponents shows an obvious increase due to excess liquids brought by liquid bridge break-up. Besides, numerical and experimental results confirm that the ratio of longitudinal and lateral dimensions of the pattern (denoted with R) can alter the exponent of the power-law relationship in low capillary number region: when the ratio deviate from 1, the exponent will increase. In high capillary number region, the ratio R shows no remarkable influence on the exponents.

Keywords: surface energy-directed assembly, lubrication-theory-based model, full-curvature correction, entrained liquid film thickness

Track 2: Wear and Fatigue

KEYNOTE:

Research on failure Mechanism of Fastening Joint Based on Fretting Tribology

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Fretting damage widely exists in various fields of modern industry. It usually originates from the micro-area between the close and tight contact interfaces, has a strong

concealment, and is easy to be ignored. So it has a great potential danger. Under alternating load, vibration, shock, thermal load and other external alternating loads, fretting occurs on the contact surface of the threaded fastening structure, which can cause the contact surface wear and fatigue crack initiation, resulting in bolt loosening, thread seizure, and even fatigue fracture. This report introduces the main research methods of threaded fastening joint, including the study of failure mechanism based on the fretting tribology theories and research methods, the accurate finite element modeling method and simulation analysis of threaded joint, and the theoretical study of loosening behaviours. Finally, this report proposes several development directions of threaded fastening joint research in the future, including the further study of loosening mechanism, the advanced fastening system design & verifying methods and the development of tool software.

Keywords: fretting tribology, fastening and joining, failure mechanism

INVITED

Application of Hydraulic Bearing Technology in the Field of High-End Equipment Friction Reduction

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In some extreme and harsh working conditions, high speed, high precision, and high load-bearing relative motion are required without generating additional frictional effects. At this time, hydraulic bearing technology can effectively achieve this function. Hydraulic bearing technology is a hydraulic system that forces high-pressure liquid medium into the relative motion interface gap. The relative sliding surfaces are filled with a high stiffness hydraulic bearing oil film, which carries additional loads through liquid pressure, achieving almost frictionless relative motion. Application of hydraulic bearing technology in the field of high-end equipment friction reduction to achieve high-frequency response excitation for fatigue durability and performance testing of high-end testing equipment; Implement six degree of freedom fully constrained decoupling for attitude simulation control of aerospace vehicles; Realize efficient and low loss ultra precision machining of high-end CNC machine tools.

Keywords Hydraulic bearing technology; Friction reduction; High-end equipment

Achieving Low Wear in a Complex Concentrated Alloy CrFeNiNb with Multi-Phase Hierarchical Microstructure

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We propose a strategy to achieve low wear in a complex concentrated alloy (CCA) CrFeNiNb with multi-phase hierarchical microstructure. The CCA comprises a matrix of ultrafine-grained hexagonal close-packed (HCP) Laves phase (80.3 vol%), a secondary face-centered cubic (FCC) phase (18.3 vol%), a minor amount of (Nb,Cr)oxides and a trace amount of uniformly dispersed nanoscale precipitates. The CrFeNiNb CCA exhibits an ultrahigh hardness of 993 (±22) HV and an extremely low wear rate of 7.4 (±0.6) × 10^{-6} $mm^3/(N \cdot m)$ when sliding against a silicon nitride (Si_3N_4) ball. To elucidate the wear mechanism, we characterized the morphology, chemical composition and cross-sectional microstructure of the wear track. The results indicate that the cracked oxide layer, subgrain formation in the FCC phase, and the Shockley partial and full dislocations-triggered intragranular prismatic slip in the C14 Laves phase synergically contribute to the exceptional wear resistance. Furthermore, we conducted a detailed analysis of the chemical composition and crystal structure of the cracked oxide layer, along with a compressive discussion of the subsurface deformation of HCP/FCC phases. These findings offer significant insights into designing wear-resistant alloy through the formation of multi-phase hierarchical microstructure.

Keywords: complex concentrated alloys, sliding wear, microstructure

Research on Fatigue Damage Evolution and Failure of G13Cr4Mo4Ni4V Bearing Steel under Heavy Load Rolling Contact

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G13Cr4Mo4Ni4V high-temperature bearing steel is widely used in aeroengine main shaft bearings, and has excellent contact fatigue strength. A ball-on-rod fatigue testing machine is used to study its rolling contact fatigue(RCF) damage evolution and failure behavior under heavy-load lubrication conditions. Through the measurement of the three-dimensional shape of the contact track of the test rod, combined with the analysis of mixed elastohydrodynamic lubrication, the evolution law of the lubrication behavior in the contact area and its influence on the fatigue failure behavior of the surface layer and the near-surface layer were obtained. Through the analysis of the microstructure components and microstructure morphology of subsurface materials, the damage accumulation behavior of the microstructure of the materials was studied. The mapping relationship between micro-area lubrication behavior and near-surface inclusion and damage accumulation of subsurface materials was discussed. The results show that the contact surface abrasion, micropitting and plastic deformation cause the change of the lubrication state of the contact surface, and the competition mechanism and interaction between the change of lubrication state, the inclusion of the near-surface layer and the accumulation of damage to the microstructure of the subsurface material are the main factors causing different fatigue failure forms. This study is the first to analyze the

fatigue damage evolution and failure behavior of G13Cr4Mo4Ni4V bearing steel in detail, and provide data for screening materials and processes for bearing manufacturing.

Keywords: bearing steel, rolling contact fatigue, damage evolution, mixed elastohydrodynamic lubrication, plastic deformation

INVITED

Testing and Prediction of Fretting Wear and Fatigue Damage for Risk Management and Asset Protection of Nuclear Power Systems

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The presentation provides an overview of the methodologies used to predict fretting wear damage of critical nuclear structural components, namely, the steam generator and the fuel assembly. The effect of process parameters, e.g., material combinations, temperature, water chemistry, contact configuration is discussed. A newly proposed acceleration-controlled random excitation test method for conservative design of components susceptible to fretting wear damage is discussed. This method simulates realistic conditions of mixed fretting regime, and the presence of high amplitude displacement spikes. A unified fracture mechanics-based approach for fretting wear prediction under sliding/impact motions is also presented. This approach eliminates the non-uniqueness problem associated with conventional work rate approach.

An overview of the problem of fretting fatigue damage is presented in terms of the physical phenomena that govern the crack initiation and propagation processes, and their dependence on the process variables, e.g., slip amplitude, contact pressure, alternating stress amplitude, and mean stress. A methodology for predicting the fretting fatigue limit and the component life using a fracture mechanics approach is discussed. The results demonstrated the capability of the model to predict the conditions under which small fretting-induced fatigue cracks are arrested. Experimental validation of the model by predicting the fretting fatigue limit of Inconel 600 and Incoloy 800 alloys at high temperature showed the model accuracy and reliability.

A future outlook for R&D to improve simulative fretting wear testing is presented. The issues of thermally controlled fretting wear/fatigue test equipment and the satisfaction of thermal similarity requirement, through microcontact-based modelling of the phenomenon of thermal constriction to predict frictional heating, are discussed.

Keywords: fretting wear, fretting fatigue, modelling

INVITED

Artificial Neural Network Supported Characterization and Design of Polymer-Based Tribocomposites

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Over the past few decades, polymer-based composites have gained widespread application in tribological systems due to their lightweight, self-lubricating, and high damping properties. To meet the demands of compact designs, which result in increased specific loads, these materials are often reinforced with fibers and filled with internal lubricants as well as submicron-sized particles for enhancing their tribological performance.
The characterization of tribological materials is a time-consuming and laboratory-intensive process, which should not only focus on different kinds of materials but also take place under various load conditions to meet the requirements of different working conditions. In this regard, we applied Artificial Neural Networks (ANNs) as a powerful and efficient tool, in order to increase the efficiency in tribological materials evaluation. With their capability to learn and predict, ANNs significantly accelerate the testing and data processing by quickly identifying the stationary phase in tribological experiments. They also enable quicker analysis and a deeper understanding of the relationship between composition and material behavior under specific conditions, thus speeding up the optimization of material performance. Moreover, ANNs facilitate efficient comparisons between different material formulations, help to assess production costs and tribological performance comprehensively, and select the most cost-effective material solution while ensuring the required friction and wear performance. This strategic approach marks a significant step from empirical methods to systematic strategies, providing strong support and a new perspective for the development and application of polymer-based tribological composites. The results of our current research work indeed show that the application of ANNs can not only significantly accelerate the characterization process but also demonstrate a strong predictive ability for tribological performance, leading to an effective way to design cost-effective tribological materials.

Keywords: PEEK, artificial neural network

Investigation of Impact-Sliding and Tangential Fretting Wear Behavior of Zr-4 Alloy under Random Vibration

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A Zr-4 alloy tube versus Zr-4 alloy spring contact was subjected to impact-sliding and tangential fretting wear under random vibration. Under tangential fretting wear, the results revealed that amplitude of displacement (D) and normal force (Fn) were more influential in fretting regime than that of frequency (f). It was evident that the fretting performances of Zr-4 alloy tubes were determined by the fretting regime, whether under sinusoidal vibration or random vibration. Moreover, the mean energetic friction coefficient was a better candidate for comparing and correlating between sinusoidal fretting and random fretting. Similarly to the fretting regime, both D and Fn played significant roles in the mean energetic friction coefficient. An approximation methodology for predicting the wear of random using such parameter of sinusoidal fretting was presented. By comparison with experimental findings, the accuracy and feasibility of this method were proved. In addition, under impact-sliding fretting wear, the peak value of impact force and tangential force increased with the increase of impact force at the same amplitude of displacement. Meanwhile, the increasing extent of impact force was larger than that of the tangential force. Thus, it could be suggested that the impact process reduced the ejection rate of wear debris, while the tangential fretting wear procedure accelerated the formation and ejection of wear debris.

Research on Modification of Copper Matrix Composites by Composite Ceramic Powder Prepared by Ball Milling

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To address issues such as deterioration of braking stability during high-speed rail emergency braking, a copper-based powder metallurgy brake pad reinforced with a composite ceramic powder (B4C-SiC) was prepared. Through exploration of friction interface behaviors and microstructural evolution, the optimization of a high-speed, high-temperature-resistant, low-wear brake pad formulation was pursued. The study revealed that the optimal proportion of composite ceramic powder (simple mixture) in the brake pads was 5% B4C -3% SiC. Specifically, SiC significantly improved friction performance at medium to low temperatures, although it tended to detach at high temperatures. Conversely, B4C generated a stable B2O3 ceramic film at high temperatures, ensuring consistent friction performance, thus exhibiting complementary effects. Furthermore, the composite ceramic powder prepared via high-energy ball milling experienced the fracture-recombination of bonds, resulting in new infrared peaks. This phenomenon possibly contributed to the fluctuation in mechanical properties of the brake pads with increasing B4C-SiC powder content, ultimately leading to the enhancement of friction stability. The formation of new bonds during milling played a facilitating role in the sintering process of the brake pads (mitigating the negative impact of weak interface bonding between ceramic particles and the matrix), thereby increasing the compactness of the brake pads. Additionally, brake pads reinforced with 10% B4C-SiC powder (via ball milling) exhibited outstanding friction and mechanical performance, addressing the challenge of incompatible improvements between mechanical and frictional properties to some extent. Moreover, this formulation increased the proportion of ceramic particles in copper-based powder metallurgy brake pads, significantly enhancing high-temperature stability and friction performance.

Keywords: composite ceramic powders, tribo-film, C/C-SiC

Effect of Temperature on Fretting Wear and Corrosion of High-Silicon T91 in the Liquid Lead-Bismuth Eutectic(LBE)

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The development of high-performance nuclear steel materials for use in lead-cooled fast reactors is becoming a concern in the nuclear industry. Si elements are easy to combine with oxygen on the metal surface to form a passivation film, reducing the damage of fretting corrosion in liquid LBE. Therefore, the self-designed fretting corrosion experimental equipment was used to study the fretting corrosion behavior of high-silicon T91 in oxygen-rich LBE at different temperatures. Temperatures range from350℃ to 600℃. The friction coefficient and friction force were monitored to analyze the fretting corrosion behavior of high-silicon T91. The surface and cross section of the wear scars were analyzed by white light confocal 3D profilometer, SEM, EDS and XPS. Part of the results show that fretting behavior at all temperatures is mixed slip. The increase of Si content improves the wear resistance of the alloy surface. The combination of oxygen and Si in LBE to form a protective oxide film can reduce the damage caused by fretting corrosion. However, excessive temperature intensifies the damage depth of the wear subsurface and weakens the positive effect of Si elements. More conclusions will be presented in the report. The experimental results of this paper can provide reference data for the development of nuclear structural steel for lead-cooled fast reactors.

Keywords: fretting corrosion, high temperature, high-silicon T91

The Investigation of Lubricant Viscosity on Rolling Contact Fatigue Wear

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With the recent widespread of electric vehicles, the acceleration of drivetrain components has become a concern, leading to fatigue damage in gear and bearing sliding surfaces. Micropitting, a form of fatigue wear where micro-scale damage marks

appear on surfaces, is a critical issue. The occurrence of micropitting can directly lead to malfunction or even a halt in machine operation, necessitating urgent countermeasures. Fatigue damage in sliding components is a complex phenomenon where the microstructure and crystalline structure of materials change continuously. Its occurrence is known to be classified into two categories: surface-initiated and subsurface-initiated. In subsurface-initiated cases, it's understood that micropitting occurs after cracks originate from material heterogeneities or internal voids. However, there remain many uncertainties regarding the mechanism of surface-initiated crack formation.

In conventional research related to micropitting, experiments were conducted under conditions where rolling and sliding contact occurred simultaneously. However, it has been reported that the fatigue surface is removed by sliding wear. Therefore, testing under a pure rolling condition, which is less affected by sliding wear, is considered to be effective in investigating the mechanism of lubricant viscosity's influence on the occurrence of micropitting.

In this study, ball-on-disc traction tests with different viscosity polyalphaolefins (PAOs) were conducted under both rolling-sliding and pure rolling conditions. Subsequently, the damaged areas on the discs were evaluated using a laser microscope and MATLAB. Results showed that increasing lubricant viscosity promoted the damaged area on the discs. Higher viscosity in a base oil like PAO increases the pressure-viscosity coefficient, leading to higher contact pressure. We considered that this yielded a correlation between the micropitting and the viscosity of PAOs. To optimize the fatigue wear resistance of power transmission components, it is necessary to design lubricant from the fundamental perspective of its viscosity.

Keywords: rolling contact fatigue, micropitting, lubricant viscosity

Effect of Work-Rate on Fretting Wear and Corrosion of 690 Alloy under High-Temperature and High-Pressure Conditions

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During shutdown inspections of pressurized water reactors, the heat exchange tubes of the steam generator are often damaged and need to be replaced. The main reason is that the heat exchange tube impacted by the fluid collides with the support part, causing wear. In the corrosive environment, the interaction between wear and corrosion makes the tube suffer greater damage. Therefore, studying the damage mechanism of tubes under specific conditions has guiding significance for increasing the service life of tubes. In this paper a high-temperature and high-pressure fretting wear and corrosion device with in-situ electrochemical testing is used to measure the effect of different work-rate (4mW, 5mW, 6mW) on the fretting wear and corrosion of 690 alloy in a 0.05mol sodium chloride solution at 285°C. The corrosive data is collected and the post-

experiment samples are characterized. The contributions of wear, corrosion, and synergy in wear and corrosion are quantified, and the wear damage mechanism is analyzed. Experimental results show that as the work-rate increases, the total wear volume increases. In the synergistic effect of wear and corrosion, the wear occupies a dominant position, but the synergistic effect cannot be ignored. The main wear mechanisms are abrasive wear and oxidative wear.

Keywords: fretting wear, corrosion, work-rate, synergistic effect, electrochemistry

Understanding Structural Effects of Friction and Wear Mechanism of Carbon Fiber Reinforced Three-Dimensional Braided Composites

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Carbon fiber reinforced three-dimensional braided composites with lower coefficients of friction (COFs) and higher friction resistance are essential to meet the demands of rapidly advancing industries such as automotive, aviation, and aerospace. Therefore, this study involved the preparation of braided composites composed of different unit cells and an analysis of the effect of braided structures on the friction and wear properties of the composites. Experimental and Finite element analysis (FEA) demonstrated that the unit cell and braiding angle exert a significant influence on the friction and wear properties of the braided composites. The COFs is primarily influenced by the surface modulus of composite, with composites possessing larger surface moduli exhibiting lower COFs. The wear of braided composites is mainly caused by cracks generated by periodic plastic deformation. Although wear mainly occurs on the surface of composite materials, wear is not only affected by surface structure, but the overall structure significantly affects its wear performance. Owing to higher fiber volume fraction and tighter yarn interweaving of inner unit cell and the composite with larger braiding angle, the plastic displacement of these composite is effectively limited, thus reducing the wear performance. The wear rate of composites with a braiding angle of 40° exhibits nearly 100% reduction compared to that of composites with a braiding angle of 10°. This study provides comprehensive characterization and deep understanding of friction and wear properties of carbon fiber/epoxy braided composites, which will contribute to the low friction and wear resistance design of braided composites and broaden broadening the application field of braided composites.

Keywords: braided composites, friction and wear, carbon fiber

Study on Wear Mechanism, Microstructure and Mechanical Properties of CuCrZr Alloy Surface for High-Speed Sliding Electrical Contacts

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High-speed sliding electrical contact behavior is widely used in electromagnetic rail launch, electrified railway systems, aerospace and other fields. During the electromagnetic rail launch process, due to the existence of large current density (≥100 GA/m2) and high sliding velocity (outlet speed ≥ 2 km/s), wear and arc ablation occur on the surface of the rail, the microstructure and mechanical properties of the rail are changed, which affects the electrical contact state and the life of the system. This study investigates the wear mechanism, microstructure and mechanical properties of rail surface after electromagnetic rail launch. The results show that typical mechanical wear (adhere and furrow) and electrical wear (holes and ablation pits) occur on the surface of the rail, and the wear mechanism changes from mechanical wear to electrical wear along the sliding direction. Under the action of the heat-force cycles, polygonal grain structure appear on the contact surface of the rail, and the nano-Cr phase precipitates at the polygonal grain boundaries, which plays the role of napping grain boundaries and refining grains and makes the nanoindentation hardness of the rail surface higher than that before service. This study provide guidance for developing for high-performance rail materials aimed at reducing surface damage during electromagnetic rail launch.

Keywords: wear mechanism, microstructure and mechanical properties, electromagnetic rail launch

Friction and Wear Properties Analysis of the Spring-Energized Seal Made of Filler Modified PTFE

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The spring-energized seal has good sealing effect in the wide range of pressure and temperature, and can compensate for the deviation of compression caused by installation eccentricity and high temperature aging. However, the spring-energized seal is the contact seal, the shell material polytetrafluoroethylene (PTFE) is easy to be worn in the end face relative motion, which reduces the sealing performance and eventually leads to sealing failure. In this paper, PTFE filled with 5%wt BaSO4(Ba), carbon nanotubes (CN), glass fiber (GF), MoS2 (Mo), graphite (Gr), Si3N4 (Si) and WS2 (WS) were prepared. The wear properties and mechanical properties of PTFE filled with different fillers were tested and compared. Based on the experimental results, a wear simulation model based on the improved Archard wear model was established. The sealing performance of the spring-energized seal with different shell materials after wear was analyzed. The friction torque and wear characteristics of BaSO4 / PTFE material spring-energized seal were tested by experiments. The results showed that the friction coefficient and the dimensionless wear coefficient of Ba / PTFE are the smallest when the stable friction was achieved. Compared with the spring-energized seal made of PTFE, the friction coefficient of the spring-energized seal made of Ba / PTFE is reduced by 8.26 %, and the dimensionless wear coefficient is reduced by 92.48 %. When the relative slip is 4 × 105mm, the wear rate is reduced by 52.7 %, and the friction torque reduction rate is reduced by 27.84 %. The spring-energized seal made of Ba / PTFE has smaller friction torque and longer life under dry friction conditions.

Keywords: PTFE, filling modification, spring-energized seal, sealing performance

A Peridynamic Model for Rail Crack Initiation with Cavity Defect

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Cavity defects can aggravate the rail crack initiation. To study their effect on rail fatigue crack initiation behaviour, a peridynamic model of rail crack initiation considering the characteristics of the cavity defect was proposed. First, based on the low-cycle fatigue test data, the bond failure criterion of the rail material was derived and verified to characterize the fatigue damage performance. Then, mathematical expressions for circular, triangular and rectangular defect characteristics were proposed, establishing a prefabricated method for rail cavity defects. Based on the ordinary state-based peridynamic fatigue theory, a rail crack initiation model with the cavity defect was constructed. Finally, the behaviour of rail crack initiation with the cavity defect was analysed.

Keywords: rail crack initiation, rolling contact fatigue, cavity defect, peridynamics

Effect of Molybdenum Disilicide and Nano-graphene on Tribological Properties of Copper-based Composites

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In this work, the Cu-MoSi2-GNS composites with excellent mechanical properties and wear resistance were prepared with dual doping of MoSi2 and nanographene (GNS) to enhance copper matrix composites. The effects of second phase (i.e., MoSi2, GNS) on the microstructure, mechanical properties, electrical properties and friction and wear

properties of Cu-MoSi2-GNS composites were investigated. At the same time, the tribological behavior and damage law of Cu-MoSi2-GNS composites under various conditions (e.g., room temperature friction, high temperature friction and current-carrying friction) were systematically studied. The results show that MoSi2 particles can effectively adjust the strength, hardness and wear resistance of the materials as a wear-resistant component. As a lubrication component, the addition of nano-graphene can improve the stability of the friction operation process and reduce the wear of the dual material. When 5 wt.% MoSi2 and 0.3 wt.% GNS were added, the tribological properties of Cu-MoSi2-GNS composites were the best, with relatively low average friction coefficient and wear rate. Under different friction and wear conditions, the composites show different wear mechanisms. At room temperature, the wear mechanism of Cu-MoSi2-GNS composites is mainly adhesive wear and abrasive wear. However, at high temperature, the temperature of the friction surface increases sharply, and the adhesive wear is aggravated. At the same time, the surface delamination caused by fatigue wear is more serious, resulting in an increase in wear. The wear mechanism in the current-carrying environment is different from the wear mechanism at room temperature and high temperature. In addition to mechanical wear, there is obvious arc erosion phenomenon, indicating that the friction and wear in the current-carrying environment is the coupling effect of mechanical wear and arc erosion, which will change the wear morphology and wear resistance behavior.

Keywords: copper-based composites, wear

Track 3-I: Coatings and Surfaces Engineering

KEYNOTE

Fabrication of Electronics and Sensors Using A Surface Energy-Directed Assembly Process

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The development of internet of things (IoT) has created a great demand for all kinds of electronics and sensors, and the success of IoT strongly depends on whether the electronics and sensors could be fabricated cost-effectively or not. Printing processes, such as ink-jet printing, screen printing, and transfer printing, have a great potential to be used to fabricate the electronics and sensors owing to their merits of low cost, low processing temperature, vacuum-free and compatibility with various substrates. However, all these printing techniques have a limited resolution of micro or sub-micro scale. As an alternative to the aforementioned printing processes, surface energy-directed assembly (SEDA) process allows fabrication of multiscale structures with sub-microscale resolution and nanoscale fidelity. The SEDA process combines the solution coating methods (spin coating, dip coating, etc.) with substrate surface energy patterning. The coating method is utilized to generate a relative motion between the nanoparticle solution and the substrate, while patterns on the substrate with high surface energies are used to impede the relative motion locally and entrain certain amount of solution when the bulk solution passes by. After drying of the entrained solution, the nanoparticles left behind form micro/nano patterns which replicate the geometry of the high surface energy pattern areas. Using the SEDA process, we have demonstrated fabrication of flexible and transparent metal mesh electrodes for touch screen panels, metal oxide thin film transistors, etc. The low cost and extensive applicability of the SEDA process makes it a good candidate for the fabrication of electronics and sensors for IoT.

Keywords directed assembly, surface energy, nanoparticle, electronics

In-situ Modified MoS_2 Lubricant Grown by Laser Irradiation for Enhanced Tribology Performance

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Laser irradiation in liquid (LIL) can create extreme nonequilibrium conditions in nature such as ultrahigh temperature (104 K) and ultrahigh pressure (1 GPa) in nanoseconds, which leads to the reshaping, phase transition, and even new phase that is different to the target materials. Due to the characteristic of high efficiency and non-pollution, LIL has recently been recognized to be an important synthesis route for nanocomposites or nanostructures. Molybdenum disulfide (MoS2) with a typical layered structure is extensively used in lubrication. However, the easily agglomeration of nanosheets with large specific surface area limits the practical application of MoS2. In our work, one MoS2 nanospheres with a morphology resembling tremella-like structure were prepared by laser irradiation in liquid at ambient conditions. Such MoS2 nanospheres as glycerol additives can effectively inhibit the aggregation and precipitation, and exhibit excellent dispersion stability, good wetting property on steel surfaces due to their unique tremella-like structure. Importantly, the addition of MoS2 nanospheres can significantly reduce friction and wear. The characterization and analysis of worn surfaces indicate that the key factors for achieving ultra-low friction property are the effective formation of a MoS2 protective film, the self-storage lubricant characteristic and solid-liquid synergistic lubricating effect. Thus our study is of great significance to advance studies on nano- and submicro-spheres as additives for the usage period of fossil fuel to save mechanical energy and reduce mechanical failure caused by wear.

Keywords laser irradiation, molybdenum disulfide, additives, tribology

Flexible Transistor with All Liquid Electrodes

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The "metal-semiconductor" contact interface is a particularly important interface for semiconductor devices. The contact state has profound impact on the interface properties and the electrical performance. Atomic-level smooth interfaces acted as electrical contact interfaces is attractive. This study draws inspiration from the photolithography microchannel method to construct transistor, using liquid metal as the source/drain electrodes and ionic liquid as the gate electrode, then encapsulating the aforementioned liquid inside a flexible substrate PDMS to construct a fully flexible liquid-electrode transistor. Thanks to the atomic-level smooth electrical contact interface formed between two-dimensional materials and liquid electrodes, the transistor has excellent characteristics such as high mobility, high switching ratio, low sub-threshold swing, and low Fermi pinning. Here, we propose a new paradigm of fully flexible transistors, which opens up new ideas for solving the Fermi pinning problem and constructing flexible wearable devices.

Keywords metal-semiconductor interface, electrical contact interface, semiconductor devices

The Design Method for Surface Texture of Sliding Friction Pairs Based on Machine Learning Under Mixed Lubrication

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Surface texture plays an important role in reducing friction, which has been widely applied in mechanical equipment. In this paper, a surface texture design method for sliding friction pairs based on machine learning is proposed, which consists of three parts: model training and construction, texture design and result verification. Firstly, artificial neural network(ANN) and gradient boosting decision tree(GBDT) are selected as the optimal forward and reverse models respectively by comparing five machine learning models. Then the optimal forward and reverse models are combined to design surface texture and verify the design results. The results show that the combination of forward and reverse models is reliable. Lubricant viscosity and friction coefficient obviously affect the design of texture size, depth and coverage. Finally, the feasibility and effectiveness of this method are validated by friction experiments. The results provide a new approach for the design of surface texture.

Keywords surface texture, sliding friction pairs, friction coefficient, machine learning

All-Solution-Processed High-Resolution and High-Fidelity Thin Film Transistors and Logic Circuits Fabricated Via a Humidity Controlled Surface Energy-Directed Assembly Process

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Solution-based processes have received considerable attention in the fabrication of electronics and sensors owing to their merits of low-cost, vacuum-free, and simple in equipment. However, the current solution-based processes are either absence of patterning capability or have low resolution (> 20 μm) and low pattern fidelity in terms of line edge roughness (LER).
Here, we present a surface energy-directed assembly (SEDA) process to fabricate metal oxide patterns with high resolution and low LER, in this process, we use plasma treatment and self-assembled monomolecular layers, respectively, to make the surface hydrophilic or hydrophobic, and then combine them with photolithography to complete functionalized substrate preparation, after withdrawing the functionalized substrate from the precursor solution, the metal oxide solution was selectively entrained on the hydrophilic pattern regions, forming metal oxide patterns after dried. Experiment results show that high pattern fidelity can only be achieved at low relative humidities of below 30%. The reason for this phenomenon lies in negligible water condensation on the solution droplet. At a high relative humidity, the final metal oxide patterns shrink, resulting from water condensation-induced increase of the surface tension of the solution droplet. Employing the SEDA process, all-solution-processed metal oxide thin film transistors (TFTs) are fabricated by using indium oxide as channel layers, indium tin oxide as source/drain electrodes and gate electrodes, and aluminum oxide as gate dielectrics. TFT-based logic gate circuits, including NOT, NOR, NAND and AND are fabricated as well, demonstrating the applicability of the SEDA process in fabricating large area functional electronics.

Keywords surface energy-directed assembly, humidity

KEYNOTE

Electronic Manufacturing Tribology

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Electronic manufacturing with high intelligence and high integration features is the upstream of the high-end manufacturing industries. The critical dimension during fabrication process is quite close to the atomic scale, and the tribology phenomenon plays critical role in determining the processing quality and the product performance. The development history of tribology and electronic manufacturing was summarized and the concept of electronic manufacturing tribology was first proposed. Its important role in promoting the development of electronic manufacturing was elaborated afterwards. We also commented on the current situation of the tribology development in the typical application scenarios of the electronic manufacturing process. Tribology in the micro electro mechanical systems (MEMS), the integrated circuit fabrication, the flexible electronic manufacturing and the high-performance storage was taken as typical applications, and their tribology fundamental and research progress in the last two decades were summarized. The relevant research on electronic manufacturing tribology could enrich the micro-nano tribology, and provides important basis for developing novel and high-performance basic electronic products as well. The presentation will also focus on the development challenges and opportunities of electronic manufacturing tribology. Finally we will provide an outlook of the development challenges and opportunities. It is believed the tribology will definitely play more decisive role on the manufacturing of advanced electronics and nanodevices.

Keywords electronic manufacturing, tribology

FACs/Nanomagnetite/Epoxy Functional Coating with Wear-Resistant and Magnetic Properties

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In view of the wear problem of key components of high-end technical equipment with magnetic rheological device under magnetic field and wear composite service conditions, a series of epoxy resin (EP) composite coatings reinforced with magnetic particles (Fe_3O_4) and fly ash cenospheres (FACs) were fabricated successfully. Polypyrrole (PPy) and silane coupling agent (KH550) was used to improve the dispersibility of Fe_3O_4 and FACs in EP, respectively. The structural and morphological features of the fillers and the composite coatings were characterized by Fourier transform infrared and scanning electron microscopy. Moreover, a CFT-I material surface performance comprehensive tester was used to investigate the tribological behaviors of the as-prepared composite coatings. Vibrating Sample Magnetometer was used to investigate the coatings' magnetic property. The results demonstrated that adding a certain amount of double fillers will have a synergistic effect, and its mechanical properties are better than those of single fillers. FACs and Fe_3O_4 increase the strength and modulus of EP, which can suppress cracks and evenly distribute the load into the matrix. The tribological property of the FACs/f-Fe_3O_4/EP composite coatings was optimal under magnetic fluid friction, which is about an order of magnitude lower than the average friction coefficient under dry friction. We ascribed

this to the load-carrying capacity of the fillers, which played a more important role under the magnetic fluid lubrication condition. Compared to the Fe_3O_4/EP composite coating, the saturated magnetization of the FACs/f-Fe_3O_4/EP composite coating was reduced by only 0.99 emu/g and the susceptibility by only 1.66×10^{-4} m^3/kg. This indicates that non-magnetic FACs and PPy have less influence on the magnetic properties of the EP composite coating. Therefore, the EP composite coating jointly enhanced with modified Fe_3O_4 and FACs not only has higher wear resistance but also introduces magnetic property.

Keywords epoxy nanocomposite coating, formation mechanism, mechanical property, wear resistance, magnetic property

Surface Modification of Polytetrafluoroethylene (PTFE) Fibers through Methyl Methacrylate (MMA) Polymerization for Self-Lubricating Composites

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PTFE fibers exhibit strong inertia and possess restricted interfacial compatibility with resin, thereby constraining the application of PTFE self-lubricating composites. To address this issue, PTFE-g-MMA fibers were synthesized by grafting MMA onto the surface of PTFE fibers using high-energy irradiation and chemical grafting techniques, resulting in the enhancement of the tribological properties (the friction coefficient has been reduced by approximately 42.2% and the wear rate has been reduced by about 87.9%) and mechanical properties (the interlaminar shear strength (ILSS) experienced a substantial increase of approximately 45.8%) of the composites. The influence of grafting modification on the formation of PTFE transfer films and the effect of modification time on the tribological properties of composites were investigated systematically. The results indicated that graft modification disrupted the C–F bond of PTFE and promoted the formation of metal-chelated carboxylates, facilitating the formation of PTFE transfer films on the counter surface. This research could provide a general and feasible strategy for large-scale modification of PTFE fibers with exceptional comprehensive properties.

Keywords grafting modification, transfer film, self-lubrication

Anodization Treatment of Aluminum Alloy Inducing Formation of Low Friction Interface in Engine Oil

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Aluminum alloy is a commonly used material in automobile industry for its high strength ratio, workability, and recyclability. For engine sliding parts, such as crankshaft journal bearings, aluminum alloy is an alternative to alloys containing lead. However, aluminum-based alloys used in oil lubricated sliding contact against steel show poor tribological properties due to their adhesion to countersurface.

In this research, Al-Sn-Si alloy was treated using anodization treatment, forming anodic oxide layer, which is expected to prevent aluminum adhesion. The frictional behavior of anodized aluminum alloys slid against steel in engine oil was studied using a ball-on-disk tribometer. Al-Sn-Si alloy disks were polished and anodized. JIS-SUJ2 steel ball (Ø8mm) was used as countersurface. The sliding contact was immersed in 80 °C engine oil containing zinc dialkyldithiophosphate (ZDDP) and molybdenum dithiocarbamate (MoDTC). Load and sliding velocity were set to 25 N and 0.1 m/s. Surface analysis after friction tests were performed using Scanning Electron Microscope (SEM), and Energy-Dispersive X-ray Spectroscopy (EDS).

Friction tests revealed that anodic oxide layer does not prevent transfer to countersurface in oil without additives, resulting in a high friction coefficient $\mu \simeq 0.12$ after 1000 cycles sliding. However, in fully formulated engine oil, aluminum adhesion is suppressed by ZDDP and low frictional interface ($\mu \simeq 0.05$) is formed by MoDTC after running-in. Depending on anodizing conditions, high friction period ($\mu \simeq 0.15$) with aluminum oxide transfer was observed during the 200-400 first cycles in engine oil, while for other anodizing conditions, friction decreased in the first cycles.

These results show that aluminum transfer suppression by ZDDP is enhanced by anodic oxide layer, and this effect is affected by anodizing conditions. It is suggested that the friction system is governed by a competition between abrasive or adhesive wear of the anodic oxide layer and reaction with ZDDP.

Keywords aluminum, ZDDP, anodization

Improved Tribological Performance of Al2O3 Fibers at Microscale Via a WS2-PEG/WPU Self-lubricating Sizing Agent

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In this work, a new green modified tungsten disulfide (WS_2-PEG)-waterborne polyurethane (WPU) self-lubricating sizing agent was proposed to improve the tribological properties of microscale alumina fibers (single Al_2O_3 fiber). The chemical characterization analysis confirmed the successful synthesis of WS_2-PEG nanosheets with an average particle size of 211 nm, which significantly increased the dispersion of WS_2 in sizing agent. Subsequently, the single Al_2O_3 fibers were sized (denoted as WS_2-

PEG/WPU@single Al_2O_3 fibers) and their friction and wear properties were discussed. As a result, the friction coefficient (COF) value and the wear of WS_2-PEG/WPU@single Al_2O_3 fibers reduced with the increase of normal load because of the introduction of WS_2-PEG nanosheets, the formation of a continuous, dense and high load-carrying lubricating tribofilm on the fiber. When the concentration of WS_2-PEG nanosheets was 0.05 g/L, the COF value of fiber was maximally reduced by 43.48%, at which time the best wear resistance was achieved.

Keywords single Al_2O_3 fibers, WS_2-PEG nanosheets, wear resistance

KEYNOTE

Design and Preparation of Inner Surface Coating

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Components with inner surfaces as working surfaces are widely used in daily life, industrial production, national defense and other fields. Surface coating technology has been used to reduce the friction and wear and to prolong the work life of inner surfaces. Due to the limitation of the inner cavities, it is difficult to ensure the uniformity of coating thickness because the process of coating material entering pipe is hindered.
Aiming at the inner surface modification requirement, influence of the magnetic field and electric field on the trajectories of arc ions was studied by the charged particle tracing simulation. Based on the charged particle tracing simulation, the influencing mechanism of magnetic field and electric field on the trajectories of ions was revealed. According to the optimization results of numerical simulation, a magnetic-field-assisted arc ion plating device was developed. The influencing mechanism of magnetic field (intensity and spatial position) coupled with electric field on the thickness and uniformity of the inner surface coating were studied experimentally. Results show that the thickness and thickness uniformity of the inner surface coating can be significantly improved by changing the magnetic field intensity and spatial position.

Keywords inner surface coating, magnetic field, ion motion control

Structure and Friction Performance of Sulfonitrocarburizing Layer Prepared by Plasma Nitrocarburizing and Low Temperature Ion Sulfurizing

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During plasma nitriding, a portion of the iron particles sputtered from the substrate combined with nitrogen to form iron nitride and cover the surface of the sample, giving the treated sample a gray appearance. In this work, ion sulfurization was intended to combine with plasma nitrocarburizing to form a sulfonitrocarburizing layer on 38CrMoAl. The samples treated with nitrogen, carbon, and sulfur at the same time showed violent COF fluctuations and poor wear resistance during the friction process. A dense and antifriction sulfonitrocarburizing layer was prepared by plasma nitrocarburizing and then low temperature ion sulfurizing. Through process optimization, the sulfurizing layer achieved a balance between the anti-friction effect and the binding force. The composite structure of FeS polycrystals, sulfur-containing nanocrystals, and a nitrocarburizing layer made the sulfonitrocarburizing layer show an excellent anti-friction effect and wear resistance.

Keywords solid lubricant additives;self-lubricating composites

Research on Interface Metallurgical Behavior of Plasma Jet Cladding Coating

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Preparing high-performance metallurgical or micro metallurgical bonding coatings is one of the effective ways to obtain the high reliability of coatings under extreme working conditions such as large loads and strong impacts. The metallurgical behavior between coatings and substrates at the interface was researched according to the synergistic effect of heat and kinetic energy provided by "transfer arc + non transfer arc (combined arc)" using plasma jet cladding technology. A thorough analysis of the heating effect of the combined arc on particles and matrix was conducted, as well as the influence mechanism of factors such as spraying distances and powers on particle spreading and substrate surface structure. The reaction mechanism of self-reactive powder in the jet was analyzed through EDS element testing of droplets and coating cross-sections at different spraying distances of Al-Ni system. It was found that the heating effect of plasma spraying cladding at a distance of 24mm was equivalent to that of atmospheric plasma spraying at 100mm, and plasma spraying cladding has higher heating efficiency for particles in the jet with the combined arc. The thermal influence depth of the substrate significantly increases as the power increases, while the increase in element diffusion depth is not significant. There is a trend of micro metallurgical bonding between the coating and substrate interface, and the bonding strength has increased from 35MPa to 54MPa, which provides a theoretical basis for obtaining stable micro metallurgical bonding coatings.

Keywords plasma jet cladding, interface metallurgical behavior, combined arc, coating

Microstructure and Corrosion-Wear Property of WC10Co4Cr-AlCoCrFeNi Composite Coating Prepared by HVOF Spraying

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In the process of ultra-deep drilling, the key parts of positive displacement motor are easy to corrosion and wear in the drilling fluid conditions, so the surface protection is adopted to prolong its service life. the WC10Co4Cr-AlCoCrFeNi composite coating was prepared by HVOF spraying technology on the surface of commonly used material of positive displacement motor (40CrMnMoA), analysis the corrosion-wear resistance of WC10Co4Cr-AlCoCrFeNi composite coatings with different WC10Co4Cr content, 25% (*x*=0.25), 50% (*x*=0.5), 75%(*x*=0.75). The morphology of the coating was observed by field emission scanning electron microscopy (SEM), The phase structure and residual stress of the coating were detected by X-ray diffractometer (XRD), A single point automatic digital microhardness tester (DigiVicker1000A) measures the microhardness of the coating, nano-indenter(Agilent U9820A) measures nano-hardness, Electrochemistry workstation (CorrTest) detects potentiodynamic polarization curve, Friction and wear testing machine (UMT-Tribolab, Bruker) was used to test the corrosion-wear properties of the composite coatings. The results showed that the WC10Co4Cr-AlCoCrFeNi composite coating has compact microstructure, including BCC phase (Fe-Cr, Al-Ni), WC phase, W_2C phase and Co_3W_3C phase. with increase of WC10Co4Cr content, the BCC phase content decreases, and the number of intermetallic compound phases increases. the microhardness, nano-hardness and residual stress of the composite coating are increased, and the microhardness was 861.4 $HV_{0.2}$, 1015.2 $HV_{0.2}$, 1108.7 $HV_{0.2}$. the nano-hardness was 8.28 GPa, 9.54 GPa, 10.93 GPa, the residual compressive stress is -923 MPa, -1105 MPa, -1219 MPa, respectively. When *x*=0.5, the $(WC10Co4Cr)_{0.5}$-$(AlCoCrFeNi)_{0.5}$ composite coating has the highest open circuit potential and the smallest corrosion current density. and has the best corrosion-wear resistance, and wear rate is as low as 9.59×10^{-7} $mm^3\cdot N^{-1}\cdot m^{-1}$. the main corrosion wear failure mechanisms of composite coatings are pitting corrosion, abrasive wear and adhesive wear. and when *x*=0.5, it's the slightest.

Keywords HVOF, $WC_{10}Co_4Cr$, AlCoCrFeNi, composite coating, corrosion-wear

Nanosecond Laser Ablation of Micro-pits in Ni60/WC Coatings with Coupled Thermal-stress Simulation and Parameter Optimization

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In order to solve the problem of crack sprouting inside the micro-pit caused by improper design of laser ablation process parameters, this study establishes a thermal-stress

coupling simulation model of nanosecond laser ablation of micro-pits on Ni60/WC coated surfaces. It researches the influence of laser process parameters (laser power, scanning speed, number of ablation times) on the index parameters of micro-pit diameter, depth, and maximum residual stress. The weights of diameter, depth and maximum residual stress sub-objectives in the comprehensive evaluation objectives of micro-pits are calculated. The response surface method of Central Composite Design (CCD) and regression analysis are used to fit the response surface functions of micro-pit diameter, depth, and maximum residual stress as a function of the variation of laser ablation process parameters. The Genetic Algorithm (GA) is used to solve the minimum value of the maximum residual stress sub-objective function and to optimize the process parameters of laser ablation of micro-pits, using the values interval of the micro-pit diameter and depth functions as nonlinear constraints. The results show that the maximum residual stress varies quadratically with laser power and scanning speed, increases linearly with the number of ablations, and is coupled with the ablation process parameters. A design method for optimizing the parameters of nanosecond laser ablation by maximum residual stress is established, and the process parameters are optimized to meet the design parameters and quality requirements of micro-pits: laser power of 12W, scanning speed of 276mm/s, and the number of ablations of 4 times. The optimized process is provided for the parameter tuning nanosecond laser ablation of micro-pits on Ni60/WC coating surfaces.

Keywords laser ablation, micro-pits, thermal-stress coupling model

Track 4: Tribo-chemistry and Lubricants

KEYNOTE:

Friction Reduction due to Boundary Lubrication Layer Formed by Additive Adsorption in Lubricant

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Reducing the friction coefficient of sliding surfaces is one of the most pressing issues in building an energy-saving society, and many research results have been obtained. Most sliding surfaces in machinery are lubricated with lubricating oil. The reason why the coefficient of friction varies greatly depending on the type of additive contained in the lubricating oil is that the additive physically or chemically adsorbs to the surface to form a "boundary lubrication layer" and, in some cases, chemically reacts to form a layer called a tribofilm on the sliding surface. In general, the boundary layer is very thin, a few nm at most. However, it is extremely important to investigate the relationship between the structure of the boundary lubrication layer and the coefficient of friction, because the coefficient of friction varies greatly depending on the structure of the boundary lubrication layer, which is on the order of a few nm at most.

Our research group studies the friction reduction mechanism of adsorption-type additives from the viewpoints of "aggregation structure when dissolved in base oil", "adsorption characteristics on the surface" and "dynamics". As some examples, our research on the effect of the structure of the additive dissolved in the solvent on the formation of the boundary lubrication layer and the effect of the phase state of the formed boundary lubrication layer on the friction properties will be presented.

Keywords: Friction reduction, Boundary lubrication, Additive adsorption, Molecura structure, Phase state

INVITED:

Correlation between Tribologic Performance and Simultaneous Surface Deformation on Soft-Hard Contact Interface

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A homemade optical interferometry system for soft contact surfaces has been developed to carry out research on soft contact tribology under mechanical stress. A ceramic ball was chosen as the rigid indenter, and a glass disc coated with a layer of PDMS film served as a pliable soft pair and optical viewing window. The effect of contact deformation on friction in dry contact and lubricated conditions on soft PDMS surface was investigated by simultaneously measuring the changes in friction force and contact deformation. The results shows that friction on the surface of soft PDMS films increases with speed, and Contact area of the soft matter has an important influence on the friction, the larger area zone, the higher the corresponding friction force. Comparison results of friction demonstrated that good lubrication on soft contact zone is the key to reduce the friction, at that time images also support the hypothesis, for example continuous water film and sufficient lubricant.The results are expected to contribute to the understanding of the complex contact mechanical behavior and tribological mechanisms of soft-hard interfaces subjected to mechanical forces for the development of biomimetic materials with excellent mechanical load-bearing and lubrication properties.

Keywords: Soft contact surface, Friction, Surface deformation

Mechanochemistry of Antiwear Additives

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Antiwear (AW) additives are utilized for protection against wear and loss of metal

surfaces during rubbing in mixed-filmand boundary-film lubrication regimes. The most commonly used AW additive is zinc dialkyldithiophosphate (ZDDP) due to its excellent antiwear and antioxidation properties. However, several disadvantages of ZDDP have been revealed in the last three decades, including its deleterious impact on exhaust aftertreatment systems and its role in promoting ofmicropitting wear. Thus, there is a great interest in seeking alternative AW additives that can partially or wholly replace ZDDP. Recently, metal-free organophosphorus-containing compounds have gained increased attention. These compounds, also termed ashless additives, have long been used as AW additives in aerospace, industrial transmissions and hydraulic oils. It has been suggested[WJ1] that ashless additives form thinner, weaker more slowly film than ZDDP, and at a lower rate. It is suggested that Fe cations, which is lacking in ashless AW additives, are needed to form stable phosphate film., The underlying tribofilm formation mechanism of ashless AW additives is still unclear. Recent work has revealed that ZDDP film formation is stress activated. Investigation of the mechanochemistry of tribofilm formation of ashless additives and understanding how they control wear are thus important.
A mini traction machine with spacer layer imaging mapping (MTM-SLIM) and extreme traction machine (ETM) are employed to understand the film formation, friction and wear performance of ashless additives under mixed rolling-sliding conditions. Tribochemistry of the wear track is examined by various microscopies and spectroscopic techniques. The properties and chemistry of tribofilms formed in full film and boundary regime are examined. ontributes to the fundamental understanding of ashless additives.The role of stress and temperature are discussed.

Keywords: Ashless additive, Antiwear additive, Tribofilm

Construction of CuAAC reaction system induced by friction and its tribological properties

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Tribochemical reactions generate new organic/inorganic compounds through electron transfer, exchange and sharing between the lubricant and the friction occurrence interface. This mechanical energy-induced physicochemical reactions at the surface interface of lubricated materials during friction are considered to have a great influence on the properties and performance of the materials . The research of friction chemistry is important to improve the performance and service life of lubricating materials. But the complexity and uncertainty of the friction chemical reaction process led to the difficulty of in situ characterization of its reaction process, the initial research only based on the phenomenon of speculative reaction process, induction mechanism of action and failure mechanism, to guide the selection of lubricating materials and design development. Through certain design means to intervene in the friction chemical reaction process, so as to achieve the effect of using friction to induce the generation of lubricating substances. It is of great significance for the development, change and innovation of lubricating materials. We start from the orderly design and dynamic regulation of tribochemical reactions to induce click chemistry reactions in the friction process to generate triazole products with good lubricating effect, in order to achieve adaptive interfacial friction control by converting the energy loss caused by friction into beneficial work.

Keywords: Tribochemistry, Lubricating Materials, Click Chemistry

CO2 Capture and Conversion into Carbon-based Tribofilm by In Situ Tribochemical Reaction for Green Lubrication

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The capture and conversion of CO_2 is of great significance for mitigating the greenhouse effect and achieving sustainable development. Unlike previous CO_2 utilization methods, this work develops a novel CO_2 utilization strategy that directly converts captured CO_2 into a carbon-based tribofilm through in situ tribochemical reactions. Monoethanolamine (MEA) aqueous solution is used as the absorbent for CO_2 capture, and tribological experiments have shown that its lubrication performance is significantly enhanced under various loads and speeds after absorbing CO_2. After absorbing CO_2 for 40 minutes, the friction and wear of 75 wt% MEA solution are decreased by 45.31% and 40.38% respectively compared to the unabsorbed MEA solution. The CO_2 undergoes a chemical reaction with MEA to produce carbamates. Anions of carbamates adsorb onto substrate through carboxylate groups to form a molecular brush structure, decreasing friction coefficient. Meanwhile, the strong interaction between carboxylate groups and substrate also makes carboxylate groups prone to tribochemical reactions, forming a carbon-based tribofilm and reducing wear. This work successfully achieves green lubrication by converting CO_2 into carboxylate groups which are further in situ converted into carbon-based tribofilms through tribochemical reactions. This study not only reveals the potential value of CO_2 in tribology, but also opens up a new path for the value-added utilization of CO_2.

Keywords: carbon-based tribofilm, tribochemical reaction, green lubrication

KEYNOTE

A Novel Supramolecular Gel Composite Lubricating Materials for Space Applications

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In the field of space mechanical lubrication, in order to improve the reliability and life of space lubrication, solid lubricating film-liquid lubricant composite lubrication has been used in recent years. This lubrication method can improve the durability of sliding friction mating surfaces, reduce equipment wear, and extend the service life of motion mechanisms. However, due to the unstable factors such as volatilization and creeping of liquid lubricants in microgravity and ultra-high vacuum environments, the solid lubricating film will wear out after long-term use, and produce wear debris and other unfavorable factors. In order to solve the above problems, this study proposes a novel composite lubrication system constituting of MoS_2 film in combination with a supramolecular gel. The tribological performance of this lubrication system establishes an extended service life with a lower wear rate than MoS_2 film, regardless of functioning in vacuum or atmospheric conditions. More importantly, the results of the irradiation experiment demonstrate that the MoS_2-gel exhibits better anti-creep performance as compared to MoS_2-oil when exposed to atomic oxygen and ultraviolet light for 4 hours. The analysis of this composite lubrication mechanism also reveals the formation of a continuous transfer film on the surface of the friction pairs by virtue of the outstanding synergistic effect between MoS_2 film and gel. MoS_2 debris is present in gel as an additive, and gel is capable of replenishing automatically once the MoS_2 film depletes. Moreover, the strong anti-creep properties of gel are attributable to the multialkylated cyclopentane oil being trapped by intricate reassembling of the gelators network. It is firmly believed that this novel MoS_2-gel composite lubrication system may have good prospective applications in space and special machinery domains.

Keywords: Composite lubricating system, Friction mechanism, Supramolecular gel, Transfer film, Space applications

The Interfacial Lubrication Characteristics of Novel Lyotropic Liquid Crystal Systems

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The manufacturing industry is a strategic pillar industry in China. Clean cutting has the characteristics of high efficiency, environmental protection, sustainable development and balanced ecology characteristics, and is one of the forefront and important growth points of manufacturing technology.

The lyotropic liquid crystal system not only has the characteristics of good stability and low irritation, but also has good interfacial activity, with the capability to form a dense and ordered protective film on the surface. Therefore, it is expected to become a new type of green lubrication and protection material. We constructed a series of novel lyotropic liquid crystal systems, including sugar based surface active lyotropic liquid crystal systems [1-2], graphene oxide lyotropic liquid crystal systems [3], alkylbenzenesulfonic acid lyotropic liquid crystal systems [4], etc. We systematically analyzed the influence of the composition and structural parameters of the liquid crystal system on its lubrication and protection performance. The system mainly composed of layered lamellar liquid crystal structure has better lubrication and protection performance than other liquid crystal systems, especially for anti-friction performance. The interface protection mechanism of the constructed liquid crystal system was revealed using synchrotron radiation small angle X-ray scattering, synchrotron radiation micro infrared combined with 2D Raman spectroscopy. It has confirmed that the constructed liquid crystal system can not only be used in the field of industrial lubrication and protection, but also in human health protection, such as skin protection, with good application prospects.

Keywords: Lyotropic liquid crystal, aqueous lubrication, interfacial protection mechanism

Programmable friction: Development of stimuli-responsive Tribosystems Based on Ionic Liquid Mixtures

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An important challenge in tribological systems is the monitoring and active control of friction using non-mechanical stimuli, aiming for the perfect coefficient of friction (COF) for specific applications to enhance sustainability and efficiency. One approach is the use of electrical pulses combined with ionic liquids (ILs) or their mixtures (ILMs) as lubricants for active friction control.

Applying an electrical potential to lubricated metallic friction partners with ILs or ILMs can permanently alter the COF. Surface charges influence interactions, generating a molecular arrangement of ions near the surface by adsorption. The study investigated the impact of different ILM anion combinations on friction control. The desired COF differences can be specifically controlled by surface charge density, anion size, and elemental composition. The extent of friction changes depends on the lubricant film thickness, with ILMs showing significantly higher COF changes than pure ILs. Both

ILs and ILMs alter COF by forming tribologically effective adsorbed molecular layers on charged surfaces. ILMs offer advantages over pure ILs in terms of adsorption layer density and stability.
Applying an electrical potential within a stable electrochemical window achieved COF changes of +140% (anodic potential) and -45% (cathodic potential) with an ILM. The energy saved in friction work due to reduced COF was greater than the electrical energy introduced into the system. Furthermore, coupling the tribological system with a tribo-controller allowed automatic adjustment of preset COF over time, achieving reversible COF programming up to ±230%. The ability to change COF with ILMs combined with conventional oils lays the groundwork for the technical application of these lubricant systems. Testing in ball bearings demonstrated technical compatibility, suggesting that "programmable friction" is a step towards tribological systems that can adapt independently to changing conditions.

Keywords: Programmable Friction, Ionic Liquids, Friction Control

Study on The Regulatory Mechanism of Lauric Acid on Morphology And Interface of Thickener of Calcium Sulfonate Grease

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In order to improve the colloid stability and low temperature pumping ability of calcium sulfonate complex grease and solve the problems of high content of thickener and inapplicability at low temperature, calcium carbonate nanoparticles were prepared by reverse emulsion method from the perspective of morphology control. Lauric acid was added as the morphology control agent, and the morphology of nano-thickener of calcium sulfonate grease was regulated in situ. A series of calcium carbonate thickeners with different aspect ratios were prepared. By comparing the relationship between the morphology of calcium carbonate thickener and the physicochemical and rheological properties of grease, it is found that the thickener with larger aspect ratios can form a more compact and stable three-dimensional structure, and the prepared grease has stronger thickening ability and better high and low temperature performance. At the same time, the effects of molecular chain length and functional group of the morphology control agent on the physicochemical properties of greases were respectively studied. It was found that shorter carbon chain could improve the colloid stability of greases, while the functional group has a greater impact on the physicochemical properties of greases. The addition of organic acids and organic amines increased the drop point of greases by 47% and 48%, respectively. Organic amines can significantly improve the colloidal stability of grease, and the oil separation rate of grease can be reduced to 1.7%. From the contact Angle test between water and the surface of the thickener, it is found that organic acids and organic amines can be

adsorbed on the surface of the calcium carbonate thickener, enhance the surface energy of the thickener, and promote the interface interaction between the thickener and the base oil 150BS, thus improving the thickening ability, high and low temperature performance and colloidal stability of the grease.

Keywords: lauric acid, nano-thickener, interface interaction

Elastohydrodynamic Lubrication Performance of PUMA-PSMA Supramolecular Polymer Gel Lubricant

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Friction and wear are omnipresent in both industrial manufacturing and daily life, exerting a significant influence on the advancement of modern industry. Reducing friction and wear effectively positively impacts industrial production, and using lubricant is considered one of the most effective methods. Recently, gel-based lubricants have undergone rapid development and extensive application. These gels establish a self-assembled 3D network within the base oil, preventing undesirable flow and leakage.

In this study, a urea-containing PUMA-PSMA polymer supramolecular gelator was synthesized, characterized and tested as potential lubricant additive. In comparison to corresponding gel lubricant, the supramolecular polymer gelator exhibited enhanced the thermal stability, good mechanical strength and creep recovery performance. Followed, the tribological properties of the PUMA-PSMA gel were systematically studied using a mini traction machine (MTM-2) under different concentrations, loads, and slip-roll ratio (SRR) conditions. The lubricant demonstrated significant friction-reducing and anti-wear effects under various test conditions. Particularly under high SRR conditions, frictional heat significantly decreased the coefficient of friction (COF) of PUMA-PSMA gel. Electrical contact resistance (ECR) test results showed that the PUMA-PSMA gel effectively formed a lubricating film under various operating conditions, avoiding the direct contact between friction pairs and exhibiting excellent lubrication performance.

Subsequently, the film-forming characteristics of the PUMA-PSMA gel lubricant were studied in detail by using an optical elastohydrodynamic lubrication test rig. With sufficient oil supply, the PUMA-PSMA gel showed greater oil film thickness than the base oil. Under limited lubrication conditions, the PUMA-PSMA gel effectively undergoes shear thinning, reducing the duration of oil deficiency.

These gel lubricants could prevent lubricant loss to some extent during the friction procedure and are expected to be an innovative type of lubricant.

Keywords: Elastohydrodynamic lubrication, Film thickness, Oil starvation, Supramolecular polymer gel

INVITED:

Tribological and Mechanochemical Properties of Nanoparticle-filled PTFE Composites Under Different Loads

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The tribology behavior, tribofilm formation and structure evolution of polytetrafluoroethylene (PTFE) filled with α-Al_2O_3 and SiO_2 nanoparticles during sliding against steel counterparts under different loads were studied. It is found that both composites exhibit good wear resistance across the pressure of 1 MPa to 10 MPa, with the α-Al_2O_3/PTFE composite demonstrates better performance stability compared to the SiO_2/PTFE composite. The high wear resistance is attributed to the formation of tribofilms at the friction interface. For the α-Al_2O_3/PTFE, an island-like tribofilm is formed with a thickness ranging from 100 to 200 nm, while the tribofilm of the SiO_2/PTFE composite is thinner, measuring approximately 50 to 100 nm, and manifest a striped pattern. The chemical composition, both at the surface and subsurface levels, as well as the morphology of the tribofilms were studied using FTIR spectrometry, X-Ray photoelectron spectroscopy (XPS), and FIB-TEM. It is found that the difference in thickness and microstructure of the tribofilms for the two composites is mainly due to the tribochemistry of the nanoparticles. The α-Al_2O_3 nanoparticle plays a "cohesion" role during the formation of the tribofilm, which facilitates the formation of a thicker, more uniform, and stronger adhered tribofilm on the metallic counterpart, making it more robust against higher shear stress.

Keywords: polytetrafluoroethylene, nanoparticles, tribofilm, mechanochemistry

Graphitic Carbon Formed by Diesters and Its Superior Tribological Performance

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The tribological performance of lubricants can be largely governed by the organic friction modifiers (OFMs), especially under boundary lubrication. Usually, the OFMs can form a tribofilm on the rubbing surface through tribochemical reactions to prevent the direct contact of the tribopair surfaces, hence reducing friction and wear. In this

work, a series of novel diester with different chemical structures have been used in polyalphaolefin (PAO) as OFMs to investigate their tribological performance. It shows that the diester with hydroxyl and amine groups exhibit lower friction and wear that methyl groups. Their superior tribological performance can be attributed to the graphitic carbon formation during rubbing. This graphitic carbon film presents low Young's modulus and hardness at nanoindentation test, which may provide low shear stress to reduce friction and wear at macroscale tribological test. The different tribochemical reactions mechanism of OFMs will be proposed according to the stability of free radicals that are generated during rubbing. This work has bridged the tribological properties across different scales, and provide insights to lubricants design.

Keywords: organic friction modifiers, boundary lubrication, graphitic carbon

Investigation of Influencing Factors in Tribochemistry of Ionic Liquids for Nanoscale Film Fabrication

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3D tribo-nanoprinting methodology by harnessing tribochemistry reactions has opened new future possibilities to manufacture nanofilms for the expanding fields of microelectronics, medical devices, flexible electronics and sensor technologies [1]. In the current study, tribofilm formation from Trihexyltetradecylphosphonium bis(2-ethylhexyl) phosphate ([$P_{6,6,6,14}$][DEHP]) ionic liquid (IL) dispersed in poly alpha-olefin (PAO) base oil has been experimentally tested. The effect of contact pressure, reciprocating frequency, and additive concentration on tribochemistry reactions and the subsequent growth of tribofilms was investigated.

To characterise the distribution and thickness of tribofilms, a new methodology based on Conductive Atomic Force Microscopy (CAFM) was developed and used. The experimental results obtained after sliding an EN31 steel pin on an EN31 steel plate at different test conditions indicate that tribofilms can be generated with this ionic liquid. A detailed surface chemical analysis of the formed film reveals differences in composition. The paper will discuss tribofilm growth mechanisms from this additive and its potential for 3D tribo-nanoprinting.

[1] Dorgham, A., et al., 3D tribo-nanoprinting using triboreactive materials. Nanotechnology, 2019. 30(9): p. 095302.

Keywords: Tribofilms and 3rd bodies, NanoTribology, Tribo-nanoprinting

Amino Acids-Based Ionic Liquids as Multifunctional Water-Based Additives

Towards Green Lubrication

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Green lubrication is one of the significant trends in the advancement of tribology. The utilization of water-based lubricants in certain applied fields, as an alternative to oil-based lubricants that are prone to causing environmental pollution, represents one of the effective strategies for achieving green tribology. Herein, several novel amino acid-based ionic liquids (AAILs) were synthesized and employed as multifunctional water-based lubricant additives. The corrosion resistance properties, antibacterial activities and lubrication functions of additives were characterized by immersion corrosion test, broth microdilution method and SRV trials, with the detailed exploration of their lubricating mechanism obtained from QCM, SEM, TOF-SIMS and XPS analysis. For the anti-corrosion lubricant additives, Lys-LGA and Arg-LGA, the anti-corrosion properties of water can be significantly improved at a 0.5 wt% addition to water (from level D for water to level A for lubricants), and the coefficient of friction (COF) and wear volume (WV) of water can be reduced by approximately 70% and >90%, respectively. For the antimicrobial lubricant additive PL-CG, dosing in water at 1 wt% can reduce the COF and WV of water by about 75% and more than 90%, respectively. Meanwhile, PL-CG additive exhibits excellent antimicrobial activity (>99.9% bacterial kill at 1 wt%) and exceptionally low cytotoxicity (IC_{50} >1024 μg/mL). The results of the mechanism studies show that the physical adsorption film and the tribochemical reaction film collectively establish a protective barrier at the friction interface to endow lubricants with outstanding friction reduction and anti-wear properties. These environmentally friendly AAILs additives are expected to be used as critical additives for metal working fluids and hydraulic fluids.

Keywords: Ionic liquids, Lubrication additives, Green lubrication

Tribological Material Removal Behavior of Boron Carbide by Different Active Metals

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Boron carbide is recognized as one of the hardest materials, which is widely used in abrasive processing, bulletproof armor, aerospace, and nuclear industry. However, boron carbide is difficult to be processed due to the extremely high hardness and chemical stability. It is necessary to study the machinability of boron carbide in order to manufacture the required boron carbide parts. In this study, tribological tests was adopted to investigate the material removal behavior of boron carbide by three different active metals (iron, titanium and chromium) under different loads and friction velocities. The results demonstrate that boron carbide can be effectively removed by the three active metals. Among them, titanium exhibits the highest removal rate for boron carbide, followed by iron and chromium. In terms of surface roughness, boron carbide exhibits the highest surface quality after friction with iron, at a load of 10 N and a friction velocity of 1.05 m/s, the surface roughness of boron carbide decreased from Ra 170.73 nm to Ra 61.54 nm after 15 minutes, exhibiting a smooth surface. While during the friction process with titanium, intense wear occurs on the boron carbide surface, with a significant amount of titanium bonding to its surface, resulting in a worst surface quality. There are graphite existing in the scratches detected through Raman spectroscopy. It indicates that utilizing active metals for machining boron carbide is a feasible approach.

Keywords: boron carbide, active metal, tribological material removal

Track 5: Biotribology and Biomimetics

KEYNOYE:

Molecular Forces and Interfacial Adhesion, Friction and Lubrication in Engineering Systems

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The adhesion, friction, and lubrication in engineering systems play a crucial role in governing the relevant properties of the materials involved and their application performances, which are essentially determined by various molecular and surface forces. In this presentation, I will discuss the development of intermolecular forces and interfacial science, along with their applications, and introduce the basics of these forces and common nanomechanical techniques. I will discuss some challenging issues that are not yet completely understood, such as the correlation between adhesion and friction, stick-slip motions, and the effects of surface roughness. I will also showcase several examples demonstrating how we have quantified several non-covalent interactions, such as cation-π, anion-π, hydrophobic interactions, and hydrogen bonding, along with their synergetic effects. Furthermore, I will present our work on developing self-healing materials and surface coatings with tunable adhesion and friction/lubrication behaviors, based on these reversible molecular interactions. These insights offer valuable guidance for the development of novel functional materials and coatings for engineering, bioengineering, and environmental applications.

INVITED:

Skin Tribology and Its Application in Product Development

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In our everyday life, our skin is in contact with various kinds of product and surfaces. The interaction will generate friction and skin friction is influenced by many factors. Therefore, the tribology of human skin is a research topic that has continuously attracted scientific studies over the past years. Recent tribological studies on materials contacting skin cover medical and sports applications, textiles, as well as appropriate surfaces for consumer products and automotive applications.
In order to study the interaction between skin and contacting products, we firstly developed a series of artificial skin models by mimicking the mechanical property, active transdermal delivery property and tactile sensing ability of human skin, respectively. Based on which, the frictional behavior of various skin contacting products were studied, including (1) the friction between finger and cosmetics, hair care products during and after application and its correlation with sensory attributes and skin hydration; (2) the instrument and simulated test methodology development for studying the friction behavior of wound dressing and medical sutures for reducing skin damage and pain; (3) the development of laser textured surfaces with enhanced tactility for automobile, household appliances and furniture applications, through which the correlation between surface texture parameter, skin friction and comfort was established. The study emphasized the importance and significance of skin tribology in the development of skin contacting products.

Keywords: Skin friction, tribological interactions, skin contacting product

Targeted Repair of Super-Lubricating Surfaces via Pairing Click Chemistry

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Intact advanced lubricating coatings can rival natural hydration lubricating systems. However, once damaged, their lubricity is drastically diminished as the delaminated coating materials are either unable to re-bond to the original substrate due to the irreversible bond breakage or easily bridge the opposing rubbing surface via non-speciffc interactions. Inspired by the reversibility and selectivity of dynamic click chemistry, super-lubricating surfaces with targeted self-repairability are developed through a surface-recognized strategy. The rubbing surfaces exhibit superlubricity with friction coefffcient $\mu \approx 0.002$ at physiologically high pressure (≈7.5 MPa). When

wear-induced coating-substrate breakage occurs, the lubricating materials can target and reassociate with their pairing surfaces through speciffc dynamic covalent linkages, circumventing surface bridging, and recovering high lubricity even upon repeated damage. This study offers an innovative paradigm for developing durable lubricating surfaces with bespoke reparability for biomedical applications.

Keywords: polymeric lubricating coatings, super-lubricating systems, targeted self-repairability

Low Friction Performances of Orthodontic Stainless Steel Archwire and Bracket

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Orthodontic treatment is the restoration of the abnormally positioned teeth for human beings. The fixed orthodontic appliance consisting of archwire and bracket has been extensively applied for the dental clinical applications. The relative sliding of the archwire to bracket produces first static and then kinetic friction forces, which greatly affects the tooth movement efficiency. The achievement of low friction forces could strongly reduce the risk of root resorption and patient pain, shorten the treatment time, and improve both anchorage control and direction of tooth movement. Therefore, the target of this work is to reduce the friction force between the commercial archwire and bracket. Carbon films were produced on the stainless steel archwires with a customized mirror confinement electron cyclotron resonance (MCECR) plasma sputtering system under various substrate bias voltages. The friction tests between brackets and carbon film deposited archwires were conducted by using a reciprocating tribometer in artificial saliva environment. It was found that friction coefficient of archwire and bracket in artificial saliva environment strongly decreased from 0.52 to 0.12 with the fabrication of carbon films on the archwires. The friction coefficient varied between 0.12 and 0.16 with the change of substrate bias voltage, suggesting a superior friction behavior of the carbon films deposited archwires. The low friction mechanism is clarified to be the formation of salivary adsorbed layer as well as graphene sheets containing tribofilm on the contact interfaces. The clarification of the low friction mechanism is beneficial for designing low friction archwire-bracket system for clinical orthodontic applications.

Keywords: archwire-bracket, carbon film, low friction

Study of Friction Haptics and Tactile Perception in Bionic Skin With Gradient Tunability

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Human fingertips accurately perceive the characteristics of objects through fast and slow adaptive mechanical transduction based on fingertip and physical contact friction vibration. However, due to the high-precision micro-nano texture of fingerprints and the soft and hard composite skin composition, it is still challenging to design artificial ion skin with fingertip-like tactile ability. Inspired by the formation of fingertips and the layered structure of modulus contrast, the gray-scale exposure 3D printing technology was introduced. By perfectly controlling the crosslinking density of the material, the soft and hard composite ion skin can be manufactured with light precision. This ion skin has a rigid ridge similar to the fingerprint and soft subcutaneous tissue, which can realize friction electric dynamic pressure sensing and friction tactile texture recognition without strain interference. By studying the correlation and internal synergy between tactile perception and frictional tactile sensation, the artificial tactile sensory system is further manufactured into a soft robot skin to mimic the frictional tactile sensation of the finger in the grasping action and the simultaneous fast and slow adaptation to multimodal sensation. This approach may inspire future design of high-performance ion tactile sensors for intelligent applications of soft robots and prostheses.

Keywords: Grayscale 3D Printing, Frictional tactile, Tactile sensing

KEYNOTE:

Bioinspired Surface with Strong Wet Friction and Its Applications

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The bio-device contact interfaces have growing requirements in diverse functions, such as the securing fixation of wearable sensors and the anti-adhesion of electrical knives and electrocoagulation hooks. These bring up the common requirements of bio-device interface, i.e. the strong wet attachment and high-temperature anti-adhesion properties. However, since gas and liquid generally exist between the contact interface, their behavior is extremely complex and greatly affects the surface function. To discover the law of dynamic behavior of interfacial liquid and their influence on surface function is very necessary for the innovative design and manufacturing of bio-devices contact surface. This speech will focus on (1) the functional strategy and fabrication approach of micro-nano hierarchical bioinspired surface, and (2) the progress in the study of dynamic liquid behavior on the micro-nano hierarchical surface.

Keywords: wet friction, bioinspired surface, hierarchical micro-nano surface, precision medicine

From Finger Friction to Brain Activation: Tactile Perception of Surface Texture

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Touch is a common method employed by people to perceive the quality of a product. The recognition and satisfaction of consumers are determined by the tactile experience of the product surface, which is a key influencing factor in the product design, production and distribution process. The tactile perception of the contact surface is derived from vibrations and friction when fingers slide over the surface and are formed in the somatosensory cortex. Therefore, friction and vibrations are exciters of tactile perception, and a sense of skin and cognition of the brain are involved in tactile perception and play indispensable roles in perception. However, little research has systematically elucidated the mechanisms of tactile perception from frictional behaviors of the skin to cognition of the brain. To study the tactile perception of material surfaces, subjective evaluation, skin friction and vibrations, and neurophysiological responses of brain activity were investigated systematically. Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) methods have been used to investigate the corresponding functional regions and EEG signals in the cerebral cortex involved in tactile perception. The relationships between the friction contact characteristics of the skin, brain activation and subjective evaluation and the physical characteristics of the surfaces were established, and the brain cognitive mechanism of tactile perception was revealed. The results can provide theoretical support for the quantitative characterization of tactile perception, and the findings can also help in providing technical support for the development of virtual reality technology and tactile reproduction for the disabled.

Keywords: Surface texture, Tactile perception, Skin friction, Functional magnetic resonance imaging, Electroencephalograph

Laminar Drag Reduction in Closed Channel Using Bioinspired Textured Surfaces

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Low flow drag is of great importance to a variety of engineering applications, and an effective way to achieve low drag is to use bioinspired micro-structured surfaces. This work aims to reduce the skin-friction drag in closed channel flow using textured surfaces inspired by leaves of indocalamus and rice. The channel formed by a polydimethylsiloxane chunk and a silicon wafer was fabricated to study drag reduction behavior for water or liquid paraffin oil in laminar flow. Bioinspired textures were

processed on silicon wafer surface using deep silicon plasma etching method. We measured the pressure drop of water or paraffin oil passing through textured channels with different velocities. The maximum pressure drop reduction for the paraffin oil flow with low velocity (Re≈1) and for the water flow with high velocity (Re<1000) were about 5.1% and 27.3%, respectively. We also presented the contact angles of bioinspired textured surface, and then proposed mechanisms to explain the drag reduction. The hydrophobicity leading to the changing from the liquid-solid interface to the liquid-air interface is believed to provides the drag reduction for water flow, while the thin oil film formed on the textured surface due to the oleophilicity helps to reduce the oil flow drag.

Keywords: Bioinspired textured surface, Closed channel laminar flow, Skin-friction drag reduction, Mechanisms

Interactions of Asymetric Spatula-Shaped Adhesive Microstructures with Rough Surfaces

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Throughout the course of biological evolution, numerous organisms have evolved hair-like attachment structures to achieve stable adhesion on various surfaces. Inspired by this, researchers have explored biomimetic adhesive microstructures, with a main focus on axisymmetric mushroom-shaped structures. However, spatula-shaped ones may be better suited for adhesion on rough surfaces. In this study, we introduce two bio-inspired adhesive prototypes featuring an inclined seta and spatulate tip. The former prototype incorporates a cylinder (seta) with a variable cross-section and a thin, leaf-like plate, while the latter comprises a uniform cross-section square column and a plate of variable thickness having a wedge-shaped cross-section. Prescribing the vertical displacements of a prototype seta, the adhesive interactions between these prototypes and surfaces having various roughness are investigated using finite element analysis. The asperity radii of rough surfaces were taken as 30 nm, 1 μm, and infinity (representing a flat surface). Results revealed the spatula could adapt relatively well to the 1 μm radius asperity compared to 30 nm, due to the asymmetry of the structures. This also led to a leverage phenomenon that competes with adhesion and tends to separate the contact surfaces. Although the thicker spatula tip showed poor flexibility and effective contact area, it enables the regulation of attachment under unidirectional loading. This study provides new insights into spatula-shaped adhesive contact mechanics and offers valuable inspiration for the future development of artificial adhesives.

Keywords: Artificial adhesives, Surfaces roughness, Finite element simulations

An Investigation of Film Forming and Lubrication Behavior of Whey And Salivary Proteins

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Whey protein is helpful to aid muscle recovery and to maintain the muscle mass for its high leucine content. However, it has poor consumer acceptance due to mouthdrying, especially for older adults. Mucins are vital components of human whole saliva which contribute to the oral lubrication. The directly exploration of their film forming behaviors in oral environment is necessary to understand the mechanism of the mouthfeel. The sequential adsorption experiments demonstrated that the Whey Protein Isolate (WPI) and mucin molecules could form hydrated layers immediately on polar surfaces by chemisorption. Moreover, mucin showed stronger adsorption capacity, thereby replacing WPI molecules adsorbed on the Au surface. On the other hand, the pre-formed mucin layers promoted the formation of a mucin-WPI hybrid layer. The hybrid layer structure was also probed by the film thickness measuring apparatus under the pure rolling condition with a load of 10N. The center gap between the contact surfaces was about 5nm higher with additional mucin layer, especially when the entrainment speed was lower than 100mm/s. The film thickness and the quantity of adsorption mass increased with time, following similar mathematic model. Both can be fitted with the Elovich model. Besides, unexpected aggregation of WPI would be suppressed at 0.1% concentration because the sharply increased film thickness was reduced at the end of the experiment for the 0.1% WPI samples. Further investigations of tribological mechanism implied that the presence of mucin leaded to 30%-50% reducing of the friction in the boundary and mixing regime. The excellent lubrication performance of the mucin/WPI emulsion was attributed to the hybrid layer of mucin and WPI molecules and the mucoadhesive property of mucin. The study provides a guide for using mucin to improve the smoothness of WPI and to reduce mouthdrying.

Keywords: food oral tribology, mucin, biolubrication

Clarification of Heparin Lubrication Mechanism for the Low-friction Catheter on a Polyurethane Surface

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Catheters are commonly used in modern medicine for treating diseases during

cardiovascular procedures. A low-friction surface is required for medical devices such as catheters or guidewires that are inserted into blood vessels. Without low friction, introducing these devices into the body can cause pain and poses a risk of damaging the mucous membranes or the intima of the blood vessels, potentially burdening patients. Heparin is a widely used anticoagulant that can act as a lubricant and form a film on polyurethane surfaces. Saline containing heparin is often injected between the guidewire and catheter as lubrication. To clarify the state of lubrication of the contact surface and find out mixed lubrication conditions where low friction can be expressed between the guidewire and catheter, this study plan to apply heparin on a polyurethane board and make a friction test with a sapphire hemisphere in saline solution. Accordingly, measuring the water film between contacting surfaces in situ with the Optical Thickness Meter to clarify the relationship between polyurethane's mechanical properties and the friction coefficient. A fundamental understanding of surface properties of the biomaterials at a nanometer scale should be generated.
Research results show that the lowest friction coefficient between a guidewire and PTFE (polytetrafluoroethylene, a catheter material) was approximately 0.027, measured at a sliding speed of 0.05 mm/s, a normal load of 0.02 N under saline containing heparin condition. Friction tests under dry conditions indicated a friction coefficient of approximately 0.4, suggesting that high friction is achieved when the water film breaks.

Keywords: Low friction, lubrication under saline, Poleurethane

Friction Properties of Mucins on The Corneal Surface

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Mucins are a family of extensively glycosylated, high molecular-weight proteins synthesized by moist epithelial tissues, including those of the ocular surface[1]. In the physiology of the eye, the mucin layer on the surface of the cornea plays a crucial role, not only protecting the eyeball from damage from the external environment but also maintaining normal visual function and its friction properties are crucial to maintaining the stability and health of the ocular surface[2, 3]. MUC1, MUC4, and MUC16 are transmembrane proteins that are cleaved during biosynthesis. MUC1 is cleaved within the SEA module[4], while MUC4 is cleaved within the von Willebrand domain (vWD) module, with the putative cleavage site located at the amino acid sequence GDPH[5]. MUC16 is cleaved within a 12-amino acid juxtamembrane region located in the extracellular domain [6].Understanding the behavior of the mucus layer with respect to friction not only helps explain the pathogenesis of certain ocular surface diseases but also provides a theoretical basis for the design of improved ophthalmic treatments and corneal surface lubricants. Therefore, in this study, C1 esterase inhibitor secreted protease (StcE)[7], neutrophil elastase (NE) and TNF-α[8] is used to treat immortalized human corneal epithelial cells to establish different mucin-deficient cell platforms. Atomic force microscopy (AFM) is used to test the friction on the cell layer in a liquid environment to investigate the frictional properties of the mucus layer on the corneal surface.

Keywords: Membrane-associated mucins, ocular surface, tribology

Track 6 Nanotribology and Superlubricity

KEYNOTE

Hydration Lubrication in Presence of Multivalent Ions

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Hydration lubrication (HL) stands out among lubrication mechanisms as it enables superlubrication between solid surfaces. While it is widely observed in nature, its full potential in engineered systems has yet to be fully realized by humans. HL operates through surface hydration layers that possess remarkable load-carrying capacity and maintain low shear resistance even under significant compression. In cases involving hard, non-porous surfaces, hydrated ions have emerged as exceptionally effective promoters of HL due to their robust hydration capacity and affinity for adsorption onto various surfaces, particularly those endowed with ionizable surface groups such as mica, SiO2, Si3N4, or sapphire.

On softer polymeric surfaces, HL can originate from the presence of highly hydrated macromolecular chains firmly bound to surfaces. The conformation and interaction of these chains with free ions dictate the interface's ability to efficiently dissipate frictional energy. While HL has been extensively investigated both experimentally and theoretically using monovalent ions as model systems, our understanding of the effects of ion multivalency and concentration on HL remains limited. To bridge this gap in knowledge, we conducted studies on HL in both hard and soft contacts utilizing the surface forces apparatus.

Our research underscores the critical role played by the structure of the boundary layer in the frictional dissipation of both hard and soft contacts across various scenarios. Our findings unveil novel fundamental insights into lubrication in aqueous environments, offering a pathway to the rational design of synthetic lubricants capable of harnessing the properties of HL to achieve superlubrication in diverse biological and synthetic systems relevant to everyday life.

Keywords hydration lubrication, cartilage, cornea, multivalent ions

INVITED

Liquid Superlubricity Achieved with 2D Nanoflakes as Additives

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In this work, the recent progress in liquid superlubricity would be discussed, especially the synergy of Liquid and 2D Nanoflakes based Superlubricity. First, we found that the superlubricity could be achieved with the lubrication of phosphoric acid. Thereafter, we extended the Superlubricity of phosphoric acid to mixture of acid and glycerol, and then, established an acid-based superlubricity system. We also synthesized an ionic liquid based on the reaction between ethylene glycol and Lithium salt, which could achieve superlubricity with a friction coefficient of 0.004. The superlubricity mechanism can be mainly attributed to the formed composite tribochemical layer. Thereafter, a robust liquid-superlubricity state ($\mu \approx 0.005$) under a pressure of 600 MPa was realized, which was enabled by the combination of graphene-oxide (GO) nanosheets with an ionic liquid between the frictional pairs of Si3N4/sapphire. The extreme pressure property and extremely low shear stress between the interlayers of GO nanosheets contributed to the achievement of superlubricity. Finally, a robust macroscale liquid superlubricity was achieved by the introduction of Molybdenum Carbide (Mo2CTx) MXene nanoparticles as lubricating additives in the ionic liquid. The maximal contact pressure in the superlubricity state could reach at 1.42 GPa, which far exceeds the limitation of superlubricity regime in previous studies. The results claimed that a composite tribofilm formed at the interface by tribochemical reaction contributed to the excellent anti-wear performance, thereby providing a lubricating condition under ultrahigh contact pressure. These studies provided a novel method to achieve liquid-superlubricity under extreme conditions—by the synergistic effect of 2D materials and liquid molecules—accelerating the achievement of liquid-superlubricity in industrial applications.

Keywords liquid superlubricity, nanoflakes, additives

Simple but Effective: Liquid Superlubricity with High Load Capacity Achieved by Ionic Liquids

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Macroscale superlubricity is a new field that can greatly reduce energy consumption due to friction, which accounts for approximately 30% of human nonrenewable energy. However, prior research on liquid superlubricity mostly involved low contact pressures

(< 600 MPa). Here, we evaluated the lubrication and adsorption properties of ionic liquid alcohol solutions (ILs(as)) with different alkyl chain lengths and monovalent anions between Si3N4 and sapphire surfaces. Robust macroscale superlubricity and ultrahigh load capacity exceeding 1 GPa were obtained by protective adsorption layer caused by tribochemical reactions. Zeta potential measurements and simulation analysis revealed that the ceramic interfaces were enriched with numerous ionic liquid (IL) anions, preventing the direct collision of the asperities of the friction pairs. The relatively low sliding energy barrier and extremely strong electrostatic repulsion developed between these asperities enhanced the superlubricity and ultrahigh load capacity. Meanwhile, long alkyl chains and tetrafluoroborate anions more easily met the hydrodynamic boundary conditions at the solid–liquid interface, and the formation of low energy consumption channels through the smooth potential energy fluctuation surface generated extremely low shear stress. Such macroscale lubrication provides a novel method of achieving extremely high contact pressure in ILs(as), which could enable liquid superlubricity in practical industrial applications.

Keywords macroscale superlubricity, ionic liquid, load capacity, sliding energy barrier, electrostatic repulsion effect

Detection and Regulation of Ultrafast Electron Energy Dissipation Behavior at The Heterojunction Interface of Two-Dimensional Materials

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Superlubricity has the extreme characteristics of near-zero friction energy dissipation, which can push the performance of advanced equipment to the extreme level. However, superlubricity still faces critical challenges from the laboratory to the engineering practice, one of which is the lack of understanding of the phonon electron energy dissipation pathway in the friction process. The friction electron dissipation process occurs at the femtosecond time scale and the atomic space scale, which has exceeded the theoretical limit of the existing detection methods in the field of tribology. To solve this problem, this work innovatively coupled the femtosecond transient absorption ultra-fast optical path and the q-Plus noncontact atomic force microscope to develop a new method for ultra-high spatiotemporal resolution friction electron dissipation detection. The following results were obtained: (1) Direct imaging of the ultra-fast energy dissipation process of electroacoustic coupling, it was found that the increase of defects would accelerate the scattering time of electroacoustic coupling from 7.1 ps to 2.4 ps, and the time change was used to realize the regulation of electroacoustic coupling rate by using atomic defects; (2) The Bose-Einstein condensation (BEC) process of interlayer excitons in transition metal chalcogenide (TMDCs) materials was detected by transient absorption technology, and it was found that the interlayer excitons were affected by the moiré potential, and then the exciton condensation was regulated. The team's research provides theoretical support for clarifying the friction energy dissipation pathway, and is of great significance for revealing the mechanism of solid superlubricity and realizing active design of superlubricity.

Keywords superlubricity, electrons dissipation, defect

Research on Ion Beam depostion of Solid Lubrication Composite Films Nanotirbology Technology

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By preparing composite solid lubrication molybdenum disulfide coatings on the surface of steel and ion implantation into the ball surfaces, the study systematically investigates the properties of the films and surfaces after ion implantation, such as friction reduction and wear resistance. By examining the effect of the surface nanofilms transfer on the friction coefficient,The microstructures and phase transformations were also studied by grazing incidence X-ray diffraction (GIXRD) analysis, X-ray photoelectron spectroscopy (XPS), and transmission electron microscopy (TEM). The TEM analysis confirmed the presence of amorphous and nanocrystalline phases in the balls. The XPS and GIXRD analyses confirmed new solid lubrication pahse. The tribomechanical improvement induced by implantation is attributed to the substructure and nanofilms of solid lubrication .
the research reveals the friction system of the novel solid lubrication films and ball prepared by ion beam, further enhancing the tribological and wear performance of solid lubrication films.

Keywords ion beam, solid lubrication, film friction

KEYNOTE

Phononic Insight into Sliding Friction

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Friction plays a pivotal role in the dynamics of global energy, accounting for an estimated one-third of the world's primary energy consumption. It is traditionally viewed as a dissipative force, converting kinetic energy into heat at the interface where two surfaces interact. However, our research challenges this conventional understanding by suggesting that interfacial forces actually transform kinetic energy into potential energy within the material's bulk, a process that conserves rather than dissipates energy. This potential energy amasses until it exceeds a specified threshold,

culminating in the partial release and dissipation of energy as phonons throughout the bulk. This shift in perspective redefines our interpretation of damping effects in sliding friction. We suggest a new perspective where damping is directly proportional to the speed of oscillation. This contrasts with the traditional belief that damping correlates with the relative sliding velocity, a concept ingrained in the classical Prandtl-Tomlinson and Frenkel-Kontorova models.
Building on this novel concept, we introduce a phononic friction model that provides a robust framework for predicting frictional forces. Our model has been validated by results from atomic force microscopy experiments and molecular dynamics simulations across various speeds and loads. It sheds light on aspects of friction that have remained puzzling, as observed in seismological research and lab experiments, such as the influence of spring stiffness and velocity-dependent behavior. This model provides quantitative understanding without depending on traditional dissipative postulates.

Keywords sliding friction; dissipative force; conservative force; phonon

Electrotunable Friction of Ionic Liquids on Curved Graphene

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Ionic liquids have emerged as innovative lubricants owing to their advantageous physical and chemical properties. Arising from their ionic constitution, their tribological behavior can be electrically tuned through altering the adsorption configuration of cations and anions on solid surfaces. While extensive research has been conducted on their nanotribological properties on smooth surfaces like graphene, their behavior on curved surfaces remains poorly understood. Therefore, this study aims to investigate the nanoscale tribological behavior of ionic liquids (ILs) on graphene with different curvatures. The interfacial behavior, including multi-layer adsorption and friction, at the solid-liquid interface will be examined under varying potential. The electrotunability of friction in function of surface curvature and potentials will be thoroughly discussed and interpreted based on the chemical interactions between ions and surfaces, as well as ion-ion interactions. This work will provide a strategy for the electrotunability of ionic liquid lubrication on real (rough) surfaces.

Keywords ionic liquids, electrotunable friction, curvature

An Example of Superlubric Ferroelectricity

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Recently, interfacial ferroelectricity was discovered in two-dimensional (2D) material stacks that break inversion symmetry, such as parallelly stacked h-BN bilayers, homogeneous and heterogeneous quasi-2D materials. The crystal symmetry translates lateral shifts between parallel two-dimensional layers to sign changes in their out-of-plane electric polarization, a mechanism termed “slidetronics”. If the interlayer shift is superlubric, the polarization switch will be very fast and energetically efficient, which is a promotion to the devise of next-generation memory devices.
We predict an one-dimensional slidetronics for double-walled boron-nitride nanotubes. Local electrostatic polarization patterns along the body of the nanotube are found to be determined by the nature of the two nanotube walls, their relative configuration, and circumferential faceting modulation during coaxial interwall sliding. By careful choice of chiral indices, chiral polarization patterns can emerge that spiral around the nanotube circumference. The intrinsically low interwall friction characteristics of multiwalled nanotubes supports the fabrication of coaxial sliding GHz oscillators. By connecting local probes (e.g., conducting tips) to the outer wall of the oscillator, the periodic local polarization variations could generate AC currents, thus supporting the realization of nanogenerators.
References:

Keywords superlubrication, ferroelectricity, polarization

Accurate Estimation of Dynamical Quantities for Nonequilibrium Nanoscale Systems

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Fluctuations of dynamical quantities are fundamental and inevitable. For the booming research in nanotechnology, huge relative fluctuation comes with the reduction of system size, leading to large uncertainty for the estimates of dynamical quantities. Thus, increasing statistical efficiency, i.e., reducing the number of samples required to achieve a given accuracy, is of great significance for accurate estimation. Here we propose a theory as a fundamental solution for such problem by constructing auxiliary path for each real path. The states on auxiliary paths constitute canonical ensemble and share the same macroscopic properties (NVT) with the initial states of the real path. By implementing the theory in molecular dynamics simulations, we obtain a nanoscale Couette flow field with an accuracy of 0.2 μm/s with relative standard error < 0.1. The required number of samples is reduced by 12 orders compared to conventional method. The predicted thermolubric behavior of water sliding on a self-assembled surface is directly validated by experiment under the same velocity. This theory only assumes the system is initially in thermal equilibrium then driven from that equilibrium by an external perturbation. It could serve as a general approach for extracting the accurate estimate of dynamical quantities from large fluctuations to provide insights on atomic level under experimental conditions, and benefit the studies on mass transport through (biological) nanochannels and fluid film lubrication of nanometer thickness.

Keywords fluctuation; non-equilibrium statistics; nanoscale; low speed; simulations

KEYNOTE

Molecular Simulations to Solve Industrial and Environmental Issues

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In this century, while various technologies such as mobility and communication seem to have reached the stage of perfection, for some reason we feel unstable. Despite the fact that carbon dioxide is at fault, the research and development of automobile engines is said to be a problem, and the use of highly functional materials such as PFAS (Per- and poly-FluoroAlkyl Substance) is said to pollute the environment.In this keynote talk, we will introduce an example of analysis of interface science using molecular simulation as a method for to be better the environment and society. For a hydrogen society, we will explain analysis of low friction and wear surface coatings and hydrogen storage materials. Regarding PFAS, we explain SDA (hierarchical dipole array) model, which is a physical chemistry theory originating in Japan, to understand the origin of functions such as water and oil repellency and how to understand these kind of molecular assemblies. The simulation results support and expand the theory very well. In addition, regarding the relationship between water and materials, we will introduce the results of aquatic functional materials.Supercomputers are said to be like telescopes peering into the future. I would like to discuss the future prospects of molecular simulation that will encourage the Tribology society by making full use of supercomputers.

Keywords hydrogen; PFAS; molecular simulation

Interlayer Friction Behavior of Molybdenum Ditelluride with Different Structures

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The interlayer friction behavior of two-dimensional transition metal dichalcogenides as crucial solid lubricants and lubrication additives has attracted extensive attention in the field of tribology. In this study, the interlayer friction is measured by laterally pushing the MoTe2 powder on the MoTe2 substrate with the atomic force microscope tip, and density functional theory simulations are used to rationalize the experimental results. The experimental results indicate that the friction coefficient of the 1T'/1T' interface is 2.025 × 10-4, which is lower than that of the 2H/2H interface, while the friction coefficient of the 1T'/2H interface is the lowest at 6.875 × 10-5. The lower interfacial friction of 1T'/1T' compared to 2H/2H interface can be explained by the relative magnitudes of the ideal average shear strengths and maximum shear strengths obtained based on the interlayer potential energy, while the smallest interlayer friction of the 1T'/2H heterojunction is related to the weak interlayer electrostatic interaction and the weakening of the potential energy corrugation caused by the incommensurate contact. This work suggests that MoTe2 has comparable interlayer friction properties to MoS2 and is expected to reduce interlayer friction in the future by inducing the 2H-1T' phase transition.

Keywords two-dimensinal materials; interlayer friction; interlayer shear strength

Research on the Mechanism of Frictional Anisotropy Based on 2D SiP

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The friction, wear and fracture of 2D materials are related to the crystallographic direction. And the anisotropy of friction affects the reliability of micro-nano devices and provides the basis for atomic-scale fabrication with tunable functions. As a new type of 2D lubricating material, SiP has a better anisotropic structure than other traditional 2D materials like graphene and molybdenum disulfide. Taking SiP as the research object to explore the mechanism of frictional anisotropy can expand its functional design and application in micro-nano devices.

Here, the frictional anisotropy of 2D SiP materials and the relationship between the property of anisotropy and Raman vibration, potential surface energy (PES), and atomic differential charge density were investigated by atomic force microscopy (AFM), Raman spectroscopy, and the first principle calculations.

The results show that the frictional anisotropy of SiP is 180° symmetry, and the frictional difference between zigzag and armchair directions is related to the fluctuation of PES and atomic differential charge density in these two directions. Combined with the results of Raman spectroscopy, the relationship between the vibrational intensity of different bonds and the frictional anisotropy is given. This study provides a new idea for understanding the origin and nature of frictional anisotropy of 2D materials.

Keywords frictional anisotropy, SiP, 2D materials, first principle calculation, atomic force microscopy

AFM Probe for Measuring Ultra-low Friction Coefficient of 10^{-6}

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As superlubricity research advances, the coefficient of friction (COF) may fall below 10^{-6}. However, little is known regarding improving COF measurement resolution $\Delta\mu$ by atomic force microscopy (AFM). Accordingly, this study established a theoretical formula for COF measurement by AFM and deduced the corresponding $\Delta\mu$. $\Delta\mu$ is associated with the dimensional properties of the AFM probe, the mechanical properties of the cantilever material, the properties of the position-sensitive detector, and probably the anti-vibration performance of AFM. Subsequently, the theoretical formula was first applied to the AFM probe with a solid rectangular cross-sectional cantilever. Shortening the cantilever length l and increasing the tip height h_{tip} are feasible strategies for reducing $\Delta\mu$. After optimizing the dimensions of the rectangular cross-sectional cantilever of the AFM probe, $\Delta\mu$ can reach 7.1×10^{-6} under the maximum normal force. Furthermore, based on the theoretical formula, a distinctive strategy was adopted to further minimize $\Delta\mu$ by optimizing the cantilever's cross-section of the AFM probe, inspired by civil engineering. $\Delta\mu$ can be reduced by decreasing the width of the horizontal side w_R and the wall thickness t and increasing the width of the vertical side w_H. Moreover, the I-shape demonstrates the highest reduction in $\Delta\mu$, followed by the U-shape. Considering the processability, the AFM probe with the U-shaped cross-sectional cantilever was designed and fabricated, and the dimensions are 35 μm w_R, 3.5 μm w_H, 0.5 μm t, 50 μm l, and 23 μm h_{tip}. After calibration, the AFM probe can achieve $\Delta\mu$ of 1.9×10^{-6} under the maximum normal force. The friction detection capability of the fabricated AFM probe is improved by 78 times compared to the commercial tipless-force modulation mode (TL-FM) AFM probe with the conventional solid rectangular cross-sectional cantilever. This work provides a promising method for measuring ultra-low COF in superlubricity.

Keywords superlubricity, coefficient of friction, atomic force microscopy

Study on Conductive Edge-Warping Graphite Mesas for Robust Structural Superlubricity

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Structural superlubricity (SSL) refers to a state of ultra-low friction and zero wear observed when two solid surfaces slide relative to each other. Despite the remarkable friction reduction achieved by SSL systems based on the self-retracting motion of graphite mesas, complete elimination of friction has remained elusive. Recent investigations have identified amorphous carbon at the edge of the graphite mesa, as the primary source of friction in such SSL systems. Here, the tensile stress of metal thin-films is exploited to engineer vertically conductive edge-warping graphite mesas (EWGM). Through this approach, robust SSL performance is realized, demonstrated by sliding an 8 μm side length square EWGM on an atomically smooth Au substrate for 11,000 cycles under a 1 mV constant voltage. In this SSL configuration, friction coefficients lower than 1.5×10-4 are achieved, with static contact resistance between EWGM and Au substrate as low as 28 Ω, and sliding contact resistance as low as 32 Ω. Furthermore, the EWGM exhibits SSL behavior on polished silicon wafer substrates. Additionally, the dependence of EWGM's friction on graphite mesa size and sliding speed is investigated. This study represents the first successful fabrication of conductive EWGM. Remarkably, in both the EWGM-Au and EWGM-Si SSL systems, measured frictions are more than one order of magnitude lower than those of graphite mesas lacking edges, and no wear is observed during extended current-carrying sliding. Overall, these findings establish a solid groundwork for the future realization of macro-scale conductive SSL systems.

keywords structural superlubricity; graphite mesa; edge warping

Symposium 2: Triboelectric Nanogenerators for Energy and Sensors

KEYNOTE

TENG-Based Pulse Wave Sensor

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Unconstrained measurement of physiological signals including electrocardiograph, respiration, and temperature by sensors through incorporation into commonly used objects has sparked a notable revolution in healthcare monitoring. However, unconstrained precision epidermal pulse wave monitoring is rarely reported. Although the current flexible skin-mounted sensors can capture pulse waves, they lack the capability to perceive tiny pulse pressure in an unconstrained manner. Herein, utilizing thin-film materials and multilevel microstructure design, an ultrathin and flexible

sensor (UFS) with the features of high flexibility, shape-adaptability, and ultra-broad-range high pressure sensitivity is proposed for unconstrained precision pulse wave sensing. Given these compelling features, the UFS is mounted to the surfaces of commonly used objects and successfully detects the fingertip pulse wave even under an ultra-broad-range finger-touching force. Key cardiovascular parameters are also extracted from the acquired fingertip pulse wave accurately. Furthermore, a proof-of-concept healthcare system, by combining the UFS and flexible devices (for example, flexible phones or E-newspapers) is demonstrated, offering a great advancement in developing an all-in-one system for IoT-based bio-health monitoring at all times and places.

Keywords: TENG, ultrathin and flexible sensor, epidermal pulse wave monitoring

INVITED

High Performance Tribovoltaic Nanogenerator for Self-Powered Sliding Ball Bearing

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The tribovoltaic effect is regarded as a newly discovered semiconductor effect for electromechanical energy conversion. However, tribovoltaic nanogenerators (TVNGs) are widely limited by low output power and poor wear resistance for device integration and application. Here, we invent a TVNG using a ball-on-disk structure composed of gallium nitride (GaN) and steel ball. It exhibits an open-circuit voltage exceeding 130 V and an ultrahigh normalized average power density of 24.6 kW m-2 Hz-1, which is a 282-fold improvement compared to previous works. Meanwhile, this TVNG reaches an ultralow wear rate of 5×10-7 mm3 N-1 m-1 at a maximum contact pressure of 906.6 MPa, surpassing the TVNG composed of Si by three orders of magnitude. Based on the TVNG, we construct the first tribovoltaic bearing consisting of steel balls, a retaining frame, a GaN ring, a seat ring, and a shaft ring. By integrating a management circuit, a transmission module, a relay, and receiving terminals, we achieve a sensing signal transmission in 16 seconds at 300 rpm, enabling the monitoring of ambient pressure and temperature. This work not only realizes a GaN-based TVNG with high-performance and low wear simultaneously, but also achieves frictional energy harvesting for industrial bearings, demonstrating great potential for intelligent components and self-powered sensor nodes in the industrial Internet of Things.

Keywords: tribovoltaic effect, gallium nitride, low wear, sliding bearing, frictional energy harvesting

Substantially Boosting Performance of Triboelectric Nanogenerators Via

triboelectrification Enhancement Effect

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Improving performance of triboelectric nanogenerators (TENGs) is crucial for their practical applications. Conventional methods such as surface modification of materials, ion injection, and charge excitation strategies have inherent limitations, including complexity, increased costs, and restricted applicability to various types of TENGs. Here, we propose a novel triboelectrification enhancement effect (TEE) to efficiently enhance the triboelectric charges of tribo-materials, achieving a remarkable 14.8-fold improvement in charge generation and a staggering 173.2-fold increase in output energy compared to a conventional TENG. By exploiting the dynamic contact between tribo-materials, the TEE offers a universal solution to enhance the performance of all types of TENGs. A contact-separation mode TENG using TEE achieves ultrahigh transferred charge and power density of 2.2 μC and 20.6 W/m3, respectively. After implementing power management, the TENG produces a pulse direct current output of 10.2 mA, and lights six 100 W high-power commercial lamps. Importantly, the prototype can power buoys and wave warning systems with wireless transmission by harvesting energy from both the water surface and underwater, illustrating the practicality of TEE in enhancing the performance of TENGs. This work provides a universal, simple, and zero-cost method to boost the performance of TENGs, thereby advancing their practical applications.

Keywords: triboelectric nanogenerator, triboelectrification enhancement effect, high performance

Long-Life Diamond-Based Tribovoltaic Nanogenerator

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The semiconductor direct-current tribovoltaic nanogenerator (SDC-TVNG) is promising for developing a new semiconductor energy technology. However, dynamic metal–semiconductor Schottky contact interfaces suffer from wear which may affect their working lifetime and limit their practical applications. Here, the SDC-TVNG built with diamond without wear for ultralong life is reported. The triboelectrification and tribological characteristics of the diamond-based direct-current tribovoltaic nanogenerator (DDC-TVNG) are systematically studied with a ball-on-flat configuration. The DDC-TVNG maintains high triboelectric output after 115200 reciprocating cycles without wear under the contact pressure of 1.99 GPa, which is far more than that of the silicon-based DC-TVNG. The working mechanism of the DDC-TVNG is attributed to the tribovoltaic effect. An increased normal load and sliding

frequency enhanced the triboelectric output. This work extends the investigation of semiconductor tribovoltaic nanogenerator and contributes to deeper understandings of tribovoltaic effects.

Keywords: diamond semiconductor, tribovoltaic effect, wear resistance

Enhanced Output Performance of Triboelectric Nanogenerator Utilizing The Floating Structure Design For Harvesting Wave Energy

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The Wave Energy Converter (WEC) plays an important role in the wave energy triboelectric nanogenerators (TENGs). To enhance the adaptability and usability of the triboelectric nanogenerator in wave environments, this work proposes a floating design method for improving the output performance of TENG. Based on typical TENG modes, different shell structures are used as carriers for TENG to verify the impact of floating structures on TENG's output performance. Based on floating dynamics theory and simulation analysis, the motion response of different WEC structures in waves are studied, and the energy capture characteristics of various structures in waves are analyzed. Meanwhile, a coupling TENG model is designed in Contact-separation and freestanding mode as the power generation unit to be validated. Wave simulation tests demonstrate significant differences in TENG output performance across various floating structures. The Boat-Type floating structure significantly enhances the output performance of TENG, compared to the lowest-performing square float. The Boat-Type floating structure increases the open circuit voltage, short circuit current, and transfer charge of the TENG by 155%, 414%, and 218%, respectively. In the capacitor charging test, the speed for charging a 10uF capacitor increased by 8.5 times. This work can improve the compatibility of the triboelectric nanogenerators with waves, increase its output energy density, and enhance its environmental adaptability, providing the theoretical foundation and technical support for the application of friction nano-generators in the field of ocean energy generation.

Keywords: triboelectric nanogenerator, wave energy converter, wave energy

INVITED

MEMS Device and System For Friction Energy Harvesting at Liquid-Solid Interface

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Relatively low output of alternating current (AC) pulsed electricity generated by impinging a water droplet on a hydrophobic surface is difficult for practical utilization. This is because conventional nanogenerators typically employ displacement current as the driving force to output AC. It is thus inevitable to face a series of complex power management issues, such as AC-DC conversion and AC phase asynchrony, leading to a bulky, inefficient and costly power MEMS system. Inspired by the formation mechanism of thunderbolt, a high voltage direct current (DC) droplet-based nanogenerator with a new electrostatic transduction mechanism was innovatively developed. The new droplet-based nanogenerator uses the principle of spatiotemporal charge separation to build a unique water charge shuttle architecture, which integrates power generation, conversion and storage functions into the same device, thus achieving high voltage DC output. To build a practical integrated MEMS system, a high-performance droplet-based nanogenerator inspired by an electric ray was developed, which has the characteristics of compact array architecture, high voltage DC output, and controllable energy release, successfully realizing the voltage-controlled electric shock process. By developing dedicated DC-DC BUCK management circuits and integrating sensor applications, the developed MEMS prototype demonstrated continuous driving of environmental Internet of Things sensors, showcasing its great potential in micro-energy harvesting and self-powered sensing systems. More importantly, this new concept MEMS device is proved to employ both displacement current and conduction current as the driving forces, which can be defined as total current nanogenerator. This nature-inspired high voltage DC MEMS provides new insights into the theory and technology of energy harvesting from liquid-solid interfaces.

Keywords: nanogenerator, liquid-solid triboelectrification, MEMS, direct current output, total-current power generation

Tribboelectric Nanogenerators: Driving the Future of Intelligent Transportation Systems

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With the evolution of the automotive industry, the development of intelligent transportation systems to support smart cities and modern transportation networks has garnered significant attention. Advanced sensors are crucial for these systems. Triboelectric nanogenerators (TENGs), as innovative self-powered sensors, offer numerous advantages, including a simple structure, low cost, and easy installation. In complex transportation environments, TENGs are particularly beneficial due to their distributed nature and their ability to harvest energy from the environment for self-

powered sensing and monitoring. Consequently, the integration of TENGs into modern transportation networks holds the potential to make them essential components of various sensor systems. Human-vehicle-road co-development is the core of building a intelligent transport system, in which the driver as a key link, their driving behaviour directly affects the stability of the transport system and the efficiency of road operation. Therefore, it is of great significance to improve the driving skills of drivers and make them develop good driving habits. Secondly, vehicle motion monitoring is also vital to ensure the safety of the entire traffic personnel, through real-time monitoring of vehicle motion status can provide timely warnings in dangerous conditions to the driver and the surrounding vehicles to avoid traffic accidents. In addition, as the carrier and support of transport, road is one of the important transport infrastructures. The damaged road seriously affects the driving safety, transport efficiency and the durability of vehicle suspension systems, making road health monitoring essential. Therefore, this paper describes the application of friction nanogenerators from three aspects: driver monitoring, vehicle motion status monitoring and road traffic monitoring. This paper explores the innovative applications of triboelectric nanogenerators in intelligent transportation systems, emphasizing their crucial roles in driver behavior, vehicle status monitoring, and road condition assessment, providing effective technical support for the construction of smart city transportation networks.

Keywords: tribboelectric nanogenerator, intelligent transportation system

Continuous Fabrication of Triboelectric Yarns For Strain Sensors

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In recent years, wearable electronics and smart textiles have attracted enormous research interest due to the rapid development of the Internet of things (IoT). To meet the requirement for power electronics, various flexible energy harvesters have been developed to harvest energies from the environment. Yarn/fabric-based TENG has demonstrated excellent potential in energy conversion from human motions to electricity. However, the development is still at its infant stage. The systematic study conducted in this research has revealed the outstanding capability of yarn/film-based TENG, yarn/fabric structured TENG mechanical movement sensing.

Using a continuous coating process, a high-performance triboelectric yarn was effectively prepared. This method shows the advantages in effectively achieving stable and continuous silicone rubber coating, controlling coating thickness, and maintaining the mechanical robustness of the coated filament. The triboelectric filament consists of a conductive core yarn as the electrode and a layer of silicone rubber coating as the dielectric material. It shows great elasticity, which can be stretched up to 250%. Under compression with PET film, the yarn with a short length of 20 cm can generate peak voltage and current outputs of 225 V and 2.4 μA.

Based on the silicone rubber-coated yarn, a novel yarn/film structured triboelectric device was designed using the triboelectric yarn and PET film as dielectric materials. The triboelectric devices can be used as a force sensor or balance to measure the forces received. By incorporating an elastic spacer into the device, we further showed that the devices were adjustable in both the response threshold and detection range. Compared to the triboelectric force sensors reported previously, our yarn/film devices showed a much larger detection range and higher flexibility in tuning the detection range.

Keywords: triboelectric nanogenerators, conductive yarns, self-powered sensors

Self-Powered Flow Sensing For Automobile Based on Triboelectric Nanogenerator With Magnetic Field Modulation Mechanism

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Automobile flow sensors are critical in ensuring the engine air-fuel ratio, improving fuel efficiency, and reducing pollution. This paper presents a self-powered shaftless turbine intake flow sensor (STIFS) for automobiles consisting of a ball-bearing triboelectric nanogenerator (BB-TENG) and a magnetic field modulation type magnetic gear electromagnetic generator (MG-EMG). The contact electrification between the rolling ball and the outer ring of the BB-TENG generates a periodic electrical signal for flow sensing. In particular, the magnetic gear can improve the BB-TENG signal frequency and MG-EMG output performance. The smoothness of the airflow is improved by designing the shaftless turbine using the computational fluid dynamics (CFD) method, and the start flow of the STIFS is 160 L/min. The sensing sensitivity of the STIFS reaches 0.71 Hz/L·min-1 in the monitoring range of 300–900 L/min, and there is a well linear relationship between frequency and flow rate. In addition, the MG-EMG can generate output voltages and currents of 374 V and 31 mA to power data analysis and transmission modules in real-time. This work presents a novel methodology for self-powered wireless airflow sensing in largeflow pipelines, such as automobile intake pipes.

Keywords: automobile flow sensor, shaftless turbine, self-powered, triboelectric nanogenerator, magnetic field modulation mechanism

Track 8 Aerospace and Ocean Tribology

INVITED

Effects of H2O on Friction of MoS2: A Study from DFT Computations and Macroscopic Sliding Experiments

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2D materials of MoS2 are known for their uses as lubricants for friction reduction due to easy shearing layers bonded by van der Waals interactions. However, the parallel reorientation of the MoS2 layers could not produce the same low friction due to the presence of H2O molecules from moisture in the environment, yet an increase in the environment humidity significantly degraded the lubrication performance. The increased friction of MoS2 in humid environments has been conventionally attributed to the oxidation process with formation of MoO3. By using sliding friction tests and first principles simulations, the authors revealed that the adsorption of water molecules itself was able to increase the friction of MoS2 by forming interfacial hydrogen bonds between water molecules and S atoms from MoS2. Such a process was confirmed by the thermal desorption of adsorbed molecules that led to a recovery of the friction. Meanwhile, Raman and TEM observation indicated that oxidation of MoS2 during the test period was insignificant. Understanding the effects of environment molecules on the friction of MoS2 would shed light on designing high-performance lubricating thin films operating in harsh environments.

Keywords: MoS2, friction, H_2O, interfacial hydrogen bonds

Solid-Liquid Coupled Microcapsules and Their Potential Aerospace Applications

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Microcapsule composites are high-performance self-lubricating materials based on liquid lubrication, but the low lubrication carrying capacity is the main factor limiting their engineering application. Solid-liquid coupling lubrication technology based on two-dimensional materials can effectively reduce the friction coefficient of the liquid superslip system and improve the lubrication carrying capacity. Combined with the controllability of the microcapsule composition, the lubrication additive MoS_2 was introduced into the microcapsule core material PAO6 to achieve the design and preparation of solid-liquid coupled microcapsules, and ultimately four microcapsules with MoS_2 uniformly dispersed in the core material were obtained. The average particle size of the microcapsules is 6-7μm, and the encapsulation rate is about 60%. The microcapsule composites with 3.2% MoS_2 content show a low coefficient of friction of 0.051 and an ultra-low wear rate of $7.5\times10^{-9}mm^3/Nm$; the lubrication load capacity of the microcapsule composites with 9.1% MoS_2 content can be increased by 317% compared with that of ordinary microcapsule composites. The combined effect of the lubricant film and the low-shear and high-bearing MoS_2 boundary lubricant film between the rough peaks improves the tribological performance of the microcapsule composites. The potential application of these solid-liquid coupled microcapsules in aerospace components is also proposed. Achieving the coating of microcapsules on the surface of aerospace components can optimise the tribological properties and avoid friction and locking formed by contact between friction bodies, ensuring the reliability and maintainability of aerospace equipment.

Keywords: microcapsules, solid-liquid coupled lubrication, self-lubricating materials, aerospace components

Research on Dual Electric Field Mutual Inductive Multilayer Triboelectric nanogenerator for Ocean Energy Collection

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Triboelectric nanogenerators (TENGs) are a novel technology for harvesting environmental micro/nano energy to produce electricity. The electric field generated by different electrode properties of materials plays a crucial role in regulating the dynamic behavior of the triboelectric charges between the dielectric layer and the metallic electrode. Adding an additional electric field can break the balance of charges between existing materials and establish a new balance by obtaining charges from the outside world. This new balance can help increase power generation. This paper analyzes the transfer mechanism of additional charges by establishing an additional electric field model, which aims to systematically study the effect of electric field mutual inductance of bilateral motors on the amount of charge of TENG. The changed state of the dynamic electric field is obtained through theoretical analysis. By introducing an external charge from the metal, the model strengthens the effect of bilateral electric field mutual inductance, thereby improving the ability of the metal electrode surface to carry the charge and establishing a new dynamic equilibrium of triboelectric charge. The relationship between the structural parameters and the electric field mutual inductance is analyzed by deriving the theoretical formula of DEF-TENG. The experimental results show that the open-circuit voltage and the transferred charge of DEF-TENG are 156% and 154% higher than that of single-electric field TENG (SEF-TENG) after introducing external charges. This study provides a novel method and guidance for the linear-to-rotary triboelectric nanogenerators to improve power generation. This provides a new structure for high-density collection of ocean energy.

Keywords: ocean energy, triboelectric nanogenerator, dual electric field

Tribocorrosion Performance of CrMoSiCN/Ag Composite Coatings Sliding

Against WC+6%Co Balls in Artificial Seawater

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Titanium alloy components are susceptible to significant challenges arising from severe tribocorrosion and microbial adhesion in harsh marine environments. An effective approach to alleviate these issues is to deposit a composite protective coating on the surface of titanium alloys. In this work, the CrMoSiCN/Ag composite coating was successfully applied to enhance the tribocorrosion resistance of Ti6Al4V alloy in artificial seawater by adjusting the Ag target current and trimethylsilane ($C_3H_{10}Si$) flow rate. The results demonstrate that the CrMoSiCN/Ag composite coatings were composed of fcc-(Cr, Mo)N solid solution, fcc-Ag nanocrystals and an amorphous matrix. While increasing the Ag content led to a decrease in corrosion resistance of the composite coating, higher levels of Si and C contributed to an overall enhancement in tribocorrosion performance. Notably, the formation of protective $Ag_2Mo_2O_7$, MoO_3 and $Si(OH)_4$ friction layers significantly enhanced the corrosion resistance of the CrMoSiCN/Ag coatings, leading to an impressively low tribocorrosion loss of 2.436×10^{-4} mm^3. The introduction of high contents of Si and C showed promising potential in improving the tribocorrosion performance of Ti6Al4V alloy.

Keywords: CrMoSiCN/Ag coating, C3H10Si flow rate, tribocorrosion

Research on Superslip Drag Reduction of Unmanned Underwater Vehicles Based on Composite Nanoporous Coating

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Underwater vehicles play a critical role in ocean engineering but are challenged by fluid resistance; drag reduction technologies are integral to enhancing performance and reducing energy consumption. Superhydrophobic surfaces, widely studied for their drag-reducing effects, suffer from insufficient stability and durability in practical applications. Biomimetic surfaces show potential for drag reduction, yet they must overcome challenges in durability and cost. Novel composite material coatings offer potential advantages in underwater vehicle surface treatment due to their superior properties. This study aims to develop graphene-reinforced polyurethane/titanium dioxide nanotube composite superhydrophobic coatings to improve coating durability and hydrophobic stability, addressing limitations of existing surface treatment technologies, and enhancing drag-reducing performance. Leveraging interdisciplinary

knowledge from nanotechnology and surface science, the formulation and design of coatings will be optimized to strike an optimal balance between performance and cost-effectiveness. This research will bring innovation to drag reduction technology for underwater vehicles, aiding sustainable development in ocean engineering.

Keywords: underwater vehicle, drag reduction technology, superhydrophobic coatings, composites, graphene-reinforced polyurethane

Effect of Heat Flux Control on Frictional Heat Between Bristles and Rotor for a Multi-stage Brush Seal

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Massive heat generated between frictional pairs, result in pre-failure (i.e., adhesion, melting and frictional wear) in multi-stage brush seal. Thus, overall sealing performance and service life are reduced. Aiming at alleviating the accumulated frictional heating effect, three heat flux control strategies between frictional pairs were proposed. A three-dimensional tube bundle model was established based on multi-stage brush seal with differentiated structure at each stage. After experimental verification of simulation, frictional heating effect and heat transfer characteristic were further analyzed. Results demonstrated that gradually reducing interference and differentiating bristle structure can reduce the maximum temperature growth rate at downstream stages by 8.61%-35.93% and 10.59%-36.21%, respectively, indicating frictional heating effect at the downstream stages is significantly alleviated. To pursue both an alleviation of frictional heating effect and a balanced inter-stage pressure drop, gradually increasing the fence height of backing plate represents the viable alternative strategy. Conversely, if there is an additional requirement to enhance of sealing performance, differentiating bristle structure is deemed as an optimal strategy. These findings explored the influence mechanism of factors (i.e., pressure drop borne by bristles Δp, the stiffness of bristles γBTP, the interference Δr and contact force at bristle tips Fn) on frictional heating effect. The above studies provide a theoretical basis to alleviate frictional heating effect and breakthrough the limitation of pre-failure in multi-stage brush seal.

Keywords: multi-stage brush seal, heat flux control, frictional heating effect, three-dimensional tube bundle model, flow and heat transfer characteristic

Research on the Mechanism of Aerospace Fasteners Biting Based on Tribological Analysis Methods

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Fasteners are the most widely used basic products in aerospace models, the connecting designing technology of which could affect the reliability of aerospace models. Biting is the most common failure mode of aerospace fasteners, once biting, the rocket assemble process and even the launch mission will be severely adversely affected. Based on the surface and interface frictional mechanics analysis of screw pairs, simulation analysis under different friction coefficients, friction and wear tests under different matching states, observation and chemical analysis of surface and interface after wear experiment and so on, the main factors causing aerospace fasteners biting will be investigated. Meanwhile, the impact pattern could be deeply analyzed and the mechanism could be systematically summarized. The research results of this article aim to improve the biting phenomenon and enhance the reliability of fastening connecting in aerospace models, thus, required theoretical basis and technical support will be provided.

Keywords: mechanism, fasteners, biting

Nonlinear Dynamic Analysis of Three-Point Angular Contact Ball Bearing Under Variable-Load Condition

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The inner ring of a three-point angular contact ball bearing (TPACBB) is designed with a split structure, enabling it to withstand bidirectional axial loads while conserving space and exhibiting high load-carrying capacity. During bearing operation, there exists a phenomenon of multi-point contact, including two-point contact and three-point contact, between balls and raceway. The complex and time-varying contact characteristics will affect sliding, friction, and lubrication, ultimately the service performance and life of the bearing. Comprehensively considering the interaction between ball, cage, raceway and lubricant, a dynamic model for three-point angular contact ball bearing (TPACBB) with multi-degree-of-freedom is established to investigate the change mechanism of multi-point contact and the dynamic performance of TPACBB during different contact states. Based on this model, the critical axial load at which the multi-point contact state transmits, and the number and location of contact points in TPACBB are discussed under a steady working condition. Specifically, a relationship between the critical axial load and operating conditions (such as load and rotational speed), as well as structural parameters (including curvature radius and contact angle) is analyzed. Furthermore, at variable-axial load, the dynamic characteristics of TPACBB and change mechanism of contact point are analyzed when the contact state transits from three-point to two-point contact. The findings reveal that the multi-point contact phenomenon of TPACBB is related to load. Under smaller axial loads, TPACBB is more prone to three-point contact, which effectively reduces the contact stress on the inner ring, thereby enhances its load-carrying capacity, but leads to higher sliding rate.

Keywords: three-point angular contact ball bearing, variable-load condition, dynamics model

Friction and Wear Characteristics of Open Stern Shaft Lip Seal

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Aiming at the serious wear caused by thermal damage and heavy load under low speed and heavy load friction condition of ship's stern lip seal, a coupled thermal-solid numerical analysis model was established based on the Archard equation, and the effects of temperature of the open lip seal and the lip tip force load on the wear and deformation of the end face were analysed. The trend of the friction torque of the open lip seal lip during the start-stop process is revealed, the surface morphology characteristics are analysed, and the wear mechanism under different friction states is explored. The results show that the friction torque of the lip seal increases and then decreases until it stabilises during the start-stop phase, and the wear is reduced by 88% compared to the dry friction condition; The blowback gas allows the lip to dissipate heat in a timely manner, reducing the effect of temperature on wear; Different lubricating media have a large influence on the friction of lip seal lips, and the friction coefficient under oil lubrication condition is 0.3 times of that under seawater lubrication condition; Reasonable design of the lip seal structure, through the realisation of dynamic adjustment of the blowback gas pressure, can effectively improve the uneven wear phenomenon and enhance the service life of the lip.

Keywords: open lip seal, wear characteristics, Archard's equation

A New Bearing Dynamics Model Considering Cage Flexibility by Shell Elements

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In the aero-engine mainshaft bearing, the cage will be subjected to high-frequency and violent collision from rolling elements during operation. In order to predict dynamic

performance of the bearing, the movement stability and the failure conditions of cage accurately, the cage flexibility should be considered in the bearing dynamic model. At present, the research on cage flexibility mainly adopts the lumped-mass approach or the finite element method (FEM) based on commercial software. However, the lumped-mass approach ignores the shape of pockets and thus cannot obtain the deformation of pockets, while the current cage models based on FEM rarely consider lubrication and the effect of pocket deformation. In this paper, the rigid dynamic model of bearing is improved and a new flexible cage model is proposed, which uses shell elements with five degrees of freedom to simplify the cage and takes the influence of lubrication on the cage into account. Also, the deformation of the pockets, the cross-beams and the lintels can be calculated in the model. The correctness and accuracy of the model has been verified by the experimental results. For bearings operating at high speed and heavy loads, the result comparisons are made for the different cage flexibility models, and the effects of the cage flexibility on dynamics of bearing is explored.

Keywords: cage flexibility, dynamic model, shell element

Friction and Wear Behaviors of NiTi Based Composites at Elevated Temperature

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In the aerospace field, mechanical components are often operated in harsh conditions such as high temperature, high speed, and high loads. Therefore, it’s significant to develop a material with excellent tribological and mechanical properties under high temperature. In this paper, NiTi based self-lubricating composites contained Ag, Bi2O3, MoS2 were prepared by spark plasma sintering (SPS). Dry sliding wear tests were performed against a ball under 30N normal load at room temperature (RT) and elevated temperatures of 300℃, 500℃ and 800℃，The worn surface was studied using a scanning electron microscope (SEM) and an X-ray diffraction (XRD) to investigate the wear mechanisms. It was found that the addition of Ag Bi2O3, MoS2 reduces the friction coefficient and wear rate to 0.24 and 5.2×10-6mm3/Nm with a decrease of 37.8% and 34.7%, respectively, compared to the coating substrate at 800°C. This study investigates the effects of adding multiple solid lubricants in NiTi-based composites and provided ideas for the preparation of high-temperature composites with excellent comprehensive performance.

Keywords: NiTi based composites, high-temperature, self- lubrication

Tribo-Informatics Approach for Analyzing the Tribological Performance of Bushings in The Variable Stator Vane System

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Determining the friction and wear behaviors of aero-engine key components under realistic conditions is important to improve their long-term reliability and service life. Here, the friction and wear behaviors of different shaft-bushing materials in the variable stator vane (VSV) system were investigated by two types of tribo-tests. These are the basic pin-on-disc test with an RTEC-5000S tribometer and the actual shaft-bushing test with a special high-temperature tribometer. The coefficient of friction, the friction torque, and the wear amount of the polyimide material and high-temperature alloy material of bushings were compared. Different machine learning (ML) models were established based on the experimental information to predict the coefficient of friction (COF) and wear rate. The results indicated that there is a significant temperature warning line for the wear amount of the polyimide material, while the high-temperature alloy material exhibited stable tribological performance under experimental load and temperature conditions. ML analysis indicated that the extreme gradient boosting (XGB) outperformed other ML algorithms in predicting the COF (R^2 value = 0.956), while the kernel ridge regression (KRR) produced the best performance for predicting the wear rate (R^2 value = 0.997). The tribo-informatics research for bushings in the VSV system can accelerate the structural optimization and material selection of key bushings, and this study will also serve as a key input for the dynamic model of VSV systems.

Keywords: variable stator vane, bushings, machine learning methods

Investigation into The Tribological Characteristics of PTFE Slide System for Offshore Platform Jacket

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In ocean engineering, offshore platform jacket is a significant component of offshore drilling platforms and offshore wind power. The offshore platform jacket is a large-scale equipment, and the slippage shipment is an important part of its offshore installation construction. In actual slippage shipment, a slide system consisting of wooden slide shoe and PTFE slide plate is required. The PTFE slide plate has a honeycomb surface structure, with wooden sliding shoes installed on top of the slide plate, and the jacket placed on the sliding shoes for dragging. This paper aims to elucidate the friction and wear characteristics of a PTFE slide system composed of a PTFE slide plate and wooden slide shoe. Firstly, by exploring the compression

characteristics of different types of wooden sliding shoe, the elastic modulus and yield strength of wooden sliding shoe are obtained, and suitable wooden sliding shoe is determined for the slide system; Subsequently, friction and wear experiments were conducted on the PTFE slide plate and wooden sliding shoe under load conditions, as well as electron microscopy observation and energy spectrum analysis of the surface of PTFE slide plate and wooden slide shoe. The changes in friction coefficient of PTFE slide plate under different loads and reciprocating frequencies, as well as the differences in surface morphology and composition before and after friction, were obtained under both non-lubricated and lubricated conditions.

Keywords: offshore platform jacket, PTFE slide plate, fiction and wear

Influence of Surface Slip on Hydrodynamics and Flow Field around a Two-Dimensional Hydrofoil at a Medium Reynolds Number

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In present study, the effects of surface slip on the hydrodynamics (lift and drag coefficients) and flow around a two-dimensional NACA (National Advisory Committee for Aeronautics) 0012 hydrofoil at the Reynolds number of 1.0106 at 0° - 10° angles of attack are numerically investigated. Three slip positions (both surfaces, the upper surface, the lower surface) and eight slip lengths from 1 μm to 500 μm are applied on the NACA 0012 hydrofoil surface. For the both surface slip and the upper surface slip conditions, surface slip has been found to increase lift and reduce drag by postponing the flow transition, laminar separation bubble, and flow separation on the hydrofoil surface. Slip can also induce upshift of the mean velocity profile, decrease the displacement thickness, and mitigate the turbulent kinetic energy in the flow field. However, counter-intuitive effects are found under the lower surface slip condition, where the total drag demonstrates a non-monotonic variation with the angle of attack. The effects of the surface slip length and the underlying mechanisms are clarified. Finally, the flow map demonstrating the complex interaction between the surface slip and the flow is presented, which shall provide valuable insights for practical applications of slippery materials in the ocean engineering.

Keywords: surface slip, superhydrophobic surfaces, hydrodynamics, drag, turbulent flow

Semi-Analytical Model for Analyzing Microstructural Effects in Conductive Sliding Contacts

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In the exploration of the reliability of sliding electrical contacts, the electrical, thermal, and mechanical effects at the contact interface form an intricate and interwoven network that collectively determines the contact's performance and lifespan. The electrical effects, driven by the irregular surface microgeometry, result in a smaller actual contact area than the nominal one, leading to increased contact resistance and unstable current density. This non-uniform resistance distribution generates localized overheating (Joule heating), which elevates the temperature at the contact surface and alters material properties. Thermal effects can lead to the formation and removal of oxide layers, further increasing contact resistance. The distribution of contact pressure and its dynamic changes during sliding cause wear, altering the geometric shape of the contact and introducing new sources of resistance.This work examines the interaction of these effects in sliding electrical contacts through a comprehensive semi-analytical approach, focusing on the microstructural effects, including surface roughness and oxide layers. The objective is to clarify how these multi-physics effects influence contact behavior, offering insights for enhancing contact design. The semi-analytical model considers the interfacial electrical resistance and its associated Joule heating, providing a more realistic representation of the contact behavior.

Keywords: sliding electrical contacts, multi-physics coupling, contact electrical resistance, joule heating, semi-analytical model

Track 9 Industrial Tribology and Instruments

KEYNOTE

Electric Currents in Mechanical Drivetrains – Challenges and Opportunities

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The phenomenon of electric current passage can cause damage to tribological contacts of mechanical components. Due to the increasing electrification of drive trains and the increased requirements for speed variability, the challenges posed by parasitic current passage are increasing. It can be assumed that between 10 % and 50 % of bearing failures in electric motors and generators are affected by the phenomenon of current passage. Furthermore, it can be assumed that the failures will further increase due to the increasing use of fast frequency converters.
The parasitic currents can lead to electrical breakdown of the bearing lubricant film. The resulting sparks with locally high energy densities can cause various types of damage to the components in the current flow (e.g. rolling bearings, lubricant and gear stage). It is known that the damage patterns that occur, for example to the rolling bearing, are strongly dependent on the electrical environment (motor power, grounding

conditions, switching frequency, type of cable, etc.). In addition, it has been shown that the mechanical boundary conditions also influence the electrical substitution system of the rolling contact.
This talk deals with the challenges and opportunities arising from this phenomenon.

Keywords: electric currents, rolling bearings, gears

Friction and Wear Evolution Mechanism and Service Performance Degradation Characteristics of Heavy-Load Transmission Wire Rope

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Aiming at the problems of friction, wear and performance degradation existing in the service of heavy-load transmission wire ropes, the evolution mechanism of friction and wear characteristics of the wire rope was revealed using a self-made wire-sheave friction and wear test machine and mechanical property test device. The influence of different surface wear on teh residual tensile strength and bending fatigue life of teh wire rope was analyzed. The results show that: the friction coefficient decreases with the sliding distance, and its evolution process is obviously affected by the wire rope structure, and the friction coefficient is about 0.65 in the relative stability stage. The friction temperature increase rate was first fast and then slow. The maximum temperature rise is about 65 ℃. The wear features are mainly furrow, spalling and plastic deformation. The wear mechanism is mainly adhesive wear and abrasive wear. With the increase of sliding distance, the residual strength and the breaking rate of bending fatigue of the worn wire ropes show a nonlinear degradation trend. The maximum breaking force decreases from approximately 49.6 kN to 42 kN. The maximum number of bending fatigue decreases from 10 708 to 4 070. The wear results in the decrease of the tensile plasticity of the steel wire and the expansion of the bending fatigue crack. The fracture mechanism of the steel wire under the two working conditions is ductile fracture and brittle fracture, respectively.

Keywords: transmission wire rope, sliding friction, wear evolution, breaking tensile, bending fatigue

Replacing Copper in Composites with Industrial Waste: A Novel Approach for Cu-Free resin-Based Braking Material

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Resin-based braking material is currently the most widely used automotive braking material due to its simple preparation process, low cost, and good comfort. However, the heat-fade behavior of resin-based braking materials limits their application in high-performance braking systems. Copper has excellent thermal conductivity and plays a crucial role in the high-temperature tribological properties of brake materials. Recent studies have found that copper-containing particles produced during the braking process are harmful to the human body and the environment. The development of high-performance copper-free braking materials has become an urgent research topic. In this study, the resin-based brake materials were filled with industrial waste to develop copper-free brake materials. The changes in the physical and chemical properties of copper and industrial waste during braking were investigated, and their role in resin-based composites was discussed. The effects of industrial waste on the mechanical properties, friction, wear characteristics, and wear mechanisms of resin-based brake materials were investigated. Compared with copper, industrial waste was found to be more beneficial for the overall friction and wear characteristics of resin-based composites, making it a potential substitute for copper in brake materials. The inclusion of industrial waste facilitated the development of a surface friction film during the braking material's friction process and encouraged the transition from abrasive wear to adhesive wear. This research proposes using industrial waste to replace environmentally harmful and costly copper in brake materials. This substitution not only enhances the performance of brake materials but also reduces their costs.

Keywords: brake material, friction and wear

Tooth Backlash Inspired Comb-Shaped Single-Electrode Triboelectric Nanogenerator for Self-Powered Condition Monitoring of Gear Transmission

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Gear transmissions are an integral part of most rotation machinery. Their abnormalities can affect the reliable operation of the equipment. Most sensors that monitor gear transmissions lack self-powered capability and have weak features due to the restricted mounting locations. In this study, the tooth backlash inspired triboelectric nanogenerator (TB-TENG) is proposed for self-powered condition monitoring of the gear transmissions. A series of comb-shaped copper foil electrodes is arranged on the non-load tooth sides to create a single-electrode TENG. Through the rational use of the tooth backlash space, the TB-TENG does not affect the tooth meshing or participate in the load transmission, ensuring both durability and structural compactness. The TB-TENG outputs are evaluated under various working conditions, structural optimizations, and different working environments based on the established TB-TENG test system. Consequently, the maximum output power density corresponding to the optimal

resistance is obtained. Based on the output signal model, the effectiveness of the TB-TENG in self-powered condition monitoring is verified. Moreover, the denoising convolutional auto-encoder (DCAE) is trained based on the TB-TENG voltage signals, achieving a diagnostic accuracy of 98.4%, equivalent to accuracy based on vibration signals. The practical applicability of the proposed TB-TENG is demonstrated through deployment testing in an industrial parallel-gear transmission system. Specifically, TB-TENG can accurately monitor gear speed under variable speed conditions to assess operation stability and health status. Finally, the theoretical and experimental basis for the TB-TENG is provided with applications for self-powered condition monitoring.

Keywords: tooth backlash, triboelectric nanogenerator, self-powered condition monitoring

Friction and Lubrication Technology of Aerospace Bearings

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Friction and lubrication technology of aerospace bearings is discussed in this report. With the development of aerospace technology, higher requirements are raised for the self-lubricating properties of bearing cage materials. The lubrication condition of aerospace bearings under extreme environment is analyzed, and the application of lubrication technology under various service conditions is introduced, especially for the application of bearing cage materials applied in the low-temperature power bearings for rockets and long life and high reliability bearings for attitude control systems. The influence of temperature on the lubrication film formation and the friction and wear properties are discussed, and the effect of long-term sustained-release lubrication and the retention mechanism of oil film are also discussed, which provide theoretical basis and technical support for the optimal design of aerospace bearings. Finally, the future research targets and key development direction of aerospace bearing lubrication technology are introduced.

Keywords: aerospace bearings, cage, self-lubricating technology

Compensation Algorithms for Lubrication Uncertainties: Enhancing Accuracy and Robustness in Ultrasonic Lubricant Film Thickness Measurement

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Accurate measurement of lubricant film thickness is pivotal for assessing lubrication

conditions and transmission efficiency in mechanical equipment. Among various measurement approaches, the ultrasonic reflection technique has garnered significant attention due to its non-destructive nature, and minimal physical size. Nevertheless, the precision of the ultrasonic technique can be susceptible to lubrication uncertainties such as largely ranged temperature, various surface coatings, and complex contact geometry in industry settings. This study addresses these influencing factors by introducing distinct compensation techniques to enhance the accuracy of ultrasonic measurement. The effectiveness of these techniques is systematically explored, providing a comprehensive understanding of their impact on measurement reliability. The refined ultrasonic reflection technique, post-compensation, is subsequently applied to practical industrial scenarios, with two representative examples in tilting-pad thrust bearings, and fuel pump tribo-pairs. Comparative analyses are conducted between experimental testing and numerial simulation data to verify the effectiveness of the refined ultrasound measurement algorithms.

Keywords: ultrasonic measurement, lubricant film thickness, compensation algorithm

A Study on the Feasibility of Using Water-Based Lubricant of Siloxane Polymers Emulsion for the Hot Stamping of Aluminum Alloys

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Hot stamping of aluminum alloys is an important manufacturing method to achieve the goal of light weight automobiles. The scratch and cracking caused by friction and wear in the production process are the main obstacles in mass production of aluminum (Al) alloy components. At present, there is no specific lubricant for hot stamping of Al alloys, and there are only a few research studies have been reported in open literature on the applicability and lubrication mechanism of lubricants pertaining to the hot stamping of Al alloys. In this work, a water-based lubricant which is produced for similar working conditions was selected for friction experiment to evaluate its performance under hot stamping conditions to explore its effectiveness and lubrication mechanism. A pin-on-disk tribological test configuration was employed to simulate the hot stamping process in terms of a heating process and a reciprocating sliding between the tool and workpiece. The test utilized a hot work tool steel and 7075 aluminum alloy workpiece material. Through the experiments, it is found that the water-based siloxane emulsion can provide low friction coefficient by minimizing the direct contact between the tool and workpiece surfaces. Under low friction conditions, abrasion appears to be the main wear mechanism. The occurrence of severe adhesion and consequently the sharp rise in the friction coefficient indicates the failure of the lubricant film. The roughness values of contacting surfaces have been seen to the main influencing factor in determining the stability of lubrication film. However, the cleaning of used lubricant from the

tool/workpiece surfaces could be an issue in the use of lubricants in hot stamping application. The design of lubrication recipe based on the characteristics of the hot stamping would the main focus of further research.

Keywords: hot stamping, water-based lubricant, pin-on-disk test, wear, friction

Electrified Tribotesting: An Approach to Screening e-Fluids for Electric Vehicles

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As electric vehicle (EV) adoption surges, the need for robust lubricants capable of enduring the rigorous conditions within EV powertrains is escalating. The combination of high starting torques, rapid speeds, and unmanageable electrical currents flowing through contact points poses challenges for testing EV lubricants. Traditional tribotesters are not adequate for effective lubricant analysis in electrified settings. This research introduces a customizable benchtop tribometer equipped with a power source and a resistance data logger to assess the tribological efficacy of diverse EV lubricants under electrified circumstances and varying sliding conditions. Results indicate that the presence of electrical currents at contact interfaces significantly impacts friction, electrical contact resistance, and wear. Consequently, the electrified tribological testing methods explored in this study could potentially offer faster and more precise screening of electric/hybrid lubricants.

Keywords: friction and wear testing, electrified contract, lubricant

Study on Anti-Adhesion and Tribological Properties of Coal Conveyor Belt

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Coal adhesion on conveyor belts during the port coal transportation process is a common problem that can cause coal spills on the return trip. In severe cases, this can result in bulging, wear, misalignment, and even tearing of the conveyor belt, significantly impacting the safety and efficiency of coal transportation. In this experiment, an atomic force microscope (AFM), a three-dimensional white light

interference topography instrument, a UMT3 multifunctional friction and wear testing machine, a video contact angle measuring instrument, and other equipment were used to compare and analyze the composition, surface morphology, surface wettability, macroscopic and microscopic adhesion properties, antistatic properties, and tribological properties of seven different types of commercially available industrial conveyor belts. It was investigated whether there was a correlation between the conveyor belt's composition and microstructure and its anti-adhesion performance. The research is of great significance for the development of anti-adhesion and long-life conveyor belts, the improvement of resource utilization and environmental protection.

Keywords: coal conveyor belt, anti-adhesion, coal dust

Tribo-Testing System Design for Sustainability

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The research and application of tribology are of great significance for promoting sustainable economic development. Strengthening the research and development of tribology will provide reliable anti friction and wear-resistant solutions for equipment manufacturing related industries, as well as for clean energy production and efficient use, reducing greenhouse gas emissions, and other fields.
This report starts from the current tribology research status of coatings and lubricating materials in the fields of new energy vehicles, wind power generation, photovoltaics, etc., introduces the tribology working conditions involved in environmentally friendly and energy-saving emission reduction requirements, and details the development of new tribology testing technologies that promote sustainable economy.

Capturing Every Moment: Unravelling Friction, Wear, and Transfer Mechanisms of PTFE Using in-situ High-Bandwidth Microscopy

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Introduction: In-situ high-speed microscopy is widely used in tribology for real-time imaging of transient and dynamic events. However, its application is restricted by limited onboard storage, allowing for only short-duration recordings, typically ranging from a few seconds to minutes. Extending recording durations to cover an entire tribotest, which typically last hours or days, often requires compromising frame rates or image resolution.

Methods: In this study, an in-situ high-bandwidth microscope capable of continuous, high-speed, and high-resolution recording was developed. This microscope was integrated into a pin-on-disc tribometer to investigate the tribological mechanisms of unfilled PTFE. Two experiments were conducted. The first involved sliding PTFE balls against 304 stainless steel discs and capturing images of the disc wear tracks. In the second experiment, the steel discs were replaced with glass discs to facilitate in-contact imaging. Both experiments were performed in an enclosed chamber with relative humidity set at 0.1%, 54%, and 80%.

Results: PTFE/304 tests show a constant migration of PTFE transfer lumps along the disc wear tracks in dry air (0.1% humidity) and the formation of tribofilms on the pins in humid air (54% and 80% humidity). These tribofilms are formed by the tribochemical reactions between PTFE and steels. As moisture is introduced, both friction coefficients and wear rates reduce. These reductions are caused either by the tribofilms on the pins or the adsorbed water on the discs. By replacing the 304 with glass discs, which do not react with PTFE, the two factors can be studied independently. The decrease in friction coefficients of PTFE/glass with increasing humidity, in the absence of tribofilms, indicates that friction reduction is primarily due to the adsorbed water on the discs. In contrast, the insensitivity of wear rates of PTFE/glass to changes in humidity suggests that wear reduction is predominantly governed by the tribofilms on the pins.

Keywords: in-situ tribometry, polymers, humidity

Solvothermal Synthesis of Ceria Nanoparticles and Their Chemical Mechanical Polishing Properties

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Chemical Mechanical Polishing (CMP) is a crucial process in integrated circuit manufacturing. As ceria CMP slurry stands as a significant consumable with a high price, the synthesis method and performance research of ceria nanoparticles have garnered widespread attention. This study experimentally investigates ceria nanospheres with tunable particle sizes synthesized via the solvothermal method and their CMP properties. Polyvinylpyrrolidone serves as the surfactant, and cerium nitrate acts as the cerium source in the solvothermal reaction. We explore the synthesis mechanism by adjusting reactant content, reaction time, and temperature. Crystal structure and surface properties are analyzed using scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and thermogravimetric analysis (TGA). CMP experiments assess the polishing performance of nanospheres. Mesoscopically connected crystals enable controllable synthesis of tunable-size ceria nanospheres. Within this synthesis system, reducing the dielectric constant effectively reduces

nanoparticle size. Addition of reducing agents like ethanol enhances the proportion of trivalent cerium in synthesized ceria. Particle size significantly impacts the CMP performance of ceria. Larger ceria nanospheres exhibit higher CMP material removal rates and superior surface quality. A maximum temperature of 700 °C before ceria oxidation enhances removal rates as an optimal heat treatment temperature.

Keywords: ceria nanospheres, chemical mechanical polishing, solvothermal method

A Quantitative Characterization Model for Nonlinear Friction of O-Rings

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For the nonlinear friction of O-rings in sliding, the method combining the nonlinear properties of both interfacial friction and body deformation of O-rings is proposed. The nonlinear quantitative characterization model is established based on the adjusted Iwan model and Kelvin-Voigt model. The influence of medium pressure, lubrication, and rubber viscoelasticity are discussed. The result shows that the proposed model can provide an accurate determination of the nonlinear behavior of O-rings in vibration.

Keywords: hysteresis behavior, adjusted Iwan model, nonlinear friction, O-rings

Influence of Friction Pair Characteristics on Tribological Properties of Carbon-Base coated Self-Lubricating Radial Spherical Plain Bearings

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As a new type of bearing, carbon-based coated self-lubricating radial spherical plain bearing(SSPBs) can be used in extremely harsh working conditions because of its wide source of self-lubricating coating materials, good consistency of preparation process and strong adaptability to the environment. The key to determining bearing service performance is the self-lubricating coating at the relative moving interface. However, there are few reports on the influence of the SSPBs of the friction pair characteristics(coating position) on the tribological properties. Therefore, the hydrogen-containing diamond-like (H-DLC) coatings as the lubricating materials were prepared on the inner ring with an outer spherical surface and the outer ring with an inner spherical surface by unbalanced magnetron sputtering. The SSPBs with inner spherical coating (H-SSPBs-O), outer spherical coating (H-SSPBs-I) and double side coating (H-SSPBs) were developed by the combination and assembly of inner and outer

ring parts with and without self-lubricating coating. The microstructure results show that the coating is well combined with the inner and outer ring substrate with no micro-defects such as cracks. Due to the structural limitation, the coating thickness of the inner spherical of the outer ring is lower than that of the outer spherical of the inner ring . The test results under vacuum oscillating show that H-SSPBs life (153044) and friction torque (0.0039N·m) are better than H-SSPBS-I (21230, 0.005 N·m) and H-SSPBS-O (18590, 0.008 N·m). The difference in tribological properties of these three kinds of bearings is closely related to the formation and transfer of friction transfer film at the interface of relative motion based on the phase composition analysis results. With the increase in oscillating times, the wear failure mechanism of carbon-based SSPBs changes from abrasive to adhesive wear. The above results show that double-sided coating should be used for carbon-based SSPBs to improve their tribological properties.

Keywords: carbon-based films, radial spherical plain bearing, tribological properties

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Track 1-I: Friction and Lubrication

INVITED:

Study on Shear Behavior and Friction Mechanism of Water Molecules at Low Temperature Interface

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The observation of the structure and behavior of interfacial water molecules is beneficial for revealing the underlying mechanism of shear interface behavior in water-based lubrication. Here, we investigate the influence of temperature and surface wetting characteristics on friction through atomic force microscopy (AFM). Combining sum frequency generation vibrational spectroscopy (SFG) and molecular dynamics (MD) simulation to reveal the microscopic mechanism of the influence of interfacial water on friction. It was found that an increase in the proportion of "liquid like" water is beneficial for reducing the friction coefficient at the shear interface. This work unifies the influence of water molecule structure on water-based lubrication within a certain range.

Keywords: interface water structure, SFG, friction

Effect of Hydrated Ions and Wettability on Ice Friction

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Ice friction plays a vital role in both fundamental research and practical applications. However, one unsolved puzzle regarding ice friction is the effect of hydrated ions and wettability on its tribological properties. Here, we report the discovery of the extent of hydrated ions, different surface wettability and their combination on ice friction. By simply changing the initial type and concentration of ions in the ice-making solution, the ice friction coefficient can be reduced by 70 percent. Experimental spectra, low-field nuclear magnetic resonance (LF-NMR), density functional theory (DFT) calculations, and Molecular dynamics (MD) simulations demonstrated that the addition of ions could break the H-bonds. For negatively charged surfaces, cations play an important role in ice friction. Ionic ice had a lower friction coefficient because of hydration repulsive force and more free water molecules produced by H-bond breaking. Wettability regulates ice friction coefficients by changing the adhesion between water-solids, and hydrophilic surface exhibited stronger adhesion force. Regulation of surface wettability can modulate ice friction by about 20 percent. The effect of regulating wettability to modulate ice friction coefficient is relatively weak comparing with hydrated ions. This study provides guidance for the selection of ions and surface wettability to modulate ice friction.

Keywords: ice friction, hydrogen bonds, wettability, hydrated ion, hydration lubrication

Lubrication Calculation of Polymer Materials Considering Surface Force

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Studies have shown that in the presence of surface forces, the friction coefficient of polymer materials is significantly reduced compared to the absence of surface forces. In this study, a mixed lubrication calculation method with surface forces was applied to polymer materials, and a series of calculation results were obtained and compared with experimental results. The calculation results indicate that the surface force significantly reduces the friction coefficient of the polymer material due to its smaller elastic modulus and lower yield strength. Surface force can completely separate the friction pair surface, transforming the lubrication condition from mixed lubrication into the boundary lubrication state. The calculation results are in good agreement with the experimental data. This study suggests that surface forces is beneficial for reducing friction in polymer material friction pairs. The anti-friction design of polymer material friction pairs can be achieved by increasing surface forces, reducing surface roughness, and decreasing contact stress amplitudes.

Keywords: aqueous lubrication, surface Force, polymer materials

KEYNOTE:

How Advanced Safe and Sustainable by Design Materials and Lubricants Meets Tribology

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This paper explores the significance of tribology in the development of safe and sustainable by design materials and lubricants, emphasizing its role as a tool to achieve the Green Deal Goals. Tribology is a fundamental pilar for addressing the sustainability of the material at the design phase of their development. The control of the friction and the increase of the durability of the materials have a direct impact on the energy consumption of the system, the expected life of the final product and its carbon footprint. This approach is valuable also to achieve the goals of Advanced Materials 2030 Initiative (AMI2030) that it is now joining efforts with the Graphene Flagship to create "the Innovative Materials Partnership for Europe". On the other hand, in order to develop safe and sustainable by design materials and lubricants, it has been created the IRISS international network in Safe and Sustainable by design (IRISS), in order to harmonize the criteria to evaluate, both the safety and sustainability.The IRISS project aims to connect, synergize, and transform the "Safe-and-Sustainable-by-Design (SSbD)" community in Europe and globally towards a lifecycle approach, with a holistic integration of safety, climate neutrality, circularity, and functionality already at an early stage of designing and manufacturing materials, products, and processes. In this project, Tekniker is responsible to summarize the criteria and tools used by the research community, concerning sustainable by design and lifecycle assessment. The European Tribological Centre (ETC), i-TRIBOMAT, intend to facilitate the search of the right material and lubricant to optimize the tribological system. There is a need to shorten the time, number and size of experiments required to identify the behaviour of a material or combination of them (e.g., metal, coating, lubricant), then modelling and characterization needs to be combined to accelerate the development.

Keywords: safe, sustainable, lubricants, materials, tribology, biodegradable, recyclable, reuse

Synthesis of Long Term Superlow-Friction Carbon Films from Al/Cr/Si Element-Doped Acetylene Plasmas

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To meet the urgent needs of long-duration lifetime solid lubricating coatings for aerospace agencies. we investigated the friction and wear performance of Al/Cr/Si or Al/Ti/Si doping diamond-like carbon films DLC derived from acetylene plasmas. The films were deposited on steel substrates by a high power pulsed magnetron sputtering (HiPIMS) process at room temperature and the tribological tests were performed in dry nitrogen. Tests results revealed a close correlation between types of doping elements the source gas plasma and the friction and wear coefficients of the DLC films. Specifically, films grown in Al/Cr/Si element-doped plasma with a higher content of Al have much lower friction coefficients and wear rates than other element-doped films, which can maintain long-term lubrication for more than 24 hours when the friction coefficient is lower than 0.008. Similar correlations were observed for wear rates. Besides, the DLC-AlCrSi films exhibit well adhesion strength, which is more than 70 N. We used a combination of surface analytical methods to characterize the structure and chemistry of the DLC films and worn surfaces, and provide an adequate mechanism explanation to the long-term lubrication performance of the coating.

Keywords: solid lubricating, long-duration lifetime, diamond-like carbon films

Friction and Energy Dissipation of Graphene Manipulated via Moiré Superstructure

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Friction control is inseparable from technological advancements. In this regard, two-dimensional (2D) van der Waals materials are considered as natural lubricants due to their atomic-level thickness and mechanical robustness, enabling quasi-zero friction contacts from the nanoscale to the microscale. However, regulating superlubricity in sliding contacts remains a technical challenge, as friction interfaces in contact are inherently more difficult to control through post-modification in comparison to the exposed surfaces. Drawing the inspiration from twistronics in electronic systems, we propose the control of superlubricity in graphene via different moiré superstructures. Friction force microscopy and molecular dynamics simulations explicitly reveal moiré patterns of graphene at different twist angles on Pt(111) surface. With the applied normal load, the transition from superlubric to dissipative sliding is observed. We identify a novel mechanism at the moiré superstructures level correlated with the twist angle, wherein the moiré patterns are manipulated through highly dissipative shear process beyond a critical normal load. This dissipative mechanism not only brifges different sliding regimes in a reversible manner but also provides a subtle intrinsic means to control superlubricity.

Keywords: graphene, moiré superstructures, friction control, critical load, dissipation mechanism

Catalytic Superlubricity via In-Situ Formation of Graphene during Sliding Friction on Au@a-C:H Films

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Superlubricity, especially refers to the frictional state of the friction coefficient below 0.01. In 1990, Japanese scientists Hirano and Shinjo first proposed superlubricity. In fact, as early as 1971, Skinner of the Cavendish Laboratory in the UK reported a friction coefficient of graphite as low as 0.005 (Nature, 232(1971)195). The superlubricity state corresponds to a friction coefficient that is one to two orders of magnitude lower than the conventional (μ~0.1), which can significantly improve lubrication efficiency, save energy and resources, improve equipment operation reliability and wear life (~10^7). In present work, a new strategy, called catalytic superlubricity, is proposed and carried out to achieve superlubricity by in-situ formation of graphene via introducing gold onto hydrogenated amorphous carbon (Au@a-C:H) film during friction. The results show that mulilayer graphene along with oriented polyolefin-like structures are formed due to the catalysis of Au nanoparticles, which is embedded in amorphous carbon matrix. Furthermore, the density functional theory calculations indicates that interlayer binding energy between graphene and the hydrogenated amorphous carbon (a-C:H) films' surface is comparable to that between graphene layers, resulting in low interfacial interactions between sliding interfaces for low friction. Then, the low interfacial interactions lead to superlubricity with a friction coefficient of 0.003. This study opens up a new routing for facile and scale up fabrication of superlubricant a-C:H films in industrial applications.

Keywords: catalytic, graphene, superlubricity, a-C:H film, Au

Multiscale Tribological Study of Titanium-Doped a-C Films

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a-C films have been attracted due to excellent properties such as high hardness and low friction coefficient, but widespread application of a-C films have been limited by high residual stress. Doping Ti can reduce the residual stress and improve tribological properties of a-C films. However, the mechanism of Ti improving the tribological properties of a-C films is still unclear. In this paper, a multi-scale analysis methods including experiments, molecular dynamics and first principles were used. It was found that when a small amount of Ti-doped a-C films, Ti exists in a-C films as a simple substance phase. Due to the low sliding potential energy between Ti crystal planes, it leads to the fracture inside Ti during the friction, so that the a-C films on the top of Ti peel off and adhere the grinding pair to form transfer films, which reduces the coefficient of friction.

Keywords: a-C films, tribological properties, multiscale

Detection and Modulation of Ultrafast Friction Energy Dissipation at Superlubricity Interfaces

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Superlubricity has the extreme characteristics of near-zero friction energy dissipation, which can push the performance of high-end equipment to the extreme level. However, superlubricity still faces critical challenges from the laboratory to the engineering practice, one of which is the lack of understanding of the phonon electron energy dissipation pathway in the friction process. This is because the friction electron dissipation process occurs at the femtosecond time scale and the atomic space scale, which has exceeded the theoretical limit of the existing detection methods in the field of tribology. Focusing on the problem of friction and energy consumption reduction, the team took the lead in proposing a friction energy dissipation detection method with ultra-high spatial and temporal resolution, and achieved the following innovative achievements:(1) a micro friction theory based on ultra-fast electron energy dissipation was established, and the layer-dependent mechanism of large-scale superlubricity interface was explored, realizing the active design of superlubricity system with angular robustness; (2) the mechanism of defect-induced enhanced surface potential morphology was proposed for the first time, and the mechanism of defects on ultra-fast friction energy dissipation was clarified, forming a new online and quantitative detection method for superlubricity interface defects; (3) coupling the femtosecond transient absorption imaging detection system and friction microscope, breaking through the core technologies such as bridge-type long-span high-precision displacement platform design, and taking the lead in the world in the in-situ detection of frictional electron energy dissipation dynamics. The research team has solved the key scientific problems such as the unclear mechanism of ultra-fast friction energy dissipation at the superlubricity interface and the lack of detection methods, and proposed a new method for the detection and regulation of ultra-fast electro-phonon energy dissipation at the superlubricity interface, filling the gap in the field of in-situ detection technology of friction energy dissipation.

Keywords: friction, energy dissipation, superlubricity

Research on Solid Superslip Technology of Environmentally Adaptive Diamond like Coatings

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A key factor currently limiting the application of traditional diamond-like carbon-based coatings is that they require harsh environmental conditions (vacuum, inert gas, etc.). The difference in a testing environment atmosphere will lead to significant differences in the tribological performance of DLC coatings (gas humidity, environmental atmosphere). The mechanism of achieving and failure of DLC coatings is also completely different from the testing environment atmosphere. The oxidation effect of oxygen and water in the environmental atmosphere on the coating can lead to a sharp decrease in the durability of the coating and even super slip failure. Pairing with hydrogen containing diamond-like carbon (steel balls) and molybdenum disulfide coating (silicon wafers). Through reciprocating friction testing machine testing, the friction coefficient was about 0.008 in the low humidity environment and about 0.006 in the vacuum environment, achieving super sliding under cross environmental conditions. Changing the gas environment during the friction test will have a slight impact on the friction coefficient. Switching the gas environment atmosphere multiple times can still maintain superlubricity. The presence of molybdenum disulfide promotes extremely low wear during the friction process, and it still maintains superlubricity after 30000 reciprocating friction tests.

Keywords: diamond-like carbon, hydrogen, molybdenum disulfide

Ultra-Low Friction of Two-Dimentional Materials Based on Mechanical-Scanning Using Atomic Force Microscopy

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Atomically thin two-dimensional two-dimentional materials is well known for its excellent lubrication characteristics and is usually used as a solid lubricant in diverse micro/nanoelectromechanical systems (MEMS/NEMS). The friction on atomically thin graphene and MoS2 deposited on a SiO2/Si substrate is reduced almost five times to achieve an ultra-low friction state (coefficient of friction nearly 0.0025) by rubbing the surface with an AFM tip under the different load and electric field. The electric field leads to a shift and accumulation of charges at the interface between atomicall thin 2D materials and the SiO2/Si substrate. Then, tight-binding with high interfacial bonding

strength is experimentally found by the charges transferring during the rubbing process. The ultra-low friction state of atomically thin 2D materials could attribute to the electronic tight-binding between atomically thin 2D materials and the SiO2/Si substrate, which suppresses the atomic-scale deformation and limits the local pinning capability. The ultra-low friction state on atomically thin 2D materials is patterned further by controllably regulating position, time, stress and electric field during the rubbing process. This approach can provide an additional channel to achieve ultra-low friction on atomically thin 2D related two-dimensional materials. The nanopatterning of ultra-low friction could promote and expand engineering applications of atomically thin 2D materials as lubricants in various MEMS/NEMS with nano-scale components.

Keywords: electric-carrying, Friction, Atomic force microscopy, graphene

Mechanisms for the Emergence and Evolution of Atomic-Level Defects at Two-Dimensional WS2 Friction Interfaces

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The emergence and evolution of defects is one of the key factors leading to superlubricity failure, but the microscopic mechanism by which defects affect friction is still unclear. Existing studies are mostly based on atomic force microscopy (AFM) experiments. However, traditional tribological instruments are mechanically based and can only detect atomic-level defects after concentration surge and superlubricity failure, which limits the understanding of the friction mechanism affected by defects emergence and evolution. Here, the femtosecond transient absorption microscopy was innovatively used to observe the ultrafast electron energy dissipation process，which was affected by atomic-level defect sprouting evolution at the two-dimensional (2D) WS2 friction interface. Different from traditional mechanical characterization instruments, this method detected low-concentration defects at the emergence and evolution stages in the time dimension. A series of atomic-level defects with concentration gradients were introduced into the samples using contact AFM, and the defects were identified using scanning transmission electron microscopy (STEM). It is found that friction did not change significantly at low defect concentrations. In this case, the defect energy levels capture electron to form defect-bound exciton, which provide a new nonradiative energy dissipation channel, leading to decreased exciton lifetimes and increased energy dissipation. This work reveals the microscopic mechanism for emergence and evolution of atomic-level defect at 2D transition metal dichalcogenides (TMDCs) friction interface, and provides a new method for characterizing the low concentration defects when the friction force is unchanged.

Keywords: friction, defects, electronic friction

Characterization of Lubrication Properties of Various Additives and Isooctyl Stearate

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In order to solve the cutting problem of deep hole machining, Improve the lubrication performance of the cutting base oil isooctyl stearate, phosphorus nitrogen antiwear agent , nano copper, nano-lanthanum borate additives of Shenyang Lubricating Oil Factory, Ammonium phosphate, fatty cluster phosphate ammonium salt additives containing phosphorus and nitrogen produced by Shenyang Hualun Lubricating Oil Manufacturing Co., LTD.sulfide fat, sulfide fatty acid ester, fine lard eight degree centigrade additive of Hebei Yida Borun Technology Co., LTD.Mixed with base oil at a ratio of one percent, two percent, four percent, eight percent, sixteen percent or one and a half percent, one percent, one-and-a-half percent, two percent, two-and-a-half percent, respectively. The test load of the four-ball machine is one hundred and ninety-six cows and the wear time is 1h. Thermo sciencetific Apreo 2C X-ray diffraction was used to analyze the element composition on the surface of GGr15 steel ball grinding spot produced by Shanghai Steel Ball Factory, and the lubrication properties of isooctyl stearate were investigated. The results show that: All the additives showed good lubrication performance. When the addition of fatty cluster phosphate ammonium salt is one-and-a-half percent, the grinding diameter of isooctyl stearate is reduced from zero point five four millimeter to zero point three four millimeter, a decrease of thirty-seven point zero three percent, and the carrying capacity (PB) is increased from four hundreds and ninety Newtons to nine hundred and eighty-one Newtons, an increase of one hundred point zero two percent.

Keywords: lubricating oil additive, spot diameter, carrying capacity, lubricating property

Track 1-II: Friction and Lubrication

KEYNOTE:

Understanding the Friction Laws of Amontons and Coulomb by Evaluating the Real Contact Area

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This paper discusses the two early theories of friction, which are still fundamental physical concepts for evaluating the resistance to motion caused by friction. To date, it is still unclear whether the frictional force has a linear relationship with the normal load, with a clearly defined linear factor, the coefficient of friction, or whether more parameters are needed to account for the frictional force, i.e. whether there is a multi-parameter relationship to the frictional force. One of the fundamental questions to answer this aspect is the relationship between the normal load and the contact area. The immediate question to be answered is whether the nominal or the real contact area should be considered and whether there is a difference in relation to friction. Until recently, a high-resolution real contact area of multi-asperity sliding contacts was not experimentally validated. Accordingly, the analyses were mainly theoretical. In this work, we present the experimental analyses of the real contact area with sub-micrometre lateral resolution during sliding and the corresponding frictional force in a multi-asperity contact of different rough steel surfaces against a smooth sapphire disc. We evaluate the nominal and real contact area and discuss how this affects the relationship between the friction and normal load and thus, how the laws by Amontons and Coulomb can be understood when the area of contact interface is better known through high-resolution experiments.

Keywords: real contact area, friction, sliding, amontons, coulomb

INVITED:

Manufacturing and Performance of Fused Filament Fabricated PEEK Composite Sliding Layers on Different Metallic Substrates

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Additive manufacturing (AM) allows parts with complex geometries to be manufactured in a single process, enabling a large degree of freedom in design. In particular, fused filament fabrication (FFF) as one of the AM techniques has gained increasing acceptance due to its simplicity and lower investment costs. By depositing the molten strands on the defined paths, preferential orientations of the materials can be realized, especially when using fiber-reinforced polymeric materials.
The aim of this study is to investigate how the thin layers printed on different metallic substrates behave under tribological load conditions and to explain this behavior. For this purpose, polyetheretherketone (PEEK)-based composite sliding layers filled with carbon fibers with a thickness of 0.5 mm were printed on steel and aluminum substrates. Afterwards, tribological performance of these sliding layers was thoroughly studied by using a plate-on-ring tribometer, in particular the effects of the fiber orientations and

different metallic substrates on the tribological properties. The experimental results demonstrate that if the sliding direction is parallel to the carbon fibers, the COF of the sliding layer is significantly lower compared to the sliding normal to the fiber direction, which is independent on the metallic substrates. Similarly, the specific wear rate measured parallel to the fibers exhibits much lower values indicating a high wear resistance. In addition, we found that different substrates change the thermal household in the tribosystem and have a significant effect on the tribological behavior, especially when the sliding direction is normal to fibers. In this regard, the sliding layers with a steel substrate show better tribological performance.

Keywords: PEEK composite sliding layers, fiber orientations, metallic substrates

Model Braking Friction Material: A Lever for The Study of the Microstructure – Properties – Friction Behavior Link

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In industry, developments of braking materials are based on experience acquired over the long term and a trial-and-error approach to improving performance through iterative adjustments to the formulations. This has led to heterogeneous and complex materials, by the high number of components, by their very great variability in chemical nature, morphology, size, volume fraction, as well as by the production process itself. The empirical industrial approach does not does not allow a real understanding of the physical phenomena involved. There is a lack of a real understanding of the link between the microstructure resulting from the choices of formulations and development processes, the properties of the material induced by these choices and the behavior in friction. From an academic, numerous studies have looked at the impact of a component by varying its content arbitrarily to then see the impact on braking performance in terms of coefficient of friction and wear. However, this approach does not allow a real understanding of the role of the component in the material properties or in the friction mechanisms. It is therefore necessary to have a multidisciplinary approach to understand the link between the material, through its microstructure and the resulting properties, and the friction and wear mechanisms involved in contact. This objective is difficult by the complexity of the material. The first step in this approach is to simplify the industrial material and develop a material with a simplified formulation. This material is then used to study the microstructure – properties – friction and wear mechanisms continuum. Two examples are presented. The first uses a formulation variation as a lever for the study of the continuum by studying the introduction of brass shavings. The second lever uses a variation of the development by modifying the hot molding step during the development of the material.

Keywords: material, microstucture, properties, braking

Study on Tribological Properties of Polyvinyl Alcohol Hydrogel Composite PEEK Matrix Materials

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Hydrogels are mostly used to provide lubrication for engineering and biological friction surfaces. We used dopamine modified polyvinyl alcohol hydrogel on the surface of polymer materials to improve the lubrication property of polymers. The hydrogel lubricant with low friction and wear properties can be obtained by grafting dopamine onto polyvinyl alcohol through coupling reaction. Dopamine/polyvinyl alcohol hydrogel was coated on the surface of PEEK friction pair. During the friction between PEEK disk and silicon nitride ball, the friction coefficient of the hydrogel coated surface was reduced to 0.02, which was significantly lower than that of pure water. Self-swelling hydrogel/polymer matrix was prepared by physical mixing and two-step method in order to enable the hydrogel to achieve spontaneous lubrication. To stabilize the hydrogel in the matrix, the hydrogel prepolymer was wrapped with microcapsules, mixed with polymer powder and sintered. When the matrix rubbed in the water environment, it spontaneously formed hydrogel, which played a lubricating role on the friction surface. This research studied the self-lubrication of the matrix, and provided a new way of the lubrication of hydrogels.

Keywords: hydrogel, polymer, friction

KEYNOTE:

Discrete Contact Mechanics and its Applications in Tribology

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The contact and internal stresses within contacting bodies essentially depend on the mechanical and surface properties of the bodies. Due to the surface roughness the contact is discrete, and the real contact area is much smaller than the nominal one calculated from the classical contact mechanics. So the real contact pressures are much higher than the nominal ones and depend both on asperities shape and their density. Evaluation and control of the contact and subsurface stresses in contact interaction is very important for prediction of the efficiency and lifetime of various tribocouples.
The analytical approach is developed to study the normal contact of elastic bodies taking into account both their surface macro- and microgeometry. This approach is

based on two- scales analysis: at microscale the solution of the discrete contact problem with taking into account the mutual influence between the contact spots and height distribution of asperities is constructed and then used for formulation of the contact problem at macroscale. The effect of surface microgeometry parameters on real and nominal contact pressures, subsurface internal stresses, real and nominal contact areas, and on approach of the contacting bodies is investigated for different macro- and microgeometry characteristics of contacting bodies.

The present work was supported by RSF (project No. 22-49-02010).

Microstructure Evolution, Mechanical Properties and Tribological Performances of Cu-based Composites Incorporated with Cu-coated Ti3SiC2

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Titanium silicon carbide (Ti3SiC2), a typical ternary-layered material of Mn+1AXn phases, combines both ceramic and metallic advantages, which is among the most concerned reinforcements for metal-based composites. In this paper, Ti3SiC2 surfaces were electroless plated with a uniform Cu layer to be employed as reinforcing agents for Cu-based composites. Dense microstructure, superior mechanics properties and excellent friction behaviors were achieved as the composite sintered from powder mixtures of 85 wt.% Cu and 15 wt.% Cu-coated Ti3SiC2 particles milled at a ball/powder weight ratio of 8:1 and a rotational speed of 350 rpm. Tribochemical reactions were elucidated for the generation of Cu-Ti-Si oxide tribofilm at friction interfaces, which changed with variations in the rubbing conditions of applied load and rotational sliding speed.

Keywords: Cu matrix composites, Ti3SiC2 reinforcement, friction and wear, spark plasma sintering

Low-Density Self-Lubricating Composites with “IPN Structure-Liquid Lubricant” Coupling Mechanism

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The goal of net zero carbon emission is of a great concern to energy conservation and emission reduction. In aerospace and other industrial fields, one of main energy consumption forms is the friction between the motion pairs despite that energy consumption caused by equipment mass cannot be ignored. Therefore, extremely low-density self-lubricating composites with interpenetrating network (IPN) structure-liquid lubricant coupling mechanism is designed and prepared to meet the pressing requirement of energy saving and emission reduction. The liquid lubricant is in situ

locked into polyurethane acrylate (PUA) IPN structures. After locking the liquid lubricant into PUA with IPN structure (IPN-PUA), the coefficient of friction (COF) decreases to 0.085, and the wear rate reaches 6.58×10-15 m3/(N•m). Such composite materials also possess an extremely low density of 1.107g/cm3, which contributes to their excellent versatile self-lubrication and low-density characteristics when compared with other polymeric materials. Moreover, it has good micromechanical properties with the nanoindentation modulus of 4.5 GPa and nanoindentation hardness of 248 MPa. During the friction process, the liquid lubricant is extruded under pressure, along with the formation of a lubricating oil film at the friction interface. In this way, the combination of oil film and transfer film enables the material to achieve excellent self-lubricating properties. Based on the above research, the mechanism of synergistic lubrication between graphite and liquid lubricant was also studied by adjusting the ratio of graphite to liquid lubricant. When the ratio of graphite to liquid lubricant to IPN-PUA was 6:18:76, the material exhibited both good tribological and mechanical properties. Through first principles and molecular dynamics simulations, it was found that liquid lubricants make graphite more prone to interlayer slip, which further reduces the friction coefficient of the materials.

Keywords: low density, coefficient of friction (COF), interpenetrating network (IPN) structure-liquid lubricant coupling

Research on the Mechanical and Tribology performance of Copper-Based Materials Reinforced with Ternary Ceramics Containing MAX Phase

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Cu-based materials are widely employed in high-speed train braking and brush systems due to their excellent mechanical properties, friction performance, and electrical conductivity. In order to broaden their application, ceramics such as Al2O3, TiC, and SiO2 have been incorporated to enhance the high-temperature stability of Cu-based materials, albeit with less than satisfactory results. MAX phase ceramics possess a unique layered structure and exhibit outstanding properties of both metals and ceramics. To address issues such as deteriorated braking stability caused by excessive surface temperatures during high-speed emergencies on Cu-based friction surfaces, a ternary composite ceramic powder (Ti2AlN-ZrO2-B4C) reinforced Cu-based powder metallurgy brake pad containing MAX phase was prepared using powder metallurgy. By investigating friction interface behaviors and microstructural evolution, the study aimed to elucidate the contributions of different components, particularly Ti2AlN, within the ternary composite ceramic powder to the mechanical and frictional performance of Cu-based materials. The research revealed that an appropriate proportion of Ti2AlN could significantly enhance the shear strength of Cu-based materials to 34.3 MPa. This enhancement was attributed to the diffusion of Ti and Al elements from Ti2AlN into the Cu matrix, forming complex solid solutions during high-temperature sintering. The presence of solid solution reactions greatly enhanced the bonding between Ti2AlN and Cu. When the matrix underwent shear stress and fracturing occurred, the extraction of particles consumed some energy, thus resulting in an increase in shear strength. During the friction process, due to the stronger bonding between Ti2AlN and the matrix compared to ZrO2, which tended to detach first during the low-speed stage, causing abrasive wear with the friction pair. However, during high-speed braking, -B4C was plowed to form debris and accumulated near Ti2AlN micro-protrusions, eventually oxidizing to form a friction film.

Keywords: copper-based materials, Ti2AlN-MAX phase, tribology behavior, wear mechanism

Tunable Tribology Properties of Shape Memory Polymer

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High-performance polymer with tunable tribological behavior to meet variable service conditions still remain a challenge. Shape memory polymer with properties of morphing and modulus changing upon temperature changing is a promising material to adjust the tribology. Herein, we investigated the tribological properties of shape memory polymer under different conditions. The shape memory polymer exhibits the tribological behavior of stable coefficient of friction (COF) and low wear rate. Besides, the COF increases and wear rate decreases with the temperature increasing showing the tunable friction property of the shape memory polymer. We propose a new model of wear-compensation through shape recovery to explain the adjustable friction behavior of thermal-responsive polymer from the aspect of shape recovery and energy conversion. This work provides an effective pathway to control tribology of polymer material and paves the route for the application of shape memory polymer in tribology field.

Keywords: tribology, shape memory polymer, wear

INVITED:

Effect of Pitch Coke Type on Braking Behaviors of Copper Metal Matrix Composites Mating with 30CrMnSi Steel and C/C-SIC

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Exploring braking behaviors of copper metal matrix composites (CMMC) with different types of pitch coke (PC) mating with 30CrMnSi steel and C/C-SiC. In this study, the braking behaviors and wear mechanisms under different energy-density braking conditions have been investigated. Pitch coke consisting of fine mosaics (PC1)shows higher hardness and elastic modulus than pitch coke consisting of flow type. The hardness and thermal conductivity of CMMC with PC1 are increased by 15.2 % and 10.3%. CMMC with PC1 exhibits superiority in improving friction coefficient and decreasing wear loss. When mating 30CrMnSi, under the low energy-density braking condition, the friction coefficient and stability of CMMC with PC1 are increased by 17.9% and 16.3%, the wear rate is decreased by approximately 50%. CMMC with PC1 features outstanding braking properties, which can be identified by the dramatically rising friction coefficient (from 0.248 to 0.362) and lower wear rate (decreased by 33.7%). The integral interface of Cu/ PC1 endows the CMMC with fewer damage on the tribological surface. This work provides a promising strategy to fabricate CMMC featuring superior braking properties.

Keywords: CMMC, PC, braking properties, C/C-SIC;

3D Printing of Self-Lubricating Polymeric Composites and Devices

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With the superiorities of light weight, corrosion resistance, low noise and long-term maintenance-free, self-lubricating polymer composites have a variety of applications in aerospace, automotive industry and other frontier fields. Typically, polymeric self-lubricating composites can be classified as solid-liquid and solid-solid composites according to the filler. In our work, two manufacturing strategies for self-lubricating polymeric composites are proposed, namely the vat photopolymerization 3D printing of microemulsion (microemulsion-3DP, solid-liquid composites) and three-dimensional (3D) target-region-lubrication printing (solid-solid composites) . The microemulsion-3DP is applied for one-step fabricating self-lubricating parts with microdroplets of oil filled in polymer. In this work, talc, as an emulsion, was incorporated into the microemulsion to ensure the oil-droplets evenly and stably dispersed for Vat photopolymerization 3D printing. And the oil-droplets were fixed in the microemulsion in the process of the ink from liquid to solid in the subsequent 3D printing, that enable the one-step filling of liquid oil-droplets. Then, the complex self-lubricating structures would be fabricated via 3D printing, which realized the forming of oil-containing self-lubricating composites with complex structures in one step. For 3D target-region-lubrication printing, photosensitive polyimide filled with PTFE with excellent tribological properties for self-lubricating devices. The surface with lubricating only in regions where needed were readily realized due to the layer-by-layer manufacturing manner of 3D printing. We integrated surface patterning with the layer-by-layer forming principle of additive manufacturing and the Yin-Yang theory in traditional Chinese to investigate the tribological properties of alternating lubricated surfaces, the tribological data using machine learning and the optimized surfaces demonstrated the exceptional comprehensive properties. The two novel manufacturing strategy for polymeric composites provides new ideas for manufacturing self-lubricating parts and presents new opportunities for self-lubricating 3D architectures with rapid manufacturing, low-cost and free manufacturing.

Keywords: vat photopolymerization 3D printing, self-lubricating, polymeric composites

One Step Filling of Self-lubricating Composites with Micro-Oil Droplets and Its Application

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With the superiorities of light weight, corrosion resistance, low noise and long-term maintenance-free, oil-containing polymer self-lubricating composites have a variety of applications in aerospace, automotive industry and other frontier fields. The traditional method of preparing oil-containing self-lubricating composites mainly involved the two-step method of preparing porous materials and filling with liquid-lubricants, which leads to the limitations including complex manufacturing process, high cost, and difficulty to achieve complex structures. In the work, a novel strategy for one-step fabricating self-lubricating parts with microdroplets of oil filled in polymer, namely the vat photopolymerization 3D printing of microemulsion (microemulsion-3DP) is proposed. The main innovation is that the method realizes rapid manufacturing and free manufacturing of solid-liquid self-lubricating composite. The self-lubricating properties investigated by friction tests reveal that the friction coefficient of the 3D printed part with the lubricant one-step incorporated is decreased to 0.069 from 0.404 of the one without lubricant. As demonstrated, this innovative method of microemulsion-3DP readily achieves various self-lubricating parts, indicating the promising feasibility of fabricating parts with structures that are difficult to manufacture with traditional processing methods. At the same time, this forming strategy provides a new idea for the construction of self-demolding mold. Through the further optimization of the material system, the self-demolding mold is designed and built, which can successfully implement the demolding process for more than 100 times without the mold release agent. This demolding strategy not only reduces the processing cycle of the mold, but also effectively improves the use efficiency of the mold and the quality of demolding products. In conclusion, the manufacturing method of self-lubricating

composites will enable a wide range of applications in aerospace, automobile manufacturing, and other cutting-edge fields.

Keywords: solid-liquid composites, self-lubricating, self-demolding mold

Tribological Properties of MXene-Enhanced Lubricant oil@PI Epoxy Composites Under Harsh Conditions

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Self-lubricating materials play a crucial role in diverse fields, addressing the need for friction reduction, improved wear resistance, and enhanced lubrication. Microcapsules serve as widely used fillers in solid matrices, contributing to the development of self-lubricating materials with superior mechanical performance. In this study, thermally robust polyimide (PI) was chosen as the shell material, and lubricant oil was employed as the core material for synthesizing microcapsules through the solvent evaporation method. The shell of the microcapsules was chemically decorated to ensure uniform incorporation into the epoxy resin, forming the composites. To enhance the tribological performance of the composites under high-temperature and high-load conditions, MXene was introduced into the composite, resulting in MXene/microcapsule/epoxy composites. The tribological properties of these composites, considering variations in microcapsule sizes and contents, were evaluated using ball-on-disk tests under high loads and reciprocating frequencies. Control experiments involved directly adding lubricants into the interface between the composite surface and the counterface under conditions of low oil supply. A proposed lubrication mechanism is presented with the assistance of Dissipative Particle Dynamics simulation. Additionally, the impact of MXene content on the mechanical and tribological properties is thoroughly examined. This work aims to broaden the application scope of microcapsule/epoxy composites.

Keywords: self-lubricating materials, microcapsules, tribological properties, lubrication mechanism

Influences of Ferrochrome on The Micro and Macro Tribological Properties of Cu-based Composites

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Ferrochromium, a crucial emerging abrasive component, is incorporated into Cu-based composites (Cu-BCs) to enhance their high-energy braking properties. This study

investigates the microstructures, interfacial characteristics, and micro-tribology behaviors of two types of ferrochromium and their impact on the high-energy braking performance of Cu-BCs. The high-carbon ferrochromium (HCF), characterized by higher hardness and composed of (Cr,Fe)7C3 and (Cr,Fe)23C6-CrFe phases, forms a mechanically diffused mixed interface with the matrix that exhibits a low coefficient of friction (COF) in micro-friction tests. However, during macro-friction tests, the formed weak interface, the crushing tendency of HCF as well as third-body wear debris formed by HCFs led to the relatively high COF of Cu-BCs containing HCF. This relatively high COF helps Cu-BCs maintain their braking performance at medium and high breaking energy density (BED) conditions. On the other hand, the extra low-carbon ferrochromium (ELCF), consisting mainly of the CrFe phase, generates a diffusion interface with the matrix and exhibits a higher intrinsic COF. The influence of increasing COF of ELCF in Cu-BCs is comparatively weaker compared to that of HCF. Whereas, ELCF promotes the formation of a tribo-layer at high BEDs and provides better wear resistance for Cu-BCs. The wear mechanisms changed from plough to severe plastic deformation-induced delamination or oxidation-induced delamination for Cu-MMCs with ELCF or HCF, respectively with the increase of BEDs.

Keywords: ferrochromium, tribological properties, abrasion component, Cu-based composites

Evaluation of Tribological Potential of Ti3C2Tx-MXene reinforced Ni3Al Composites

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Advancement in science and technology has led to an increasing demand for developing the tribo-systems with lesser friction and higher weight to strength ratio to work under dynamic conditions in various industries such as in automotive, metalworking (machining and forming), power generation, military, and aerospace industries. So, in the quest to achieve high mechanical strength along with low friction and wear, Ni3Al matrix composites have been fabricated through spark plasma sintering with varying MXene concentrations at 1150 °C sintering temperature under a pressure of 40 MPa. After that, the composites were slid against Si3N4 ball at a fixed load of 10 N and sliding speed of 0.25 m/s under atmospheric conditions to evaluate the lubrication potential of synthesized composites. The results have revealed that the addition of MXene in matrix up to 15 wt. % can reduce friction and wear of composites. NAM15 composite has shown the lowest friction attributed to the synergistic lubrication of glaze and Mxene tribo-layer formed over the encountering surfaces, as confirmed through SEM and TEM. However, an increase in friction was observed for NAM20, ascribed to dominance of TiC phase formation, which acts as a barrier for tribo-layer formation. On the other hand, the continuous reduction in wear rate was observed with the

increasing percentage of MXene in Ni3Al matrix with a minimum for NAM20 (20 wt. % MXene) attributed to formation of more TiC.

Keywords: MXene composites, wear

Track 1-III: Friction and Lubrication

KEYNOTE:

Ammonia as Carbon-Free Energy Carrier and Its Impact on Engine Oil Performance

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Decarbonization requires fundamentally different energy systems enabled by using alternative energy carriers such as green electricity and carbon-free fuels such as hydrogen and ammonia. Ammonia is especially considered as future fuel for marine vessels. However, there is little knowledge about the interaction of ammonia and its combustion products with engine oils, and consequently its impact on engine oil performance. This talk reports on a methodology specifically designed to capture critical oil performance parameters that may be influenced by the use of ammonia. The approach comprises artificial oil alteration and performance tests to elaborate corrosion properties, deposit formation, and load-bearing capability of fresh and aged engine oil. Based on the degradation and stability behaviour, respectively, under various conditions and the subsequent tests, it could be shown that the selected performance parameters were severely impacted by the presence of ammonia or nitrogen dioxide compared to air. While ammonia causes lower acidification and base reserve consumption, nitrogen dioxide as one of its combustion products promotes oxidation reactions going along with pronounced acidification and base reserve consumption. The findings also suggest that deposit formation and tribological performance are negatively influenced by the presence of ammonia.

Keywords: ammonia, engine oil, oil degradation

INVITED:

Effects of Thiophosphate Extreme Pressure Anti-Wear Agents on Anti-Shudder Performance of Transmission Oil

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The transmission system of a car is prone to shudder during start, stop, and low-speed operation due to the failure of friction control between the transmission oil and components. In our study, it was found that two commonly used thiophosphate extreme pressure anti-wear agents （EP-1 and EP-2）for transmission oils not only have anti-wear effects, but also have a significant impact on the oil's anti-shudder properties. The molecular structure of EPs and the content of active S and P have different effects on the anti-shudder performance. The results of SEM and EDS showed that EP-1 had strong adsorption due to its high activity S and P, which destroyed the tribofilm formed by other additives and corroded the tribo-surface, leading to the loss of anti-shudder property. However, the low-activity S and P in EP-2 did not damage the tribofilm and had no negative impact on anti-shudder.During the development of transmission oil formulations, attention should be paid to the sulfur and phosphorus activity of extreme pressure anti-wear agents.

Keywords: thiophosphate extreme pressure anti-wear agents, transmission oil, anti-shudder performance

Influence of Grease Containing Mineral Particles on Friction and Wear Characteristics Between Spiral Wires Inside Wire Rope

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The mine shaft environment is filled with mineral particles and these suspended particles exacerbate the wear behaviour between the wires in wire rope, seriously threatening the safety of mining. In this study, to investigate the influence of mixing mineral (ore, coal) particles of different concentrations and particle sizes in grease on the fretting behaviour between spiral-contacting wires, experiments were carried out on a selfmade test device. The results show that the addition of mineral particles increases the coefficient of friction (COF) and cumulative dissipation energy between steel wires. When the ore particles with a concentration of 15 % and a size of 0.048-0.062 mm were added to the grease, the COF between the steel wires reached a maximum of about 0.234. In addition, with the increase of mineral particle concentration and the decrease of particle size, the wear depth, wear amount and specific wear rate of steel wire increase accordingly. Among them, the wear depth, wear amount and specific wear rate reach the maximum after adding ore particles with a concentration of 15 % and a size of 0.048-0.062 mm, which are about 30.5μm, 6706×103 μm3, and 2.31×10-6 mm3/Nm, respectively. Furthermore, many cutting furrows and crushing pits are added to the wear morphology of steel wire after adding ore particles. The main wear mechanism is severe abrasive wear and fatigue wear. After adding coal particles, the main wear morphology

of steel wires is material transfer (attachment of coal particles) and exfoliation, and the main wear mechanism is adhesive wear, fatigue wear and slight abrasive wear.

Keywords: mineral particles, steel wire, friction and wear, wear mechanism

Study on the Interaction Mechanism Between Degradation Behavior of Grease and Evolution of Friction Interface Properties Under Static Storage Conditions

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Long-term static storage of the ball screws result in interactive degradation of the grease and the friction interface, affecting the safety of equipment operation. In this study, the changing rule of physical and chemical properties of grease under different static storage degradation environments was investigated by accelerated degradation experiments. The oxidation and corrosion behavior of friction interface induced by grease degradation was discovered. Through molecular dynamics simulation, it was found that the degree of aggregation between the main components of lubricating grease in degraded environments has decreased, while the adsorption between the grease components and the interface has changed, leading to increased interfacial oxidation process due to base oil leakage. Furthermore, a grease degradation model based on degradation period and environmental parameters was constructed, which can intuitively reflect the lubrication characteristics and degradation trend of the grease under determined degradation factors. This study can provide explanations and guidance for the phenomenon of poor lubrication of long-term static storage equipment and the selection of equipment storage environment.

Keywords: ball screw, molecular dynamics simulation, grease degradation model

Electro-Tribological Investigation of Greases for EVs

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The visco-elastic characteristic of greases plays a very important role in its functioning as a lubricant in numerous applications wherein oils cannot be used. Apart from their rheological properties, their performance is also governed by their tribological

properties, i.e., friction and wear behaviour. With the staggering rise of electric and hybrid vehicles (EV) across the globe, the interest in understanding the electrical properties of greases has also increased. This in many cases is crutial not only for the efficiency of the systems, but also for the lifetime of the lubricated components such as bearings.
In this current study, the authors present a novel test methodology wherien investigations are carried out to characterize the electro-tribological behaviour of lubricants and greases under dynamic conditions. Tests were carried out on an MCR Tribometer with ball-on-three-plates and ball-bearing setup. Extended Stribeck curves which portray the frictional behaviour of the tribosystem as a function of sliding speeds spaning over eight orders of magnitude. Such tests offer information about the changes in the electrical behaviour of the tribosystem with changes in the sliding speed, as well as information about the transition between different lubricating regimes. Additionally, voltage ramps were also carried out to determine the breakdown voltage of the greased tribosystem at different sliding velocities. The effect of temperature on the electrical properties of the tribosystem was also studied here. Through a series of such investigations, it is possible to map the electro-tribological properties of greases and correlate them with advanced surface characterization to gain a better understanding of the system.

Keywords: electrical vehicles, greases, stribeck curves

KEYNOTE:

Analysis Method for Mechanical Seals: Integrating Physical Models with Data-Driven Approaches

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Mechanical seals, being crucial components for ensuring the safe and reliable operation of high-end equipment, are complex systems characterized by multi-scale and multi-physical coupling features. Beyond conventional analytical techniques grounded in physical laws, data-driven methodologies, particularly machine learning, are gaining prominence as pivotal directions for advancing seal performance analysis and condition diagnosis. This presentation will delve into state-of-the-art methodologies for analyzing mechanical seals, exploring three distinct paradigms: the physics-driven models, the data-driven models, and the hybrid approach that integrates both. The discussion will encompass the finite element-based multi-physics coupling model for mechanical seals, methodologies for seal condition monitoring, the application of the Kriging surrogate model for both forward and inverse seal design and the innovative Physics-Informed Neural Network model for mechanical seals. The integration of various analysis

methods can provide more accurate, comprehensive, and robust technical means for the design and analysis of mechanical seals.

Numerical Analysis of Hydrodynamic Lubrication Performance in a Carbon-Segmented Seal based on the Local Differential Quadrature-Lagrange Method

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A solution model for the hydrodynamic lubrication performance of a carbon-segmented seal based on the local differential quadrature method was established theoretically. The impacts of node density and the number of local support domain nodes on the accuracy of the algorithm were analyzed. The theoretical results of the seal pressure distribution characteristics obtained by the local Differential Quadrature (DQ) method were verified using a commercial CFD (Computational Fluid Dynamics) code. On this basis, the influence of structural and operating parameters on the seal peak pressure was analyzed. The research results indicate that the local DQ method can achieve high solution accuracy with fewer nodes. When the number of local support domain nodes is equal to 3, the accurate pressure distribution results can be obtained. When there are many interpolation nodes, the DQ-Lagrange method is prone to numerical oscillation caused by high-order interpolation. A significant hydrodynamic effect can be formed at the pocket of the carbon-segmented seal. With the increase of pocket depth and width, there is a maximum peak pressure. The larger the seal clearance, the larger the optimal value of pocket depth. As the length of the pocket and the seal radius increase, the peak pressure increases. As the inlet and outlet pressure ratio and rotational speed increase, the peak pressure increases. The results of this article provide a reference for the structural design and engineering application of the carbon-segmented seal.

Keywords: carbon-segmented seal, hydrodynamic lubrication performance, local differential quadrature-lagrange method

Friction and Wear Characteristics of Circumferential Carbon Seal

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Sliding friction of circumferential carbon seal with different grooves on inner surface affects directly sealing performance and service life. In this paper, friction and wear of both carbon sector and carbon ring on cylindrical surface were carried out to study effects of surface structure with different grooves on friction coefficient, wear amount, frictional temperature, surface morphology and leakage amount of the carbon seal. The results show that all of change trends of friction coefficient for carbon sector with different grooves underwent three processes, i.e., initial rapid decline, fluctuation, and thereafter stability. With increasing number of grooves, friction coefficient of carbon sector decreased gradually and wear amount increased progressively due to decreasing contact area between the carbon sector and surface of rotor. The wear of SC-ACR is 46.7 % larger than that of SC-N. The wear causes are mainly adhesive wear and abrasive particle wear. Friction heat experiences three processes, i.e., rapid increase, slow down and steady. With increasing number of grooves, the air storage between carbon and rotor increases, which impact the maximum temperature. The maximum temperature of SC-ACR is 6.44 % higher than that of SC-N. In the experiment of carbon ring, the average thickness wear of AC is more than 0.03 mm, while the average thickness wear of ACR is only about 0.002 mm. After wear, the increase trend of AC leakage with the increase of pressure is significantly greater than that of ACR.

Keywords: circumferential carbon seal, groove, friction and wear

Seal Updated Numerical Method Considering Contact Wear Behaviors to Reveal Lubrication Transition Mechanism

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Seals under the harsh condition would have lubrication transition with contact area on the proportion of full film and wear regime. We propose the seal is running under high pressure at the speed of 0.1-1 m/s and temperature 5℃ to 40℃, and take fluid-solid and wear multi-scale numerical method to receive seal micro convex body deformation and macro performance. Reynolds equation and leakage rate formula are considered to contact factor and shear pressure factor. Updated wear and deformation calculating to micro convex bodies is taken, and boundary of seal lubrication transition is extracted with receiving full film regime compared to measurement results. Leakage mechanism is improved and related to the contact factor, which can also extend the availability of mixed and boundary lubrication from the original elastohydrodynamic lubrication.

Keywords: mixed lubrication, contact pressure, seal

Numerical and Experimental Study on the Influence of Stages on the Leak-Age Flow and Heat Transfer Characteristics of Brush Seal

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The number of stage has a great influence on the leakage flow and heat transfer characteristics of multi-stage brush seal. The theoretical formula of the influence of series on the leakage flow and heat transfer characteristics of multi-stage brush seal was derived. The three-dimensional fluid-solid-thermal coupling solution model of multi-stage brush seal was established. The experimental device of leakage flow characteristics of multi-stage brush seal was designed and built. Based on the experimental verification of the accuracy of the numerical model, the leakage flow and heat transfer characteristics of different series brush seals were analyzed, and the influence of series on the leakage flow and heat transfer characteristics of brush seal was studied. The results show that under the same pressure ratio, from one to three stages brush seals, for each additional level, the pressure drop value borne by each stages of brush tows decreases, and the maximum pressure drop of brush tows decreases by 30.0 % ~ 36.3 %. The maximum velocity of the flow field appears below the rear baffle of the last stage brush tow, and the maximum velocity of the flow field decreases with the increase of the number of stages. Under the same pressure ratio, with the increase of the number of stages, the sealing performance of the brush seal is enhanced. For each additional stage, the leakage is reduced by 15.7 % ~ 22.0 %. Under the same pressure ratio, the maximum temperature increases with the increase of the number of stages, and the maximum temperature will increase by 3.7 % ~ 9.1 % for each additional stage.

Keywords: multi-stage brush seal, the number of stages, fluid-solid-heat coupling

INVITED:

Study on the Performance of Rotary Lip Seal Considering Eccentricity

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Extreme conditions seals, hydraulic parts, precision bearings and so on are the national major strategic needs. In this paper, for the high-speed rotating lip seal in aeroengine, combined with its service parameters, its own structure and application conditions, considering the real micro-surface topography of the seal lip and the rotating shaft, a numerical simulation analysis model for quantitative analysis of the performance of eccentric high-speed rotating lip seal was established. The model considered the coupling process of interface fluid dynamics, macro solid mechanics, surface micro-contact mechanics, heat transfer and other physical fields under the actual service status of the rotating lip seal. Using the dangerous cross-section method, with the leakage rate and friction force of the dangerous cross-section as the evaluation index, the influence of different eccentric forms, eccentricity, speed and other factors on the performance of the rotating lip seal was studied, and the simulation results were verified by bench experiments. The results show that the eccentricity will have a great impact on the performance of the lip seal. This study provides a new idea for the design of the rotating lip seal considering the eccentricity, and has guiding significance for the engineering application of the rotating lip seal.

Keywords: rotating lip seal, eccentricity, dangerous cross section

Numerical Study on Design and Leakage Characteristics of Brush Seal Between Counter-Rotating Shafts

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There are higher requirements for the seal performance and service life of the sealing structure between counter-rotating shafts of the aero-engine. The structure of carbon fiber rotating brush seal between rotating shafts was designed. Based on the theory of bristles centrifugal effect mechanics and porous media theory, the method of bristles shape variable correction porosity and resistance coefficient was used to establish a solution model for the leakage flow characteristics of carbon fiber rotating brush seal between rotating shafts. The influence of bristle lay angle, bristle diameter and rotating speed on the mechanical deformation characteristics of carbon fiber bristles was analyzed, and the leakage flow characteristics of brush seal between rotating shafts were studied. The results show that the deformation and rotation angle of the bristle will increase by increasing the speed of the inner rotor, reducing the diameter of the bristle and increasing the bristle lay angle. Considering the centrifugal effect of the bristles, when the inner rotor speed is 3230r/min, the deformation of the T650 carbon fiber bristles in the radial direction of the shaft is 16.43% of the deformation of the Haynes25 bristles. Increasing the speed of the inner rotor will reduce the leakage of the seal. When the inner rotor speed increases from 1700r/min to 9000r/min, the seal leakage decreases by 0.0358kg/s. Under the same working conditions, the fine-diameter bristles sealing effect is better. When the contact gap between the bristles and the outer rotor is 0 mm, the bristle diameter is reduced from 0.07 mm to 0.05 mm, and the leakage is reduced by 12.42%.

Keywords: counter-rotating shafts, carbon fiber rotating brush seal, centrifugal effect

Study on Leakage Characteristics of Surface Contact Static Seal

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Aiming at the leakage problem of the contact area between the labyrinth seal and the graphite slide in the aero-engine bearing cavity, an experimental device for leakage characteristics was designed and built. In order to predict the leakage rate of the surface contact static seal, a leakage rate prediction method based on numerical calculation was proposed. The sealing leakage channel is regarded as a capillary bundle. According to the fluid flow theory in the tube, the minimum size of the numerical solution model for leakage characteristics is determined. The position of the reference line of contact surface roughness is solved by using Gaussian filtering. The initial seal clearance and the seal clearance under working condition were obtained, the numerical solution model of leakage characteristics was established and the leakage factors under different contact widths were solved. On the basis of verifying the accuracy of the solution model, the influence of the microscopic contact state on the seal leakage characteristics was studied. The results show that the leakage factor increases and tends to be gentle with the increase of the contact width, and the inflection point of the curve appears near the beginning of the inlet. The sealing coefficient increases with the increase of the contact load, and the sealing coefficient is independent of the surface roughness. The greater the roughness, the greater the leakage under the same working condition. The proposed method solves the problem that the microscopic leakage model is difficult to establish due to the large difference between the seal structure size and the surface roughness peak size.

Keywords: surface contact static seal, leakage characteristics, microscopic contact state

Controlling Friction Energy Dissipation by Ultrafast Interlayer Electron-Phonon Coupling in WS2/Graphene Heterostructures

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Electrons and phonons are regarded as the microscopic carriers of friction energy dissipation and their coupling is a typical dissipation mode. However, due to the lack of ultrafast detection technic, the friction mechanism about electron-phonon coupling remains unexplained. Here, using high resolution non-contact atomic force microscopy and femtosecond transient absorption spectroscopy, we find that interlayer electron-phonon coupling dissipation channel in WS_2/graphene heterostructures can be opened by defects. This is because defects provide a recoil-momentum which satisfies the requirement of momentum conservation between electrons in WS_2 and acoustic phonons in graphene and interlayer electron-phonon coupling occurs. Besides, the

electron-phonon scattering time is accelerated from 2.4 ps to 1.1 ps. The enhanced electron-phonon coupling leads to significant energy dissipation. We further quantitatively model the friction Γ with dissipation rate τ^{-1} as Γ=2.75×$10^{-17}\tau^{-1}$ to control the friction energy dissipation by ultrafast interlayer electron-phonon coupling. This work provides a new way to understand the mechanism of electron-phonon coupling in friction.

Keywords: interlayer electron-phonon coupling, non-contact friction energy dissipation, ultrafast spectroscopy

Frictional Interval Phonon Ultrafast Dissiaption in Few Layer Graphene

Haolei Dai, Yujin Wang, Zibo Liu, Dameng Liu
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Friction phonon energy dissipation is one of the long-term research topics in nanotribology, the key problem is the difficulty of finding parameters that cut through the complex phonon properties of materials to establish a relationship with friction.
We find that interlayer breathing mode phonons can be used to characterise normal dissipation during friction, and that in fewer layers of graphene, as the number of layers increases, the interlayer phonon lifetime is extended and the dissipation rate decreases, corresponding to smaller frictional energy dissipation, which is in line with theoretical and computational results which predicates that higher frictional energy disspation corresponds to faster friction energy dissipation.
The mechanism is explained by the elasticity theory which points the way that the friction phonon energy dissipation is related with the sound speed, faster sound speed corresponds to higher phonon disspation rete。 Ultimately, in order to achieve an energy balance at the friction interface, greater frictional energy dissipation is produced.

Keywords: nano friction, few layer graphene, phonon dissipation, layer beathing mode

Twist Angle-Dependent Interlayer Hybridized Exciton Lifetimes in van der Waals Heterostructures

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Superlubricity reduces frictional energy consumption due to its low coefficient of friction. Two-dimensional materials are considered ideal vehicles for realizing superlubricity due to weak interlayer van der Waals interactions. Researchers have already realized solid superlubricity in the laboratory by using non-metric contact between layers of 2D materials. However, contact between surfaces in friction causes an increase in energy dissipation, leading to failure of superlubricity. The mechanism behind this is not well understood, hindering its practical application in engineering. The lifetime of excitons is critical for frictional energy dissipation. As the primary energy carrier, regulating their lifetime is crucial in inhibiting energy dissipation. This is the main research focus in this area. The interlayer twist angle has a direct effect on the exciton lifetime in the heterostructure of two-dimensional materials. It was found that the interlayer and intralayer excitons in $MoSe_2/WS_2$ heterostructures are hybridized at small angles, resulting in hybridized excitons with long lifetimes and strong resonances. However, there is still a gap in the studies on the corner modulation of hybridized exciton lifetimes, leading to a lack of understanding of the mechanism by which the interlayer corner affects the lifetime of hybridized exciton. Here, we demonstrated the emergence of hybridized excitons by constructing $MoSe_2/WS_2$ heterostructures with different interlayer turning angles by photoluminescence spectroscopy. Further, by time-resolved photoluminescence spectroscopy, it is found that the exciton lifetime is prolonged from 0.5 ns to 3.3 ns when the torsion angle is reduced from 12° to 1°. This work provides a new perspective for regulating the exciton lifetime, which is helpful for further exploring how to suppress frictional dissipation and realize superlubricity.

Keywords: superlubricity, hybridized exciton, twist angle heterostructures

Effects of Defect in Interlayer Exciton Lifetimes on MoS2/WS2 van der Waals Heterostructures during Friction Process

Zejun Sun, Huan Liu, Dameng Liu
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The incommensurate contact of two-dimensional transitional metal dichalcogenides (TMDCs) heterostructures serves as an ideal system for realizing solid-state superlubricity. However, during interfacial friction processes, defects are inevitable, leading to failure of superlubricity. So far, researches mainly focus on defect-related dynamics of intralayer excitons, while studies on the effects on interlayer exciton dynamics are still insufficient. Interlayer excitons are novel excitons emerged in two-dimensional TMDCs heterostructures, thus their energy dissipation is non-negligible. Here, we use an AFM tip to simulate the process of defect generation during friction by sliding it across the surface of TMDCs heterostructures. We utilize time-resolved photoluminescence to investigate the effect of defect on the energy dissipation of interlayer excitons. We find that with the increase in defect concentration, the rate of energy dissipation of interlayer excitons significantly increases, leading to a substantial increase in interfacial friction force, resulting in superlubricity failure. This work

provides theoretical guidance for the active control of frictional energy dissipation using defects.

Keywords: defect, interlayer exciton lifetime, friction

Track 2: Wear and Fatigue

KEYNOTE:

The Wear Resistance Design of Typical Tribological Materials Under Harsh Operating Conditions

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The rapid growth of industries in aerospace, transportation, and new energy requires high-end equipment capable of long-term service under extremely harsh conditions. Ensuring the reliable and continuous service of such equipment has become a critical issue impacting the national economy, public welfare, and security. Optimizing the wear resistance of tribological materials is crucial for maintaining the reliability and effectiveness of these systems. Typical tribological materials developed through advanced wear resistance design exhibit excellent performance. Considering the significant requirements of high-speed train brake friction materials, space environment friction materials, and specialized self-lubricating materials, research has been conducted on the collaborative design of tribological lubrication components, structural and functional integration, and comprehensive testing under simulated service conditions assisted by interface characterization, macro/micro tribological properties testing and wear mapping technology. The results provide theoretical guidance for successful applications.

Keywords: tribological materials, wear resistance, harsh condition

Study on the Impact of Ultrasonic shock Treatment on the Wear Performance of H13 Steel Rolling Cutters for Shield Tunneling Machines

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In the actual working condition, the tunnel boring machine(TBM) must bear both the friction of rock and the impact load within rock formations, rapid wear and impact fractures are the primary causes of disc cutter failure. H13 steel possesses excellent comprehensive properties, thus commonly used in the production of TBM disc cutters. Conventional heat treatment processes alone cannot simultaneously fulfill both wear resistance and impact resistance requirements. Implementing surface composite modification processes can enable H13 steel to meet the requirements of being externally hard and internally tough, which is crucial for enhancing its wear resistance and impact resistance. According to the aforementioned requirements, this study uses ultrasonic shock modification to alter the surface properties of H13 steel building upon quenching and tempering processes, and investigates the impact of varying ultrasonic frequencies on the wear resistance of the disc cutters. Through friction experiments, analyzing the friction coefficient(COF), wear rates and elemental spectra under different ultrasonic rolling frequencies, to explore the influence of different process parameters on wear resistance. Additionally, by examining the distribution of surface residual stress, hardness gradient, and surface microstructure structure,the influence of different process parameters on the surface performance gradient structure of H13 steel was studied. We observed that as the number of rolling cycles increased, the wear volume and friction coefficient of H13 steel gradually decreased, and the wear resistance performance improved. As the number of ultrasonic frequencies increases, results in a different distribution of elements, thereby causing a change in the wear pattern as well. This study provides a theoretical foundation and process guidance for improving the service life of tunnel boring machine disc cutters.

Keywords Ultrasonic shock; Ultrasonic frequencies; Wear resistance

Simulation and Prediction of the Effects of Corrosion Time and Fretting Wear Cycles on Wear Morphology and Mechanical Behavior of Wire

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As an important part of cable, steel wire will inevitably have corrosion and fretting wear during use. To investigate the wear morphology and surface mechanical properties of steel wire under different corrosion conditions with different fretting times, a fretting wear simulation model was constructed by abaqus based on the test results. Firstly, according to the surface roughness of the steel wire under different corrosion time obtained by the experiment, the surface node coordinates of the simulation model are changed to simulate different rough surfaces. Secondly, the wear characteristics of the steel wire under different fretting wear are obtained by setting the number of cycle jumps of the subroutine. Finally, based on the experimental data and simulation data, the machine learning database is built. Then, a machine learning model is constructed to predict the wire wear profile under different wear times. The results show that with the increase of corrosion time and wear times, the wear depth, wear area and surface stress increase. Moreover, the machine learning model can accurately predict the wear characteristics of the steel wire under different corrosion times and fretting cycles.

Keywords: wire, corrosion, fretting wear, simulation model, machine learning

Nanoscale Adhesive Wear Law for Metals

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Nanoscale adhesive wear of metal is a major factor in the failure of ultra-precision contact devices. However, the non-empirical model for predicting nanoscale adhesive wear of metals is lacking due to the unclear physical and chemical origins.In this study, molecular dynamics simulations suggest that cold welding occurs at the metal contacting interface, forming a mass of dislocation inside the metal under compressive stress, while the interface contact area gradually thins and separates due to the sliding and necking of metal atoms under the action of tensile stress, finally resulting in conical wear debris on the substrate. Such phenomenon is also proved by the AFM observation, that is, contacting and adhering of Au probe and Cu substrate to form a cone-shaped bulge under stress. Additionally, we observed a phenomenon of layer-by-layer lattice reconstruction of atoms in the interface area, hence no phase change occurs after the experiment. Based on these results, this study theoretically explains the atomic slip mechanisms at the contact interface by calculating the dislocation energy, stacking fault energy, and critical resolved shear stress and analyzing their physical relationships, during the friction process and the formation mechanism of conical wear debris. With this in mind the wear fragments appear cone shaped, we transform worn atom calculation into conical debris volume calculation, and propose a robust model for predicting nanoscale adhesive wear for metals. Moreover, results derived from molecular dynamics simulations suggest that the model is applicable for predicting the adhesive wear of a large variety of metals including Ni, Cu, Au, Pd and Fe.This study explains the formation mechanism of nanoscale adhesive wear of metal and a predicting model is established, providing guidelines for the design and fabrication of durable ultra-precision contact devices.

Keywords: adhesive wear, theoretical model, wear mechanism

Acoustic Emission Analysis for Thrust Bearing Condition Monitoring

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Mechanical equipment comprises numerous mechanical elements, and their functional deterioration leads to failures. Many failures of mechanical equipment are reported to be due to the wear of mechanical elements. In recent years, equipment aging has progressed, increasing the importance of equipment maintenance. Transitioning to condition monitoring and maintenance through constant sensing and information processing has become imperative to enhance the sophistication of production facilities by detecting abnormalities and their precursors. Acoustic Emission (AE) has garnered attention in this regard. However, analyzing AE results necessitates specialized knowledge. Yet, there is a relatively small number of qualified individuals, such as mechanical maintenance technicians, and a shortage of specialized personnel has been noted. Demand for automated monitoring and anomaly detection systems is increasing. While various studies have been conducted on AE signals and friction-wear phenomena, the correlation between AE signals and wear phenomena remains elusive. Therefore, this study aims to develop an automatic monitoring and anomaly detection system using machine learning by identifying the correlation between AE signals and friction-wear phenomena.
In this study, an AE sensor was installed on a thrust bearing test rig, and bearing lifespan experiments were conducted. From the bearing lifespan experiments, it was found that the friction coefficient is most sensitive to bearing damage, and it is most effective for monitoring surface damage. Additionally, by analyzing AE, the mechanism of abnormalities could be understood from frequency characteristics. At 0.1 MHz, the occurrence of adhesive wear was indicated, while abrasive wear and seizure were considered to occur from 0.5 MHz onwards. Furthermore, a correlation was observed between the peak intensity of AE signal frequency characteristics and the friction coefficient, suggesting the early detection of surface damage, akin to the friction coefficient. These parameters are believed to be useful for abnormal judgment of mechanical devices using machine learning.

Keywords: acoustic emission, bearing; wear

Effect of Surface Strengthening Techniques on the Fretting Fatigue

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Fretting fatigue damage occurs frequently in connected structures. The resistance of materials to fretting fatigue damage can be enhanced by utilizing various surface strengthening techniques. In this study, the effects of three surface strengthening techniques, Laser Quenching, Laser Shock Peening and MoS2 dry-film strengthening, on the wear resistance and fretting fatigue properties of the materials were investigated

respectively. The results show that after Laser Quenching, the surface hardness of the specimens increased by 79%, and the depth of the hardened layer was about 1 mm. It has good performance for improving the fretting fatigue life of the alloy, and it is more obvious at the low stress level than at the high stress level. After Laser Shock Peening, a deeper residual compressive stress layer was formed on the surface of the alloy specimens, and the value of the residual compressive stress increased with the increase of the laser energy and the number of impacts, which inhibited the expansion of the surface fretting fatigue cracks to a certain extent. The fretting fatigue life of the test specimens was improved to different degrees. The strengthening of the dry-film of MoS2 reduced the friction coefficient by lubricating to mitigate the fretting damage. After strengthening, the MoS2 coating on the test specimen surface avoids direct contact with the substrate and reduces the wear of the substrate. The flaked abrasive chips play a lubricating role as the 'third body', which reduces the coefficient of friction. The life of the test specimen coated with a thickness of 10 μm is 2.21 times that of the pre-strengthening test piece, and the life of the test piece coated with a thickness of 20 μm is 2.76 times that of the pre-strengthening test piece.

Keywords: Fretting fatigue, surface strengthening techniques, coatings

Study on the Tribological Characteristics and Damage Failure of Elevator Traction Steel Belt

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Steel belt elevator is a new type of elevator that uses traction steel belts instead of traditional steel wire ropes to achieve friction drive and transmission. It has advantages such as long service life, light weight, high comfort, safety, energy conservation, and space saving, and has become a new development direction in the future elevator industry market. Due to the completely different friction transmission and bearing performance of traction steel belts from traditional steel wire ropes, under the influence of multiple working conditions such as elevator system structure, operating characteristics, and service environment, external wear, internal steel wire rope fatigue breakage, bending fatigue, and aging of the coating layer are prone to compound damage, leading to performance degradation and friction transmission instability of traction steel belts, reducing their service life, and seriously threatening the safety and reliability of elevator systems. For this purpose, the elevator traction steel belt was taken as the main research object, and a self-made steel belt friction and wear testing machine was used to conduct critical slip and friction slip tests on traction steel belts under harsh environments and different contact parameters. The quantitative relationship between traction steel belt slip and wear and contact parameters under multiple working conditions was proposed, and the evolution characteristics of wear on in-service traction steel belts were explored, And conducted aging fatigue single or composite

damage tests on traction steel belts under different experimental parameters, exploring the interactive influence mechanism of aging fatigue damage on the external coating layer of traction steel belts and the evolution mechanism of composite damage.

Keywords：friction, damage failure, steel belt

Tribological Investigation on the Mechanics of Adhesive Layer Formation and Its Impact on Wear Mechanism in Ti6Al4VCutting

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Titanium alloys have been widely used in aerospace, general industry, medical, and automotive industries due to their exceptional strength-to-weight ratio, corrosion and heat resistance, and biocompatibility. In recent decades, the investigation of titanium milling has become a hot topic, with around 35 % of publications centering on investigating tool wear mechanisms to increase the machining efficiency. It is well accepted that adhesion is one of the main root causes of wear in Ti alloy cutting, which predominantly contributes to various tool failures, including flank wear, built-up-edge (BUE) formation, chipping, and thermal cracking. In addition to shortening the tool life, adhesion can also detrimentally impact the machined surface quality of workpieces. In view of this, the formation mechanisms of the adhesive layer were investigated in this study by combining experimental and numerical modelling approaches. The influence of load, speed, lubricant composition on the formation of the adhesive layer (transferred from Ti6Al4V disc) formed on friction counterpart (tungsten carbide pin) was investigated by using a bespoke high-speed Pin-on-Disc tribometer. Diverse surface analysis techniques were employed to characterise the composition and morphology of the adhesive layer formed on the pin surfaces and wear morphologies on contact surfaces. For clarifying the formation mechanism of the adhesive layer, a boundary element method-based model for elastic layered contact was developed to aid the analysis of stress distribution in the interfaces. The results show that the formation of adhesive layer depends on both on the mechanical properties of workpiece and working conditions, which can significantly benefit the design of working parameters in the actual cutting process for diverse workpiece materials.

Keywords: adhesive wear, Ti6Al4V, machining

Study on the Rolling Contact Fatigue Test Method and Damage Mechanism of Rails Based on Dry-Wet Alternation

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Rolling contact fatigue (RCF) damage is the critical damage form faced by rails, especially under rainy and humidity condition. In order to deeply explore the mechanisms of RCF damage under such condition, a novel wet-dry alternation test method was proposed and rail RCF damage evolution tests were conducted in this study. Detailed comparisons between the novel test method and three widely used rail RCF methods were analyzed. The results show that under wet-dry alternating conditions, the crack growth rate and wear rate were initially low, with cracks predominantly located in the region near the rail surface. Thus, there was a significant competitive relationship between crack propagation and wear in this period. Then, with the increase in cycling number, RCF damage was gradually dominated by crack propagation, which extending deeper into the material along its deformation orientation. Meanwhile, the severe material spalling lead to a rapid increase in wear rate. Through comparative analysis of the accuracy, repeatability, evaluability, rationality and practicability of the four test methods, it was found that the novel method proposed in this study had significant advantages in rationality and accuracy compared with traditional RCF test methods, providing a more effective tool for systematic studies on RCF performance of rail materials.

Keywords: rolling contact fatigue, wet-dry alternation, test method

Numerical and Experimental Studies of Fretting Wear Behaviors of Cast Polyurethane Elastomers

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Fretting wear is one of the most common forms of failure modes for seals in dynamic applications. It is critical to explore the potential fretting wear principles of elastomer materials, and to develop the fretting wear prediction methods. The wear behaviors of a series of cast polyurethane elastomers (CPU) under linear fretting conditions were experimentally investigated. An adaptive finite element method was developed using ABAQUS that integrated the user-defined subroutine UMESHMOTION to simulate the profile and depth of tangential fretting wear on the CPU. The calculation of wear was based on the Archard's wear model and time-varying friction coefficient obtained from experiments. The fretting behaviors were investigated for different test parameters, such as normal load and displacement amplitudes. It was found that the fretting wear damage of the model system was dominated by the adhesion-fatigue wear mechanism. Three kinds of fretting states were determined, namely local slip state, mixed slip state

and complete slip state. The result indicated that the present numerical simulation method can accurately predict the fretting wear of CPU, which is comparable to the experimental results.

Keywords: cast polyurethane elastomers, fretting wear, adaptive finite element, wear mechanism

Fundamental role of Cu-BDC MOFs in modifying the tribological performance of epoxy composites

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Metal-organic frameworks (MOFs) are a kind of coordination polymers consisting of metal center and organic ligands, which have been found to be effective in improving the tribological performance of lubricating oils. In the present study, Cu-BDC MOFs were synthesized through ultrasound-assisted method and incorporated alone or together with SiO_2 nanoparticles into carbon fiber reinforced epoxy composites (CF/EP) towards the goal of modifying the composites'tribological performance. Friction and wear tests revealed that Cu-BDC alone decreased the wear rate but increased the friction coefficient of CF/EP. Only when Cu-BDC was incorporated simultaneously with SiO_2 nanoparticles, were both the wear and friction behavior of CF/EP improved. In order to reveal the fundamental role of Cu-BDC MOFs during sliding, morphological and chemical analysis were conducted on both the composites'worn surface and corresponding transfer films. It was found that the simultaneous incorporation of Cu-BDC and SiO_2 into CF/EP enhanced the formation of friction-reduction and anti-wear transfer films on the counter steel surface, which governed the composites'sliding wear process. The present work verified the effectiveness of MOFs as fillers in modifying the friction and wear properties of polymer composites, which helped expand the application of MOFs in the field of tribology.

Keywords Metal-organic frameworks (MOFs), Epoxy composite, Friction and wear, Transfer film

Wear Resistance in Friction Systems with Bearing Steels in Refrigerant Oil Added Nanodiamond

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Refrigerant oil is generally used as lubricant for sliding parts of air conditioner compressors. It is a polar lubricant, unlike other oils such as engine oil, because it must be compatible with the refrigerant. Also, the use of conventional extreme pressure additives is problematic because of the large wear particles generated in the sliding parts of the compressors. Therefore, new additives are required to replace conventional additives for wear resistance. On the other hand, it has been reported that nanodiamonds can reduce the coefficient of friction and the wear volume in other oil/water lubrication systems. Therefore, the purpose of this study was to experimentally clarify the effect of adding nanodiamonds to refrigerant oil on friction and wear properties, and to clarify the role of nanodiamonds in the formation of friction interface.
Ball-on-disk friction tests were conducted using bearing steel balls and disks in refrigerant oil with the addition of nanodiamonds. Load and sliding velocity were set to 10N and 0.1m/s. Wear scars after friction tests were observed using confocal microscopy and Scanning Electron Microscope.
The addition of nanodiamond didn't decrease the coefficient of friction, but it showed stable frictional behavior. Observation of the wear scar showed that the diameter of the wear scar became smaller as the concentration of nanodiamond addition increased up to 100 ppm, and at 100 ppm the diameter was about 34% smaller. From the above, it can be concluded that nanodiamonds demonstrate the potential as an additive for wear resistance.
Additionally, friction tests were performed on grooved disks with large convexities to clarify the nanodiamond's role in the formation of friction interface. Results revealed that increasing nanodiamond concentration reduced the roughness of the wear scars on balls and disks. This may be a contributing factor to the reduced wear.

Keywords: nanodiamond, refrigerant oil, wear resistance

Evolution of Fracture and Wear in Asperity Interaction with Ploughing Effect

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A finite element model is established to simulate the asperity interaction with consideration of realistic material failure criterion. The fracture evolution during the asperity interaction is allowed which enables to reveal the formation process of wear particle. To solely show the ploughing effect and exclude the surface adhesion effect, the frictionless contact condition is used, which basically corresponds the lubricated contact. The friction, wear particle formation and wear coefficient during the interaction of two asperities (with radius R1 and R2) with ploughing effect is presented and the effect of interference ω and relative radius ratio i (R1/R2) are investigated for different materials. Two friction-wear modes are revealed and the map is provided along with expression of the transition line. This study clarifies the wear mechanism on asperity

with pure ploughing effect for the first time, showing the occurring condition of wear even when the surface is perfectly lubricated.

Keywords: ploughing effect, fracture evolution, asperity interaction, wear particle formation

Dynamic Modeling and Condition Monitoring of Spalling Fault of Planetary Gear System

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In order to study the influence of spalling fault on tooth surface meshing and stiffness of planetary gear system. Firstly, establish the geometric model of planetary gear tooth surface spalling fault, the dynamic tooth vibration response results of gears with different degrees of spalling fault were analyzed by energy method and finite element method. Secondly, according to the dynamic model of planetary gear system, the dynamic gear vibration response results of gears with different degrees of spalling faults were simulated. Finally, the fault frequency characteristics of the planetary gear were identified by the vibration response signal obtained by the experiment, and combined with the analysis of gear surface morphology, the forward mapping between the spalling fault of tooth surface and the vibration response of the planetary gear system is fully verified.

Keywords: planetary gear system, spalling fault, time-varying mesh stiffness, dynamic model, surface morphology analysis

Dynamic Response and Damage Behavior of Impact Wear for Polycrystalline Diamond Compact under Low Kinetic Energy Impact

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Polycrystalline diamond compact (PDC) cutters are the main load-bearing components in shale gas drilling, and their performance significantly affects the efficiency of shale gas extraction. One of the main reasons for cutter failure is the dynamic impact between the rock and the cutter due to the complex geological conditions of shale gas extraction. Investigating impact wear behavior and damage mechanisms is vital to designing superior-performing PDC structures and improving their effectiveness in engineering applications. This work investigates the kinetic response and damage behavior of PDCs

under low kinetic energy impacts to explain the characteristics and mechanism of PDC impact wear. The results show that the impact force varies dynamically with the impact cycles and tends to decrease. Due to the elastic-plastic properties of PDC, 87% of the kinetic energy is used for plastic deformation and fracture. Secondly, the contact time and kinetic energy absorption rate only relate to the impact mass. The contact time positively correlates with mass, while the kinetic energy absorption rate changes in the opposite direction. In addition, diamond fracture occurs with a low kinetic energy accumulation of only 0.059 J. Cobalt catalysis and stress effects were found to induce graphitization and carbon hybridization jointly during impact wear. It is concluded that the PDC impact wear mechanism under low kinetic energy impact is a brittle fracture with a combination of transcrystalline fracture and intergranular fracture. This work provides referable basic research data for designing impact-wear resistant PDC structures and improving the efficiency of shale gas extraction.

Keywords: impact wear, polycrystalline diamond compact, dynamic response

Research on Wheel/Rail Contact Characteristic and Rail Material Damage Under Special Operating Conditions of Trains

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During train operation, special operating states such as serpentine motion, braking, and starting may be occur. In the case, the complex mechanical and thermal phenomena will occur on wheel/rail contact surface, and obvious damage to rail material will also occur. In order to study the thermomechanical phenomena on the wheel/rail contact surface and the damage of rail material under special operating conditions, a three-dimensional finite element model of wheel/rail contact is established. The thermomechanical characteristics of contact surface during the serpentine motion state, starting and braking process are research. At the same time, the numerical prediction and damage experiments on the fatigue life of rail materials are conducted.

Predictions of Fatigue Life and Damage Analyses on Rail Materials

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During the long-term service of trains, contact fatigue damage between the wheel and rail has become a core issue affecting the safe operation of the train. To study the fatigue life and material damage characteristics of rail steel, a three-dimensional finite element model of the rail material's contact was established, and the number of limit passes for

the rail material was analyzed. Additionally, a twin-disc contact fatigue experiment was conducted to investigate the fatigue damage characteristics of the rail material. The experimental results show that under rolling contact conditions, the number of limit passes for the rail material is $7.73*10^6$. After rolling contact, noticeable spalling and pitting appeared on the wheel-rail surface, with fatigue cracks observed along the rolling contact direction on the longitudinal surface and a large number of cracks visible on the subsurface of the cross-section.

Track 3-I: Coatings and Surfaces Engineering

KEYNOTE

Processes and Setups of Green Chemical Mechanical Polishing with High Efficiency and Low Damage

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Traditional polishing methods, consisting of manual polishing, magnetorheological polishing, robot polishing, abrasive flow polishing and abrasive belt polishing, induce scratches on the polished surfaces, becoming the origin of fatigue during the service of high performance components. This is a potential threat for the high performance setups. Challenges met in ultraprecision machining are as follows. 1. The fundamental mechanisms of ultraprecision machining are not clear. 2. Conventional chemical mechanical polishing usually employs the toxic and polluted ingredients, leading to the pollution to the environment. 3. In-situ measurements at nanoscale are difficult to perform. Our works to solve the three challenges are listed. 1. Development of novel diamond wheels and grinding setups. 2. Novel green chemical mechanical polishing slurries and setups. 3. Development of novel instruments using biomaterials with variable cross-sections to manipulate micro- and nano specimens. Performing the in-situ measurements at nanoscale.

Keywords chemical mechanical polishing, setups, processes, slurry

INVITED

Study of Co-DLC Coatings in Combination with Functionalized Polymers for Enhanced Wear Resistance and Friction Reduction

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The integration of metallic elements into diamond-like carbon (DLC) coatings, particularly cobalt (Co-DLC), has attracted significant attention for enhancing functionalities in various applications. This study explores the interaction between

functionalized polymers and Co-DLC coatings to elucidate their tribological properties and wear resistance. Co-DLC coatings were deposited on steel substrates using deep oscillation magnetron sputtering, and different Co concentrations were achieved by varying cobalt pallets. Tribological tests were conducted using ball-on-disk tribometry, revealing reduced friction and improved wear resistance of Co-DLC coatings when paired with PLMA-b-PDMAEMA polymer compared to PLMA. Surface characterization through SEM-EDS analysis unveiled the formation of transfer films derived from carbon-rich polymers, contributing to the observed reduction in wear rates. Overall, Co-doped DLC coatings exhibited promising potential in mitigating friction and enhancing wear resistance when combined with specific functionalized polymers, indicating avenues for diverse industrial applications. This comprehensive investigation not only advances the understanding of tribological behavior but also facilitates the development of tailored materials with superior performance in real-world applications.

Keywords copolymer, sliding friction, DLC coatings

Origin of Superlow Friction in Strengthening DLC Films for Robust Superlubricity at Ultrahigh Contact Stress

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In the past decades, quantities of studies excavate potentials for promoting lubricity of diamond-like carbon (DLC) films under complex working conditions, aiming at the profound application in the advanced machineries such as aviation, aerospace and nuclear power. However, to our best knowledge, there are barely any effective theoretical and technical solutions for facing the challenge of lubrication requirement of DLC lubricants in complex-loading operation environments.
This work is dedicated to explore novel nanostructured multilayer films with controlling the relevant nanostructures of the overall carbon matrix for achieving a robust superlubricity and figure out the robust load bearing capacities with related to the optimal interfacial properties at high and alternating load contact conditions. A superlow friction coefficient of 0.001 and a near-zero wear rate of 3.13×10^{-9} mm^3 /Nm) were achieved by a thick multilayer film with a bilayer period λ of 324 nm (total film thickness of 1.53 μm) under a peak Hertz contact pressure of 2.37 GPa. It can be concluded that both the newly-grown short-ranged sp^2-ordering structures and the surface hydrogenated passivation is conductive to the building-up easy-shearing sliding interface. While, the newly-grown nanostructures of the carbon matrix at the frictional interface is clarified with respect to the adaption to the complex stress field, which would be the underlying mechanism of lubricity. This work is dedicated to explore novel nanostructured multilayer films with controlling the relevant nanostructures of the overall carbon matrix for achieving a robust superlubricity and figure out the robust

load bearing capacities with related to the optimal interfacial properties at high and alternating load contact conditions.

Keywords diamond-like carbon (DLC), superlubricity, ultrahigh contact stress

Improvement of Tribological Performance of DLC on Si-Al Interlayers through PVD Technique

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This work illustrates the influence of the Al and Si interlayers as single interlayer and double-elemental interlayer comprises of Al and Si in one interlayer on the properties of DLC which conducted on 316L stainless steel. Our study focuses on comparing the tribological effect of these three interlayers on the DLC coating using PVD technique to synthesize them. furthermore, the effect of composition of Si-Al interlayer on the tribological behaviour of DLC has been studied. Under room temperature, 5-15 N loads, and 20-30 mm/s, the friction test has been applied on different coating systems. The coating system contains Si or Si/Al as interlayer has shown the best results comparing to the coatings without interlayer/ interlayered with only Al. The strong interfaces of steel/Si, steel/Si-Al and Si/DLC, Si-Al/DLC have been established, which allowed the stable DLC coating to be formed under tough tribological conditions. In contrast, Al-interlayer has illustrated the weakest tribological performance on DLC, the reason may come through the weak steel/Al interface. Therefore, this work explains the details on the improvement of tribology in DLC using different Si-Al interlayers.

Keywords diamond-like carbon; 316L stainless steel; tribology; friction; interlayer.

Influencing Mechanisms of Contact Pressure on The Superlubricity of a-C:H Films: Key Role of In-Situ Structural Evolution of Nanoclustering Structures in Transfer Films

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Though hydrogenated amorphous carbon (a-C:H) films can provide macroscale superlubricity states in vacuum, their self-lubricating behaviors are highly dependent on the applied loads. The mechanisms of loss of superlubricity under ultra-low or extremely high contact pressure remain unclear. In this work, the origin of load-sensitive superlubricity of a-C:H films was revealed based on spatially resolved

structural analyses of the sliding interfaces. The results highlighted the key role of contact pressure-induced diversified nano-structural evolution of transfer films in controlling superlubricity. To achieve superlubricity, a sufficiently high contact pressure was required to trigger the structural evolution of transfer films from polymer-like disordered bonding network structure towards locally ordered, layered-like sp^2 nanoclustering structures. Robust superlubricity can still be maintained under extremely high peak Hertz contact pressure up to 4.87 GPa. Nevertheless, excessively high contact pressure can cause an increase in the interfacial shear strength due to the pressure-induced generation of heterogeneous transfer films with thin, poor-hydrogenated, over-graphitized local regions embedded with enriched ironic sub-micro debris and nanoparticles, which inhibited further decrease of friction coefficient under extremely high contact pressure. These findings will enable more effective space applications of superlubricious a-C:H films under extreme conditions.

Keywords diamond-like carbon film, extreme contact pressure, superlubricity

KEYNOTE

Experimental Techniques and Numerical Methods in Developing Nano Coatings for Tribological Applications

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The exploration focuses on the synergistic examination of wear and corrosion in various nanocomposite coating configurations. The principal objective is to engineer robust coatings suitable for deployment in corrosive tribo-conditions and other industry applications.

This investigation scrutinises the wear attributes of nanocomposite coatings subjected to oscillating-reciprocating conditions using a steel ball. Diverse nanocomposite coatings have been studied. Findings disclose that Ni/ZrO2 demonstrated the highest wear rate, trailed by Ni/SiC, Ni/Al2O3, and Ni/Graphene. These findings are substantiated by diverse analyses encompassing Scanning Electron Microscopy (SEM) micrographs, grain sizes, hardness, porosity, and surface stresses.

Significantly, Ni/Graphene manifested superior anti-wear characteristics in comparison to other nanocomposite coatings, credited to the reinforcing impacts of graphene. The study embraces a multidisciplinary methodology, amalgamating electrochemical, mechanical, and physical facets to formulate numerical models for forecasting coating failures. The fracture mechanics approach is employed to investigate the commencement and spread of circular blisters functioning as interfacial cracks, influenced by mechanical, diffusion, and heat conduction stresses induced by coating-substrate interfacial pressure fluctuations.

A synergistic wear-corrosion predictive model, integrating nano-mechanics and electrochemistry, has been developed. This model is relevant to any nanocomposite coating and alternative materials, employing input parameters such as mechanical properties for simulation and prognosis in contaminated environments.

Lubrication behaviors of Metal Doped MoS_2 /a-C:H Heterogeneous Interface at Large Contact Scale

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A series of silver/titanium doped molybdenum disulfide flims were constructed based on closed field non-equilibrium magnetron sputtering technology. The hardness and anti-wetting properties of molybdenum disulfide films were improved by setting about 8 % titanium doping. The silver content of this series of films is increased from 6% to 20% by changing the silver target current. The results show that suitable silver doping can effectively improve the crystal structure of molybdenum disulfide, enhance the long-term ordered layered crystal structure along the shear direction, reduce the defects and increase the hardness of the film. Excessive silver doping will destroy the crystal structure of molybdenum disulfide, make the coating structure tend to be amorphous and the hardness of the coating will decrease. The amorphous carbon film with high hydrogen content of 43 % was prepared by vacuum ion beam vapor deposition technology. Sufficient hydrogen is expected to achieve stable superlubricity under inert gas. A large scale heterogeneous contact interface was formed by silver/titanium doped molybdenum disulfide films and high hydrogen content a-C:H film. The results show that the heterogeneous interface between the 9 % silver content film and a-C:H film achieves 0.009 stable superlubricity at the contact scale of 1.5 mm under 20 N normal load. The lower sample maintains a low wear rate of 1.5×10^{-7} $mm^3/N.m$ after 6000 cycles. The relevant research provides theoretical guidance for molybdenum disulfide metal doping research and large-scale heterogeneous superlubricity interface regulation.

Keywords large scale contact, heterogeneous interface, superlubricity

Achieving Superlow Friction State in a-C:H:Si Films under Atmospheric Environment by Constructing Island Texture Surfaces

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Hydrogenated amorphous carbon (a-C:H) is capable of providing an excellent lubricity state when rubbed in dry sliding contacts. The Si-doped a-C:H film has the potential to maintain superlow friction under atmospheric environment. However, a-C:H:Si film belongs a kind of hard film, its wear debris has an adverse effect on the lubricity. In this work, several types of island texture surfaces of a-C:H:Si film were designed and prepared. The tribological properties of the a-C:H:Si films with texture or not were conducted on a ball-on-disk tester. The results show that the friction coefficient of the a-C:H:Si texture surfaces with length 240 μm, width 240 μm and height 1.7 μm or length 50 μm, width 70 μm and height 0.4 μm can be reduced to 0.011 ~ 0.015 from 0.05 ~ 0.06. The film on the ball rubbing on non-textured surface has a large area of spalling, while the integrity of the film on the ball sliding on the textured surface is better. With regards to the textured surface of a-C:H:Si film, the frictional debris can be stored in the groove between islands, which can reduce abrasive wear to a great extent. The research results have important guiding significance for the engineering application of a-C:H(Si) films.

Keywords superlow friction, a-C:H:Si film, texture, abrasive wear

Improved Tribological Performance of a-C:H/a-C:H:Si:O Coated Polyether Ether Ketone by Introducing Graded Interfacial Structure

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Amorphous carbon is one of the materials used to improve the wear resistance and solid lubricity of polyether ether ketone (PEEK). However, its high internal stress and weak adhesion strength on the PEEK are the key factors that limit the further improvement of its tribological performance. In this study, based on the gradient transition of composition and mechanical properties between the PEEK and amorphous carbon coatings (a-C:H), a-C:H/a-C:H:Si:O functionally graded coatings (FGCs) were prepared on PEEK. Compared with the single-layer a-C:H and a-C:H:Si:O coated PEEK, the friction stability period of FGCs are extended by at least 33%. When the thickness ratio of a-C:H/a-C:H:Si:O is 1/1, the wear rate of FGC was as low as 5.6×10^{-7} mm^3/Nm. The excellent tribological performances of FGCs can be attributed to the proper mechanical property transition and strong adhesion strength between the coatings and the PEEK. The deformation and stress distribution of coated PEEK were simulated using the finite element method, and it was found that the FGCs can provide more excellent deformation resistance and can also significantly eliminate stress concentration. This work can provide basic theoretical guidance to prepare functionally graded amorphous carbon coatings on PEEK for excellent tribological and wear performance.

Keywords functionally graded coatings; finite element method; tribological performance

INVITED

Superlubricity Depending on Interface Design with Amorphous Carbon Protection

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Superlubricity are noninate that friction coefficient in the level of 0.001 or below. Solid superlubricity is related most on cn carbon structures with crystal and amorphous ones that due to incommensurate contancting state. Here, we focus on amorhous carbon film via couple pairs or interface to be conjured. Superlubricity can be arrived on the steel surface which is favarate to industrial use via a-C:H/MoS2, a-C:H/Au or introduce ammonium tetrathiomolybdate etc.. DFT caculation was carried out to derived out that both incommensurate ang low affinity are contribute to superlow friction. We also have set up a PVD/PECVD mixed system for controling growing such films.

Keywords carbon films, superlubricity, interface, tribology

Unleashing Ag Self-Migration: Advancing High-Temperature Tribological Properties of Nanolayer MoS2/Ti/Ag Composite

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Abstract: Molybdenum disulfide (MoS2) is widely used in aeronautical, mechanical, and nuclear domains due to its superior lubricating properties based on layer structure. MoS2 could achieve superlubrication in a high vacuum environment. However, temperature and moisture have a significant impact on the tribological properties of MoS2, limiting their applications. To improve the high-temperature tribological properties of nanolayer MoS2, this study synthesized nanolayer MoS2 doped with a series of Ti and Ag nanoparticles (MoS2/Ti/Ag) by modifying the target electric current during the unbalanced magnetron sputtering process. Doped mental elements could significantly improve inoxidizability, mechanical properties, and high temperature tribological properties, with MoS2 doped with 9% Ag exhibiting the best mechanical qualities at ambient temperature. The high temperature tribology properties of the MoS2/Ti/Ag were investigated, and the results showed that the MoS2/Ti/Ag could achieve a stable lubrication performance in a wide temperature range against DLC coating: a stable friction coefficient of 0.036 and a specific wear rate of 3.55x10-7 mm3N-1m-1 in vacuum environments up to 450 degrees Celsius. Raman analysis was used to indicate the structure evolution of the DLC transfer layer. The cross-section HRTEM and EDS characterizations of the wear track reveal unique Ag migration channels composed of crystal clusters aggregated by Ag atoms scattered in the matrix, confirming A atoms' self-migration behavior. In alliance with insights into the high-

temperature friction mechanism, the steady friction coefficient and wear rate contributed to the graphitization of the transfer layer in high temperature and the Ag migration behavior. This phenomenon hold promise for advancing the development of durable and high-temperature-resistant lubricants.

Keywords MoS2/Ti/Ag film, self-migration, high-temperature tribology, magnetron sputtering

Mesh-Like Carbon Nanotube Multilayer Coating for Enhanced Sliding Electrical Contact Durability

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As technology advances, electricity has become essential in everyday life and the industrial field, not only for operating electronic devices but also for transmitting signals and information. Generally, these electronic devices operate using sliding electrical contact terminals, which are components in which electrical currents flow between two or more conductive objects while simultaneously undergoing relative sliding motion. However, these contacts are prone to surface damage due to the wear and heat generated from friction and electrical resistance. This damage can lead to increased contact resistance or frictional force, thereby deteriorating the durability and performance of electronic devices. Previous research has attempted to mitigate these issues by applying hard coatings or increasing the hardness of the contact material. While these approaches can reduce friction due to a reduced contact area, they inversely increase electrical resistance. To enhance the durability of electrical contacts while maintaining electrical conductivity, this research has utilized a mesh-like carbon nanotube (CNT) coating coupled with thin metal films to improve electrical properties and protect the coating from wear. The durability and the electrical characteristics were evaluated through wear tests and sheet resistance measurements. The wear tests were conducted under a load of several mN for several hundred thousand cycles, and the sheet resistance was measured using a 4-point probe. The results showed that although the sheet resistance of the CNT multilayer coating structure was slightly higher than that of the material used for electrical contacts, the difference was negligible. The wear test results showed that the CNT multilayer coating structure exhibited superior wear resistance compared to the conventional material used for electrical contacts. This is believed to be due to the excellent mechanical properties, elastic recovery, and the dissipation of contact pressure through the mesh-like CNT coating.

Keywords wear, sheet-resistance, CNT

Application of Graphene-Reinforced Silver-Based Electrical Contact Materials in Relays

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In the field of electrical contact materials, silver-based electrical contact materials are currently the most widely developed and used, boasting lower resistivity and contact resistance. However, pure silver contact materials with high purity have disadvantages such as low melting point and hardness. Moreover, the majority of electroplating processes still primarily use cyanide silver plating, but the various cyanides used are highly toxic and pose significant harm to humans. To overcome these two major drawbacks, we have added 0.5g/L of graphene to the nicotinic acid silver plating system to create a silver-graphene composite coating. Compared to silver-based electrical contact materials produced by the same process, the new electrical contact material has increased hardness from 85hv to 120hv, and reduced the friction coefficient from 0.7 to 0.5. In electrical contact operations at 24v5A, the contact resistance of the pure silver coating will sharply increase after 2000-4000 cycles. The new silver-based contact material remains stable after 50,000 cycles, and the arc energy, arc duration, and welding force between dynamic and static contacts are lower. The arc fitting coefficient obtained by arc fitting the data is 0.8556, showing that the arc energy increases exponentially with the increase of arc duration. The macroscopic and microscopic surface morphology obtained by SED shows that the surface after electrical erosion of the new silver-based electrical contact material is smoother, with fewer pores, cracks, and protrusions. The composition of the new silver-based electrical contact material obtained by EDS analysis is 85.6wt%. Therefore, it can be seen that the hardness and resistance to electric arc erosion of the silver-graphene electrical contact material have significantly improved, which we believe provides a viable approach for the future development of cyanide-free silver plating preparation of electrical contact materials and offers a pathway for large-scale production.

Keywords cyanide-free silver plating, electrical arc erosion, silver graphene composite coating

Enhancing Corrosion Protection and Tribological Performance with Mussel Adhesive Protein-Based Multifunctional Films

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2. University of Sussex, UK

Bio-based corrosion inhibitors are now being applied in biopolymer/nanoparticle composites to create smart surfaces with anti-wear, anti-corrosion, and self-healing

capabilities. In this work, a multilayered film was prepared using magnetron-sputtered TiO_2/Ag and mussel adhesive protein on the carbon steel. The corrosion inhibition effects of the film were evaluated through in-situ confocal Raman micro-spectroscopy together with electrochemical impedance spectroscopy measurements in a corrosive solution. The adhesion properties of the film were investigated with nano-indentation and nano-scratching experiments. The tribological behavior of the film was systematically analyzed through tribotests. The as prepared TiO_2/Ag/*Mefp-1* film outperforms the traditional TiO_2 or *Mefp-1* film, shows robust adhesion to the carbon steel surface, and exhibits improved anti-corrosion, lubrication and anti-wear properties. The tribological tests show that the TiO_2/Ag/*Mefp-1* film maintains a low coefficient of friction and significantly reduces wear rate. Credits for this substantial enhancement are due to the exceptional corrosion resistance of the TiO_2 film and outstanding lubrication property of the Ag film. The complexation of *Mefp-1* with metal ions can further enhance the corrosion and abrasion resistance of the film by improving the compactness of the film. The successful reinforcement of the multi-functional TiO_2/Ag/*Mefp-1* film indicates a valuable direction for developing reliable and efficient MAP-based smart film suitable for diverse engineering applications.

Keywords mussel adhesive protein, gradient-distributed TiO_2/Ag/Mefp-1 film, adhesion reinforcement

Track 3 - II Coatings and Surfaces Engineering

Synthesis and Characterization of Quaternary Alloys Coating Electrodeposited with Different Slide-roll Ratio Friction

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Remanufacture technology has been receiving a growing attention in academia and industry due to its economic and environmental benefits. Meanwhile, remanufacture technology has also been considered as a pivotal approach for achieving the industrial carbon neutrality target. Rolling element bearings are the most essential components for rotary machinery, while its maintenance and replacement cause enormous cost on energy and materials. To solve this problem, a technique of electrodeposition remanufacturing for worn or failed bearing components is presented in this paper. FeCoNi- (Cr, Mn, Cu) alloy films have been successfully electrodeposited on damaged bearing surfaces. The surface morphology, structure evolution as well as mechanical behavior of the deposited film are quantitatively examined by scanning electron microscopy (SEM), electron back scatter diffraction (EBSD), X-ray Photoelectron Spectroscopy (XPS), transmission electron microscope (TEM), and nano-indentation. It is revealed that different modes of frictional motion has a significant influence on electrodeposition process. The balance between friction generation and wear removal is necessary for repairing coating formation. Additionally, during the transformation from sliding friction motion to rolling friction motion, deposition rate and film integrity are significantly improved. And the nanocrystalline alloy film shows good hardness and anti-wear property. This work provides a novel pathway for industrial remanufacturing.

Keywords remanufacture, friction-assisted electrodeposition, quaternary alloys film

Durable and Failure Tolerable Carbon-Based Tribocorrosion Protective Coating with Interface-Graded Multilayer Structure

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With the soaring development of the marine sectors, attention has increasingly focused on high-performance materials and material systems for marine environments. However, current research on the tribocorrosion aspect for marine metallic materials and their surface coatings had mainly focused on the short-term and continuous tribocorrosion, which deviated from the practical service conditions. In present work, three amorphous carbon-based multilayer films (Ti/DLC、TiCx/DLC and Ti-TiCx/DLC) were deposited on S32750 substrates by using a hybrid system combining linear anode-layer ion source (LIS) and direct current magnetron sputtering (DCMS) techniques, and their short-term and long-term corrosion behaviors, as well as the related corrosion mechanisms, were investigated in 3.5 wt.% NaCl solution. All the films could greatly improve the tribocorrosion resistance of S32750 stainless steel in 3.5 wt.% NaCl solution. Uniform wear behaviors were observed during the short-term tribocorrosion of three kinds of films, and TiCx/DLC film exhibited the highest tribocorrosion resistance due to the highest hardness. However, the Ti-TiCx/DLC film with the best comprehensive mechanical properties showed the highest tribocorrosion resistance during the long-term tribocorrosion. The friction coefficient (COF) remained relatively low values even though the film was completely worn out in the tribocorrosion test, which was mainly related to the formation of tribocorrosion products consisting of graphitized DLC and nanocrystalline FexOy.

Keywords DLC, long-term tribocorrosion, failure tolerance

Tribo-corrosion Properties of CrN and CrN/DLC Coatings in Seawater

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CrN and diamond-like carbon (DLC) coatings with carbon-nitrogen compounds of Cr as interlayers are deposited on the surface of 431 stainless steel by the direct current magnetron sputtering technique. Coatings's microstructure and their tribo-corrosion properties are analyzed by Raman spectroscopy and friction and wear tester. The thickness of the CrN/DLC coating is 1.14 μm and multi-layer CrN/CrNC/CrC/DLC coating is 4.02 μm in thickness with the content of sp3-C bond reduced to 27.9%. The performance results show that composited DLC coatings exhibit lower friction coefficient and better tribo-corrosion resistance than the pure CrN coating in seawater. The average friction coefficient of DLC coating is only 1/5 of the substrate, and the wear rate is also lower. Though, CrN coating has excellent abrasion performance in seawater, its corrosion resistance is limited due to the columnar crystals with gaps. Due to the higher sp3 bond content (32.3%) and much denser structure (1.907 g/cm3), CrN/DLC coating has the lowest friction coefficient of 0.08. However, for the limited thickness, it is easy to fail during friction and wear. CrN/CrNC/CrC/DLC coating is much thicker with more sp2-C which plays a lubricating role in the friction process, reducing the friction coefficient. And the formation of dense passivation film in seawater inhibits the spread of pitting corrosion, with a corrosion protection efficiency of 96%, indicating that the multi-player composited DLC coating can protect the substrate. The above results provides a reference for the design of protective coating in marine equipments.

Keywords tribo-corrosion performance, transition layers, DLC, amorphization

Synergistic Lubrication and Fracture Mechanisms of Composite Surface Textures

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The synergistic interaction of fibres implanted in grooves can enhance tribological behaviour of a contact interface. By comparing the tribological performance characteristics of structures with smooth surfaces (SSs) and grooved surfaces (GSs) and two composite textures with different flocking densities (FS1 and FS2), the friction mechanism of the sliding interface is revealed. The results indicate a 27.51% reduction in the coefficient of friction (COF) of FS2 sample compared to that of SS sample. Due to its buffering and lubricating effects, the synergistic interaction between the grooves and fibres effectively reduces the fluctuations in friction behaviour and improves surface morphology. Importantly, FS2 enhances the bearing capacity and barrier effect of the surface, thereby inhibiting the fracture behaviour. These results clarify the lubrication and fracture mechanisms of this composite surface textures.

Keywords nylon fibres, composite surface textures, lubrication, fracture behaviour

High Temperature Tribology of Inconel Alloy with B4C Reinforcement

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Inconel 625 and similar alloys have excellent thermal stability and are therefore often used in high temperature applications. These alloys are also used for surface protection of less wear resistant load-bearing structures. For deposition of thicker layers (~ 3 mm) a plasma transferred arc deposition (PTAD) is often used [1]. However, protective layers from pure HT alloys usually suffer from low wear resistance; this is why they are generally reinforced with ceramic particles. The goal of our work was to investigate the wear and mechanical properties of Nibasit 625 (similar to Inconel 625) layer with B4C particles as well as the effects of the B4C particle size and heat treatment. The Nibasit 625 alloy was deposited using PTAD device on AISI 304 substrates. Two different fractions of B4C powder were used: coarse (mean diameter 168 μm) and fine (mean diameter 67 μm). One sample with each B4C powder fraction was heat treated (8 hours at 720°C + 8 hours at 620°C). The wear resistance was measured using pin-on-disc tribometer against alumina ball at 25°C, 600°C and 750°C. The CoF of all samples was the highest at 25°C and it decreased slightly with higher temperature. The smaller B4C grain size resulted in much lower (~3x) wear rate at 750°C compared to pure Nibasit and the large grain size samples. SEM observations of the wear tracks on all samples revealed that the improved wear resistance was due to re-deposition of the Nibasit matrix on the B4C particles

Keywords high temperature tribology, wear, inconel alloys

The Formation of Low Friction Interface in Friction System Using Laser Textured Aluminum Alloy in Engine Oil at Low Temperature

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To improve fuel efficiency and reduce friction loss, the use of lightweight aluminum alloy and low-viscosity engine oil are being introduced into the sliding components of automobile (e.g., pistons and sliding bearings). But these trends result in aluminum adhesion and high friction. To solve this problem, we have proposed laser irradiation that can induce tribo chemical reaction between MoDTC and ZnDTP. This study will experimentally clarify the applicability of laser irradiation in low oil temperature conditions where additives are less likely to react.

Scans of a picosecond pulse laser were provided to the whole surfaces of aluminum disks. The energy density of laser irradiation was controlled from 40 J/cm^2 to 8084 J/cm^2. Friction tests were conducted using a ball-on-disk tribometer in a unidirectional sliding motion. The laser-irradiated aluminum disk was slid against a bearing steel ball in fully formulated engine oil. The sliding speed and load were fixed at 0.1 m/s, 15 N respectively. Oil temperature was controlled from -7ºC to 80ºC.

The friction test revealed that four friction modes could be classified based on the friction curves and the morphology of the ball wear scars depending on oil temperature and energy density. According to the mapping of occurrence conditions of each friction mode, an energy density threshold (40 J/cm^2 ≦ Ec ≦ 449 J/cm^2) exists for the initial running-in. In addition, an oil temperature threshold (25ºC ≦ Tc ≦ 60ºC) exists to sustain low friction toward the end. At high energy densities, even at low temperature conditions below Tc, friction was temporarily low (= 0.05 or less), but increased toward the end. EDX analysis on the ball wear scars revealed that ZnDTP-derived elements increased, and MoS_2-derived elements relatively decreased as friction increased. This fact suggest that Tc is a temperature threshold for promoting the MoS_2 formation reaction.

Keywords aluminum alloy, laser surface treatment, oil temperature

Universal Route to Uniform Nanocrystalline Metallic Cladding for Superior Strength-Plasticity and Wear Resistance

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Nanocrystalline (NC) metals possess high strength due to their ultrafine grain size, but the absence of strain hardening and limitation to a few micrometers in size have seriously hampered their widespread application for a long time. Here we propose a universal and facile strategy to solve these problems all at once, by exploiting the synergistic aspect of multi-component NC alloy and rapid electrical-current-activated sintering (RECAS) route. We demonstrate RECAS as an efficient way to achieve dense and robust claddings versatile in dimensions (i.e. ≥1mm in thickness), yet with uniform NC grain sizes. The prepared uniform NC CoCrNi medium entropy alloy cladding (MEAc) with millimeter-scale not only overcomes the strength-plasticity (yield strength of 5.2 gigapascals and a large compressive strain of 30 percent) trade-off by multiple partial dislocation mediated process, but also exhibits excellent wear resistance via strongly grain refinement effect and crack passivation ability. This research hit multiple challenges faced in NC cladding at once, which has significant guiding insights for the design, preparation and application of NC metals.

Keywords nanocrystalline alloy cladding, strength-plasticity, wear resistance

Comparison on Wear Behavior of Two Typical AlCoCrFeNi System High-Entropy Alloys

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High-entropy alloys (HEAs) possess a wide promising application in the fields of aviation, aerospace, nuclear energy and military hardware, among which AlCoCrFeNi system HEAs have become a hot research topic due to relatively low preparation cost and outstanding overall performance. In the present research, the wear behavior of two typical HEAs with different phase structures (one is an as-cast Al0.5CoCrFeNi HEA with face-centered cubic (FCC) main phase and the other is a high velocity oxy-fuel flame (HVOF) sprayed AlCoCrFeNi HEA coating with body-centered cubic (BCC) main phase) under harsh accelerated test conditions were investigated. Their quite distinct wear rate vs. friction frequency (or sliding velocity) curves (i.e., one is in V shape and the other is reverse V shape) are revealed and explained in terms of their microstructure evolution and wear mechanisms. The results also show that the HVOF sprayed AlCoCrFeNi coating exhibits more excellent wear resistance than the widely used hard chromium (Cr) coating, while the as-cast Al0.5CoCrFeNi alloy presents more superior anti-wear performance than the AlCoCrFeNi coating at lower sliding velocities. Furthermore, this work elucidated a general principle for anti-wear metallic coating design, which is of guiding significance for wear protection of moving mechanical components.

Keywords AlCoCrFeNi, high-entropy alloy, tribological properties, wear mechanism, wear resistance

Tribochemical Reaction for Continuous Low-Friction of Hydrogenated Carbon Nitride Coatings in Dry Environments – Effect of Water and Oxygen on the Tribochemical Reaction

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Hydrogenated carbon nitride (CN_x:H), a type of diamond-like carbon, is a promising coating material for achieving continuous low friction ($\mu<0.05$) in an unlubricated dry environment under optimal conditions. In a high-vacuum with less influence from environmental factors (oxygen, water, etc.), there is a lifetime of low friction owing to the transformation of a low-frictional carbonaceous interface resulting from the desorption of the hydrogen content of CNx:H. Conversely, the low-frictional interface continuously formed at the optimal oxygen concentration or relative humidity. Therefore, environmental oxygen and water molecules play important roles in the

continuous formation of the low-frictional interface. This study aims to clarify the tribochemical reactions of environmental oxygen and water, which influence the durability of low friction, through ball-on-disk friction tests of Si_3N_4/CN_x:H under dry conditions (nitrogen and vacuum) and chemical analysis of the friction interface.
As a result, the presence of water and oxygen above a critical molecular concentration in the friction environment was necessary to achieve the continuous formation of the low-frictional interface with Si_3N_4/CN_x:H. Conversely, at molecular concentrations below the critical levels in nitrogen atmosphere or vacuum, it exhibited the lifetime of low friction. Additionally, there was a correlation between their critical concentrations for continuous low friction. Even in low-vacuum environments with fewer water molecules, continuous low friction was achieved by increasing the oxygen concentration. TOF-SIMS analyses revealed that environmental water continuously reacted and chemisorbed as H and OH groups at the interface when it exhibited continuous low friction. Furthermore, environmental oxygen reacted not only on the friction interface but also with water and formed OH group reactions during the onset of continuous low friction. Therefore, continuous tribochemical reactions involving the mutual reactions of environmental water and oxygen are considered to contribute to the continuous formation of the low-frictional interface.

Keywords hydrogenated carbon nitride; tribochemical reaction; dry environment

Track 4: Tribo-chemistry and Lubricants

KEYNOTE:

Tribology Contributing to A Carbon-Neutral Society

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The Earth is confronting numerous severe environmental issues. Global warming and environmental pollution are escalating annually. How can tribology confront these challenges? A frequently posed question is the extent to which tribology can aid in resolving these problems. Over time, tribology has facilitated the advancement of various technologies, including enhancements in energy efficiency and durability in automobiles, household appliances, industrial machinery, and factory plants. These advancements have resulted in significant environmental enhancements, such as the removal of asbestos from automobile brake systems, the elimination of CFCs from air-conditioning refrigerants, and the eradication of lead from bearings.
To achieve a carbon-neutral society by 2050, tribology must contribute more than ever, focusing on furthering energy conservation and expanding renewable energy sources. For example, in the development of electric vehicles, achieving high-speed rotation of electric motors is a major technological challenge. To realize a corresponding reduction

gear system, urgent tasks include surface modification of high-speed gears and the development of low-viscosity lubricants. However, it is considered difficult to achieve this solely through the extension of existing knowledge and technology. While tribology is perceived as a macro phenomenon, its behavior is greatly influenced by localized and short-term surface phenomena. Therefore, to elucidate detailed mechanisms, it is necessary to accurately understand surface phenomena at the nanoscale and clarify their correlation with functional expression at the macro level. In this talk, we will discuss the importance and usefulness of in-situ observation methods for tribology research.

Keywords: Carbon-nuutral, In-situ observation, EV, Tribo-chemistry

INVITED:

Ascorbyl Palmitate Vitamin C, A New Additive for Environmentally-Acceptable Lubrication of Steel

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Fatty acids are eco-friendly, disposable, and, most importantly, they are a vital branch of organic friction modifier since fatty acids can improve the tribological performance of mineral oil and diesel fuels. This work proposes a new pathway to facilitate the lubricity of fatty acids and related additives by replacing the carboxylic group of fatty acids with a bigger ascorbic acid core, the vitamin C ester also called ascorbyl palmitate (AP).

AP well-known as nutrition pills and antioxidant agent in food has demonstrated excellent lubricity as an additive in PAO4 base oil. Adding 1 wt% AP in PAO4 drastically decreases CoF up to 66% and protects efficiently the steel surface from wear. Meanwhile, it shows a more vital friction reduction ability than conventional Mo-based additives and fatty acids, especially palmitic acid. Ascorbic acid core on AP optimizes palmitic acid lubricity by forming robust chemical both bidentate and monodentate C-O-Fe bonds on steel, increasing surface coverage rate. Protected by AP self-assembled layers, steel surfaces can also handle extreme contact conditions, pressure up to 2 GPa and temperature at150°C, with unmeasurable wear1. The demonstrated performance in conditions and with materials typical of industrial applications, suggests that an eco-friendly alternative to conventional additives as AP vitamin C is indeed possible in the future and can be easily implemented by borrowing natural molecules from pharmacopeia.

Keywords: Eco-friendly lubrication, sustainable friction and wear reduction

Study on The Structure-Activity Relationship of The Anti-Wear and Anti-Oxidation Properties of Plant Oils and Additives

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With the increasing emphasis on environmental protection, resource conservation, and sustainable development in human society, bio-based lubricants have the potential advantage to replace mineral-based lubricants. Starting from the main component of fatty acids in plant oils, a comprehensive performance evaluation of anti-wear and anti-oxidation properties of bio-based lubricant base oils was conducted by computer calculating. By using clustering and factor composite scores, a category of plant oils with the highest industrial application value was selected from 87 plant oil samples. Analyzing the anti-wear performance of 79 kinds of anti-wear additives in rapeseed oil through logistic regression revealed a significant impact of the amount and category of anti-wear additives on the anti-wear performance of rapeseed oil. Among six categories of anti-wear additives (phosphoric acid, formate ester, borate ester, thiazole, triazine derivative, and thiophene), phosphoric acid additives exhibited the best anti-wear performance while thiophene additives performed the worst. A random forest classification model for anti-wear additives was established, indicating that the presence of chemical structures containing P, O, N, S, heterocycles, and two or more methyl groups in the anti-wear additives can enhance the anti-wear performance of rapeseed oil. Data analysis and machine learning methods provide valuable insights and guidance for the selection and design of base oils and additives in bio-based lubricants.

Keywords: vegetable oil, additive, QSPR, anti-wear performance; oxidation stability

Alkyl-Phosphate Protic Ionic Liquid as A Green Lubricant for Heavy Duty Applications

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Ionic liquids, molten salts at room temperature, have demonstrated enhanced tribological performance due to high stability and molecular ordering. Within the vast range of ionic liquids with potential applications in tribology, novel protic ionic liquids, that can be obtained from sustainable sources and friendly processing methods, are emerging as appropriate contenders for a more environmentally friendly lubrication.

Notwithstanding, their interactions with contacting surfaces are not yet well understood, which is key to design low friction and wear systems for those instances where asperities meet.

In this paper, an alkyl-phosphate protic ionic liquid (APIL) which presents the key advantages of simple elaboration, low cost and containing bio-based material, has been examined. This APIL contains Di(2-ethylhexyl)-phosphoric acid (DEHPA) as the anionic part and the bio-based oleyl amine as the cation. The viscosity, thermal stability, and corrosive performance of the manufactured APIL were examined previous to the tribological investigation. The worn surface was characterised by scanning electron microscope (SEM), X-ray photoelectron spectroscopy (XPS) and Time-of-flight secondary ion mass spectrometry (ToF-SIMS) to resolve the wear mechanisms and tribochemistry.

Results confirmed that the APIL used in this study possesses good lubricity under reciprocating testing conditions. One reason for the good tribological performance is the high viscosity due to the strong interaction and high molecular ordering between the DEHPA and amine, which shifted the boundary regime for PAO6 to mixed lubrication. The tribo-film generated from APIL, composed of the deposited APIL, hydrocarbons and various forms of iron phosphate, further improves the tribological performance, compared to a high-viscosity synthetic base oil, PAO150. This study not only illustrated that the prepared APIL is a good lubricant candidate for heavy-duty engineering applications but also exhibits an excellent potential as a green lubricant additive.

Keywords: Ionic Liquids, ToF-SIMS, XPS

Phosphate-Based Poly(Ionic Liquid)S: The Preparation, Characterization and Evaluated as Potential Lubricant Additives

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Recently, the poly(ionic liquid)s (PILs) have attracted much attention duo to their unique thermal stability, mechanical robustness, durability, processibility and have found numerous applications in materials science, catalysis, separation, analytical chemistry, cell biology, electrochemistry, etc. However, there are few examples utilizing PILs as lubricant additives of synthetic oils or mineral oils.
With the aim to further exposed the potential as multifunctional lubricant additives of PILs, herein, a serious of poly(tertiary (protic) ammonium phosphate)-based

polymerized ionic liquids (PDS-P) were prepared, characterized and tested as potential viscosity improver and anti-friction, anti-wear additives of PAO10. As a result, PAO10 blends with PDS-P as additive not only improved the viscosity, viscosity index of PAO10, also enhanced its friction reduction and wear protection properties. In particular, compared with the copolymer (PDS) without ionic liquid moiety, introducing 5 wt % PDS-P to PAO10 could dramatically increase their extreme pressure bearing capacity (750 N vs 1550 N), high temperature lubrication (< 100 °C vs > 250 °C). The lubrication mechanism studies indicated that the phosphate moiety of PDS-P plays a crucial role in reducing friction and wear.
Later, in order to further improve the viscosity and viscosity index of PAO10 at high temperature, a novel chain transfer agent was synthesized and used to prepared PILs. The viscosity test results suggested that the special topology of polymers caused by the employment of chain transfer agent has a big influence on their viscosity improving property.
In summary, the prepared PILs not only showed excellent viscosity improvement and anti-friction, corrosive resistance properties, but also providing a new strategy to prepare multifunctional lubricant additives.

Keywords: poly(ionic liquid)s, viscosity improver, friction reduction, wear protection

KEYNOTE:

Beyond Friction: Multimodal Triboemission and Non-Trivial Pathways of Energy Dissipation

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The injection of concentrated mechanical energy into materials at a tribological interface activates several electronic and vibrational states, which trigger cascades of physical processes and chemical reactions. While these processes consume a small fraction of the total energy, they significantly impact the performance of tribological systems and the durability of solid and liquid lubricants. Some of these processes are accompanied by various kinds of emission including emission of gases, electrons and ions, radicals and atomic clusters, triboluminescence in a frequency range from radio waves to X-rays, acoustic and mechanical vibrations, and so on. Being born in the core of the tribological contact, triboemission carries precious information about the underlying mechanisms of energy dissipation, activation of the associated tribo-physical and tribochemical processes, and material response to applied stress and strain.
This work summarizes the results of our recent studies of triboemission of gases, triboelectrification and triboluminescence aimed at establishing links between triboemission and material degradation, both structural and chemical.
We address the following key questions and aspects:

- What can be measured and how can it be measured? – Technical, methodological and metrological aspects of experimental measuring.
- How the triboemission data can be interpreted? – Basic emission sources, mechanisms, emission kinetics and their connection to material properties and the experimental conditions.
- Phenomenological description of triboemission of gases: gas emission from metals, tribological coatings, and lubricants; operando characterization of tribochemical reactions;
- Phenomenological description of triboluminescence: basic mechanisms, the effect of environment, the influence of material properties and wear intensity.
- Potential applications. The research findings led us to the development of innovative methods for non-destructive in situ and real-time evaluation of integrity of tribological materials and coatings, characterization of tribochemical transformation of lubricants, as well as other characterization methods far beyond the tribology area.

Keywords: triboemission, tribochemistry, triboluminescence

Impact of Ammonia as a Marine Fuel on Cylinder Oils and System Oils

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Environmental standards are becoming increasingly stringent and the regulatory focus on maritime decarbonization is rapidly growing. These factors are driving infrastructural developments and technological advancements for alternative fuels, engine designs, and operating practices.

For several decades, heavy fuel oil (HFO) had been the dominant marine fuel for the shipping industry primarily because of its low cost, widespread availability, and developed infrastructure. The International Maritime Organization (IMO) has enacted progressively stricter regulations that limit marine fuel sulfur content and nitrogen oxides emissions, and its latest greenhouse gas (GHG) strategy includes an enhanced common objective to reach net-zero GHG emissions from international shipping by 2050, a commitment to ensure an uptake of alternative zero and near-zero GHG fuels by 2030, as well as indicative checkpoints for 2030 and 2040. These regulatory targets are pushing ship operators to change their operational practices, install onboard air pollution control devices, and diversify their fuel portfolios to incorporate alternative fuels. Ammonia is increasingly seen as an attractive future marine fuel for several reasons, one of which is its low carbon and emissions profile. Ammonia emits no carbon dioxide during combustion, making it a zero-carbon fuel when produced from renewable sources.

Lubricant technology plays a crucial role in ensuring that the use of these alternative fuels will not have detrimental impact on engine operability. Gulf Marine is conducting extensive studies to understand how ammonia as a marine fuel affects the performance of lubricants. This paper presents the key findings from Gulf Marine's investigations related to determining the impact of ammonia on marine cylinder oils and system oils via artificial ageing, and subsequent chemical analysis as well as performance tests. Amidst bunkering uncertainty and complexity, Gulf Marine is fully committed to providing optimal lubricant solutions to enable the use of alternative fuels such as ammonia for maritime decarbonization.

Keywords: Maritime Decarbonization, Alternative Fuels, Lubricant Technology

Enhanced Gear Durability by Lubricant Technology in application to Transaxle for Electric Vehicles

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The main performance requirements of lubricant oils for E-Axle (Transaxle for Electric Vehicles) are to improve transmission efficiency, and to ensure durability for gear and bearing components. First, the torque loss was measured by using our original back-to-back gear test rig varying lubricant viscosity (3 to 7 mm^2/s at 100 degree C) and input gear speed up to 50 m/s. Transmission fluids with lower viscosity was found to decrease gear and bearing loss in the whole test rig.
However, it is necessary to consider a negative impact on the durability for gear components. The gear pitting fatigue life by lubricants was evaluated by using a FZG (Forshungsstelle fur Zahnrader and Getriebebau) gear test rig. The gear fatigue life decreased with lowing viscosity in proportion to the viscosity $^{0.7}$, which could be influenced by the difference in the oil film thickness caluculated under EHD lubrication regime.
As to impact of lubricant additive, there was a significant difference in the fatigue life by the tested extreme pressure agents. In all cases of test gears, a significant micropitting was observed in the pinion tooth dedendum. These pits propagated to macropitting with a surface originated fatigue mode. Very interestingly, the cross section in the gear interface by using surface analyses in case of the longer life sample revealed that tribofilm derived from extreme pressure agent was formed with 100-200 nm thickness. This thicker tribofilm could minimize abrasion and adhesion in the contact regions below the pitch line on the pinion gear to prevent from strain localization to generating micropitting, with a longer fatigue life. These results would suggest an importance of lubricant additive technology in case of applying lower viscosity fluids to transaxle system.

Keywords: E-Axle, Gear Fatigure Life, Lubricants

Tribological Properties of Hybrid Electric Vehicle Engine Oil After Emulsification

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With the development of increased vehicle performance and fuel economy, electric vehicles have become popular. Hybrid electric vehicles have become the most popular type. However, due to the lower frequency of use of hybrid electric vehicle engines, water can accumulate in the crankcase, causing oil emulsification and affecting lubrication performance and service life. This paper presents a systematic study of the tribological properties of hybrid electric vehicle engine oil with varying water concentrations. It was found that the film-forming ability has little influence at room temperature. The lubricity and wear resistance of emulsified oil became worse as the water concentration increased. The effect of water on the rubbing surface was investigated by XPS, SEM, and EDS. It was found that water increased the polarity of additives. The access of the ZDDP additive to the wear surface is limited in order to reduce the polymerization into long chain phosphate. Simultaneously, water disrupts the interfacial equilibrium causing calcium sulfonate and over-based magnesium sulfonate to separate from the system. The lubricity of engine oil is influenced by the stability of dispersions.

Keywords: emulsion oil, film thickness, XPS, detergent additives, tribological properties, hybrid electric vehicle engine oil.

Atomic and Molecular Scale Simulations Of Liquid Lubricants And Additives: From Phenomena To Mechanisms

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Advanced experiment technologies and characterization methods make the significant progress in tribological field, exploring and unraveling phenomena, behaviors, and mechanisms of nanotribology, however, are still full of challenges when only considering from experimental viewpoint. Contrarily, molecular dynamics simulations have provided unique insights into the nanoscale behaviors and phenomena in tribology, particularly for lubricants and various additives under shear. This report discusses the history or development of molecular dynamics simulation and its progression from a tool to corroborate theories of the liquid state, to an instrument that can directly evaluate important fluid properties, towards a potential design tool in tribology. The key methodological advances which have allowed this evolution are also highlighted. Here, we mainly discuss the important behaviors of lubricants, friction modifiers, and nanometer additives in boundary and mixed lubrication conditions, such as

adsorption/desorption, self-assembly, agglomeration, dispersion, shear process, as well as the lubricating or failure mechanism in various liquid lubricating systems. Finally, we present our research findings on the lubricating systems. The future outlook of atomic and molecular scale simulations in tribology, including the inclusion of chemical reactivity for additives, and coupling to machine learning method for the selection and design of novel high-performance lubricants and additives, is also briefly discussed.

Keywords: Molecular dynamics simulation, Lubricants and additives, Lubricating phenomena, Lubricating mechanism

INVITED

High Temperature Lubricity and Anti-Oxidation of Silicate Glass for Hot Metal Forming

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Lubrication is vital in enabling the key machinery contact components to operate durably and reliably at extremely high temperatures for space aviation and metal forming. This work reports the potential application of environmentally friendly silicate glass as high-temperature lubricant for hot metal rolling of steel. Its performance was evaluated by the ball-on-disc tribo-tests at high-temperatures. Significant reduction of friction and oxidation was achieved, which was attributed to the silicate melt and hierarchy layered structure containing crystalline that increase the load carrying capability. This structure also reduces the diffusion of Fe2+/Fe3+ and O2- through physical isolation and ion shielding by the top Fe2O3/Cr2O3 as well as the dendrites grown by epitaxy, contributing to excellent oxidation resistance.

Keywords: High temperature lubricant, Silicate glass, Tribo-chemistry

Load and Velocity Boundaries of Oil-Based Superlubricity Using 1,3-Diketone

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Since the concept of "superlubricity" was first proposed in 1990, this novel lubrication state with ultralow friction (COF<0.01) has been considered an attractive technique to improve energy efficiency and service life of mechanical devices. To seek appropriate applications in industry, it is necessary to clarify the critical operating conditions of the superlubricity systems and understand the failure mechanism. 1,3-Diketone fluid is the first macroscopic oil-based superlubricity achieved on steel surfaces under an ambient

atmosphere. In this work, the superlubricity region of 1,3-diketone oil EPND (1-(4-ethyl phenyl) nonane-1,3-dione) on steel surfaces was identified by performing a series of ball-on-disk rotation friction tests under various normal loads and sliding velocities. The results show that the achievement of superlubricity requires a sufficient running-in process to realize surface conformity. Meanwhile, it is necessary to avoid large wear debris and oil starvation during the running-in process. Moreover, based on the discovered superlubricity failure mechanism, this work proposed two methods to expand the superlubricity region. By using an optimized running-in approach or incorporating nano-additives, the superlubricity of EPND could break through its original boundaries. The results of this study provide guidance for enhancing the oil-based superlubricity system with higher efficiency and wider applicability.

Keywords: oil-based superlubricity, 1,3-diketone fluid, operating conditions, running-in, nano-additives

Mussel-Inspired Multifunctional Carboxylic Ester Additives with Super-Robust Lubrication Performances and Super-Long Lubrication Life Under Extreme Conditions

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The development of high-performance lubricant additives has been driven by increasing industrial demand and environmental concerns. Here, inspired by mussels and based on frictional interface interaction, we design a new green lubricating oil additive without phosphorus and sulfur, octadecyl gallate (OG), which is suitable for lubrication under extreme working conditions. When used as lubrication additive, it can reduce the friction coefficient by 67% and wear volume by 97%. Even under extreme conditions such as high temperature (200 °C), heavy load (500 N) and low speed (1 Hz), the lubricant additive still has good anti-friction and anti-wear performance. In particular, the OG-based lubricant additive has excellent lubrication stability with a service life of more than 1,080,000 cycles, which exceeds the results of previous state-of-the-art organic and inorganic lubrication additives. The excellent tribological properties are attributed to the fact that OG lubrication additive can in-situ generate an amorphous carbon friction film on the surface of metal friction pairs. The formation of this friction film is due to the high efficiency adsorption of OG additive on the surface of the friction pair and its low reaction energy. Under the combined action of mechanical stress and thermal activation, the OG additive is transformed into an amorphous carbon friction film with low modulus, low shear and low adhesion, which helps to achieve ultra-robust lubrication performance under extreme working conditions.

Keywords: lubrication under extreme conditions, antifriction and antiwear properties,

tribochemical reaction

The Influence of Polydiethylsiloxane (PDES) Concentration on The Tribolfilm of Chlorophenyl Silicone Oil (CPSO) under High-Temperature Lubrication

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As pivotal structural component, steels operating at high temperatures play a vital role in promoting the development of advanced equipment technology. Enduring and efficient lubricants are critical bottleneck for the construction of high-temperature frictional subsystems. Polydiethylsiloxane oil (PDES) significantly reduces the coefficient of friction (COF) (9.80-16.74%) and wear rate (28.95-54.59%) in the Si3N4-8Cr4Mo4V system without sulfur and phosphorus anti-wear additives at 250 ºC. With only 1 wt% PDES, there is a remarkable 28.95% wear rate reduction in the Si3N4-8Cr4Mo4V frictional system. The enhanced lubrication performance come from the Si-O tribofilm at lower PDES concentrations (1-15 wt%). Once exceeding a PDES concentration of 30 wt%, the as-formed Si-O tribofilm transitions to a Fe-Mo compound film, exhibiting superior friction reduction and wear resistance properties.

Keywords: tribofilm, anti-wear, high temperature

Corrosion and Tribological properties of multilayer ta-C/ta-C: Ta coatings

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In this study, multilayer tetrahedral amorphous carbon/tantalum-doped tetrahedral amorphous carbon (ta-C/ta-C: Ta) coatings with various total thicknesses (300, 600, and 1000 nm) and layer thickness ratios (1:0.5, 1:1, and 1:2) between the ta-C layer and the ta-C: Ta layer were prepared using Ion Beam Assisted-Filtered Arc Deposition. This study focused on the static corrosion resistance and tribological performance of the multilayer ta-C/ta-C: Ta coatings in a 3.5 wt.% NaCl solution. The static corrosion resistance of the ta-C/ta-C: Ta coating was found to be dependent on the Ta-O/Ta-C ratio of the coating surface. The Ta-O/Ta-C ratio exhibited an inverse correlation with the corrosion current Log i. The lowest wear rate of 7×10-8 mm3/Nm in the 3.5 wt.% NaCl solution was obtained from the coating with a total thickness of 300 nm. The wear rate of the coatings was found to be dependent on the corrosive defect density of the wear scar. After the friction and wear process in the 3.5 wt.% NaCl solution, the Log i

of the wear scar showed a positive correlation with the corrosive defect density. A decreased sp2/sp3 ratio and the formation of tantalum oxide on the wear scar indicated the lowest Log i and corrosive defect density on the wear scar of the coating with a total thickness of 300 nm.

Keywords: tantalum-doped carbon, corrosion

Effect of Chlorine-free Refrigerant Environment on Lubrication Property and Tribofilm Formation on Copper Alloy Surfaces

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In response to environmental issues such as ozone depletion and global warming, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) refrigerants, which have been conventionally used in air conditioners and other refrigeration equipment, are being replaced by hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs). HFCs and HFOs have low ozone depletion potential, and HFOs in particular are reported to be superior in terms of global warming potential. However, while CFC and HCFC refrigerants are reported to exhibit effective tribological properties due to the presence of chlorine atoms in their molecules, such effects are not expected for HFC and HFO refrigerants that do not contain chlorine atoms. Therefore, this study focused on HFC-32, which is currently being used, and the more eco-friendly HFO-1234yf. In order to investigate the tribological properties of copper alloy surfaces in each refrigerant, friction tests and surface analyses were conducted in dry condition and oil lubrication in refrigerant environments. Polyol ester was used as the base oil of the lubricant, and the three kinds of phosphoric acid additives, triphenyl phosphate (TPP), triphenyl phosphorothionate (TPPT) and tricresyl phosphate (TCP), which are commonly used as a sliding surface additive in refrigeration equipment, were also added to investigate the effect. As a result, it was confirmed that the friction coefficient was lower in the HFO-1234yf environment than in the HFC-32 environment, and that the former had better wear resistance. The phosphoric acid additives also showed higher wear resistance even in the refrigerant environment.

Keywords: Refrigerant, Tribofilm, Additive

Mechanochemistry in Lubrication of Molecule only contain C, H and O

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Considering environment protection, in recent decades, great efforts are contributed to reduce the amount of pollutive antiwear additives of sulphur, phosphorus and metal in lubricants. But this attempt was difficult to complete, because the antiwear effect was relied on those sulphur, phosphorus and metal contained additives. Those additives were very effective to generate reaction products (called "tribofilm") on friction pairs to reduce wear. Molecules without pollutive elements, like hydrocarbon liquids, were usually considered inactive in mechano-chemistry during lubrication. In traditional opinions, the role of hydrocarbon liquids were solvents of additives, friction heat transformers, and the bearers of "hydrodynamic effect" (an effect based on its viscosity), but not a reactive reagent. Contrary to this traditional recognition, in this study, we found that general hydrocarbon liquids could be very chemically active under friction. Under certain working conditions, it is even more active than the most wildly used antiwear additives ZDDP (sulphur, phosphorus and metal contained). A pure hydrocarbon liquids named PAO8 could generate antiwear tribofilm within seconds, while ZDDP often took minutes. The measured activation energy (Ea) of PAO8 was ~42 kJ/mol, lower than ZDDP that ~77 kJ/mol (the Ea of ZDDP reported in Science, 2015). The measured activation volume was several Å3, corresponded with the volume of a chain segment of hydrocarbon. Because of the tribofilm generated from PAO8, the wear rate of PAO8 reduced 99%, from 10-6 mm3/N·m to 10-8 mm3/N·m. The tribochemistry of hydrocarbon liquids requires secondary or tertiary carbon. Based on this, the breaking of the carbon-carbon bond and the formation of carbon radicals should be the key steps of the tribofilm generation. Stable radicals meant weaker carbon-carbon bonds therefore activity. Therefore, three kinds of additives only contained carbon, oxygen and hydrogen was designed, and their anti-wear activities were verified by experiments. Our results could subvert the idea of inactive hydrocarbon liquids, and showed potential on developing environmental-friendly lubricants.

Key Words Tribochemistry; Hydrocarbon; Additive; Antiwear; Kinetic; Activation energy; Radical

Track 5: Biotribology and Biomimetics

KEYNOTE:

Low Energy Biological Recognition and Biomimetic Anti-interference Technology

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The sensor is an important tool for obtaining external information, which has received great attention in the fields of electronic skin, human-computer interaction, precision equipment, and so on. Among numerous sensors, flexible mechanosensors are one of the main research directions. At present, the problem faced by flexible mechanosensor is that when there is low-frequency noise interference and the useful signal is extremely weak, the useful signal cannot be decoupled. This not only complicates subsequent information processing but also results in high energy consumption due to the need to process a large amount of irrelevant information. Therefore, it is important to find innovative methods to design sensors that can reduce noise interference. After billions of years of evolution, the fusion of organisms and nature has become perfect. This report takes the scorpion as its biological prototype. Through detailed neurobiology and biomechanical experiments, the inherent mechanism of scorpions in eliminating noise interference and achieving low-power recognition of biological-related information in complex perceptual environments has been revealed. Based on this, corresponding biomimetic design and manufacturing of sensors have been carried out.

INVITED:

Influence of Neutral and Cationised Phytoglycogen Nanoparticles on Cartilage and Ocular Lubrication

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Introduction: Biolubrication is crucial for proper functioning of many areas in the human body. Compromised lubrication plays a role in various disorders (e.g. osteoarthritis (OA), dry eyes disease (DED) and xerostomia). Currently, no treatment exists to cure these disorders. Previous studies have shown the possibility to restore biolubrication through bioactive molecules. This study aims to investigate the lubrication properties of modified and unmodified phytoglycogen nanoparticles (PGNPs) in several systems corresponding to systems in the human body.

Methods: PGNPs were modified to form cationised PGNPs (CPGNPs), where the hydroxyl groups were modified into quaternary amine groups. The quartz crystal microbalance with dissipation (QCM-D) was used to investigate their adhesion to collagen type II, saliva and mucin corresponding to the articular cartilage, oral mucosa and cornea respectively. The biotribological properties were measured on cartilage - glass and eye-eyelid systems (Fig.1).

Results: The PGNPs showed strong adhesion on cartilage, whilst CPGNPs showed strong adhesion on cartilage and ocular surface. Overall, we observed stronger adhesion properties for CPGNPs compared to PGNPs in both tested systems (synovial and ocular). Both particle types showed great lubrication properties in the cartilage - glass model simulating the synovial systems. Overall, the CPGNPs showed greater lubrication properties than PGNPs (Fig. 2).

Conclusion: PGNPs showed great adhesion and lubrication properties in tested systems.

The particles, therefore, show great potential towards a possible implementation in the treatment of osteoarthritis.

Mechanical Robustness Hydrogel with Lubrication Commensurate with Articular Cartilage

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Hydrogels have been extensively explored as artificial cartilage candidate due to special soft and wet properties. In this case, hydrogels with enhanced lubrication properties while maintaining mechanical strength and load-bearing capacity similar to articular cartilage is still needed. To be more specific, we propose a robust yet slippery poly (vinyl alcohol)/chitosan (PVA/CS) hydrogel with dual-physically crosslinked networks by harnessing freeze-thawing, salting-out, annealing, and rehydration. The mechanical properties of slippery PVA/CS hydrogels can be regulated over a wide range by altering the annealing temperature and PVA/CS proportion. The optimized hydrogel exhibits high mechanical properties with tensile strength of ~18 MPa at strain of 550%, compression strength of ~11 MPa at small strain of 39%, and outstanding toughness and anti-fatigue. Moreover, the bearing capacity to contact stress can be ameliorated by varying the annealing temperature, which in turn can custom-tailor the lubrication performance of slippery PVA/CS hydrogels. The as-constructed slippery PVA/CS hydrogel that combines high load-bearing (7.7 MPa), low friction (0.048), and anti-wear (1.0 × 105 reciprocating cycles) is comparable to natural articular cartilage. As an application paradigm, numerous biological soft tissue load-bearing substitutes with lubrication function, such as meniscus, knee pads, joint prostheses, and articular cartilage, were constructed by harnessing PVA/CS hydrogels and template casting methods. It's therefore believed that the biocompatible cartilage-like slippery hydrogel opens innovative scenarios for developing cartilage-mimicking water-lubricated coating and biomedical implants with satisfactory load-bearing and lubrication performance.

Keywords: Slippery hydrogel, Bio-lubrication, Articular Cartilage

KEYNOTE:

Biomimetic on High Frictional Pads Design: From Biology Study to Engineering Applications

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Many creatures adhere on vertical or inverted substrates and have the ability to move

in the ubiquitous three-dimensional space. Adhesive materials and structure inspired by beetle's pads have many potential applications. Here we reported our studies from morphology of insect's high frictional pads, bio-inspired mechanical design, and more importantly the applications in chip fabrication procedure.
Pads of the insects need high friction performance when they jump from or land to the substrate. Those performances result from the morphology and structure of the pads and also the characters of the materials. Those functions also needed in many applications. During flight in Chinese Space Station, astronauts are flying in weightless situation, which let side effect to the health because there is no force stimulation the muscles and this situation make the operation very difficult for the hand are required to hold its body. Here we proposed an adhesive shoe to make them adhere on the surface of space station, which provide a possibility to exercise the flexor of leg by adhesive force stimulating.
On the other hands, many industrial applications need high frictional contact pads. Such as in chip manufacture procedure, high frictional contact pads are important to make the transferring higher efficiency. Inspired by the micro-structure of locust pads, we designed soft curved pads, and compare the shear force provided by the pads and the plan pads. The results show that bionic designed soft curved pads express excellent performance, not only high shear forces, but also contact adaptivity than the others. The friction coefficient as high as 55.6 under low normal forces.

Keywords: bio-inspired high friction pads, bio-inspired adhesive shoe

Frequency Modulation Effect of Fingerprints Mediates The Sensitive Perception

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When the fingers run over the surface of an object, its information about geometry, mechanical and material properties can be easily and sensitively perceived. Mechanoreceptors especially Pacinian afferents are widely believed to convey the generated vibrations enhanced by fingerprints. However, as the afferents have very narrow range of frequency sensitivity, how do they convey features of natural surfaces that is randomly distributed and generate a broad spectrum of frequencies? Here, we illustrate the way of frequency modulation when fingerprint touches textures with different scales. Biomimetic fingerprints are used to scan on coarse and fine textures. For coarse textures, their intrinsic low-frequency does not lie within the sensitive range of Pacinian corpuscles, making them less perceptible. However, attributed to the interaction with fingerprints, a high-frequency that lies exactly in the sensitive range is simultaneously elicited. Moreover, for fine textures, when the intrinsic frequency is out of and higher than the sensitive range of frequency, a relatively lower frequency falls exactly in this sensitive range is induced. The frequency modulation effect of

fingerprints is further elucidated using the models representing the interaction between fingerprints and textures, which is demonstrated on random surfaces. We show the unification of sensitive perceptive mechanisms of mechanoreceptors on both coarse and fine textures, mediated by the frequency modulation effect of fingerprints. Our results are of great importance for restoring the sensory capabilities to people, and for the development of advanced prosthetic skin, human-machine interaction and robotic sensation and intelligence.

Keywords: Tactile perception, Fingerprints, Frequency modulation

Prediction on The Medial Knee Contact Force in Patients with Knee Valgus Using Transfer Learning Approaches

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Polyethylene wear and related problems are the leading cause of knee prosthetic revisions. The load condition of the postoperative knee joint is a key factor in determining the wear behavior of the prosthesis, but it is still difficult to measure knee contact force (KCF) experimentally. Machine learning can be used to predict tibiofemoral compartment contact forces. However, anthropometric differences between individuals make the accurate predictions challenging. The purpose of this study was to develop transfer learning models to predict the medial KCF of patients with knee valgus in rehabilitation gaits. Four subjects with instrumented tibial prostheses were considered, including one with knee valgus and three with normal knee joint alignment. Two transfer learning models were proposed: a fine-tuning model and an adaptive model. In particular, a synchronization method for extracting experimental data in a complete gait cycle was developed, since different types of experimental data have different sampling frequencies. The transfer learning models were pre-trained by the experiment data of patients with normal knee joint alignment, and re-trained by the data of the patient with knee valgus. Predictions of the transfer learning models and traditional machine learning model were validated against the in vivo measurements. The proposed transfer learning models were tested within two levels: the single subject (Level 1) and multiple subjects (Level 2). The results show that the two transfer learning models could more accurately predict the medial KCF of patients with knee valgus than the traditional machine learning model. The performance of the fine-tuning model is better than that of the adaptive model. Compared with the traditional machine learning and inverse dynamics analysis, transfer learning represents a much easier and more accurate method. It can be introduced to help clinicians validate and adjust the rehabilitation gait for specific patients.

Keywords: Knee contact force, Transfer learning, Knee valgus

INVITED:

Biological Membranes and Microcirculation of Organs and Artificial Organs

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In the process of substance exchange between organs and blood, biological membranes and microcirculation networks play crucial roles. Biological membranes serve not only as mediums and barriers for substance exchange but their microstructures also directly influence the transfer processes. Additionally, scale effects and interfacial phenomena within microcirculation dictate blood flow patterns, which are essential for sustaining vital functions of organs. From an interdisciplinary perspective of medicine and engineering, this paper initially outlines the functions of biological membranes in key organs such as the lungs, kidneys, liver, and spleen, emphasizing their central roles in gas exchange, substance filtration, and biochemical reactions. Subsequently, this study delves into the impact of scale and interfacial effects in microcirculation on blood flow and substance exchange. By precisely understanding the microstructures of biological membranes and thoroughly analyzing the patterns of microcirculation, this paper reveals an efficient pathway for the development of bioinspired micro-scale and macro-scale medical devices, moving from physiological functions to micro-mechanisms and further to practical applications in artificial organs.

Keywords: biological membranes, microcirculation, bioinspired medical devices

3D-printed PEEK Scaffold Embedded with Uhmwpe Provides Excellent Mechanical Properties, Wear Resistance and Biocompatibility for Small Joint Implant Applications

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Research scope: Metatarsophalangeal joints (MTPJs) replacement is strictly troubled by frictional wear, which is the main cause of prosthesis failure. Inspired by the composite structure and lubrication mechanism of natural joints, this work proposes a “lubrication enhancement and friction reduction” strategy, in which artificial MTPJs are modified with hyaluronic acid (HA) and its derivatives solidly enhance lubrication and reduce wear.

Principal findings: HA macromolecules are encapsulated inside the ultra-high molecular weight polyethylene (UHMWPE) matrix as a lubrication layer, which is combined with a polyether ether ketone (PEEK) support layer to form a soft-hard composite material structure mimicking the composite structure of natural articular cartilage (denoted as “UHMWPE (HA)-PEEK artificial MTPJs”). Mechanical bonding

between porous UHMWPE and PEEK support is achieved by the hot compression molding method. Reversible silylation of HA is done to shield its hydrophilic groups, followed by cross-linking and hydrolysis to restore its hydrophilicity. Finally, a secondary compression molding is done at a lower temperature to obtain UHMWPE (HA)-PEEK artificial MTPJs. The friction test results show that compared with dense UHMWPE, UHMWPE (HA)-PEEK can reduce the coefficient of friction by 31.5% and exhibit better lubrication stability, with the lowest coefficient of friction of 0.041. In addition, this composite material demonstrates satisfying in-vivo and in-vitro biocompatibility, and the fracture around the implantation site can be healed within 6 weeks to achieve implant fixation, which is promising for clinical applications.
Conclusion: Inspired by the composite structure and lubrication mechanism of natural joints, a life extension strategy of lubrication enhancement and friction reduction was proposed to modify the matrix material using HA and its derivatives. This work shall provide a theoretical reference for the study of life-extension modification of artificial joint materials based on lubrication and friction reduction strategies.

Keywords: artificial metatarsophalangeal joint, PEEK, hyaluronic acid

Biomimetic Artificial Cartilage in A Beagle Dog Model Artificial Joint Application

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Articular cartilage is an anisotropic composite structure characterized by a gradual increase in elastic modulus from the surface to the interior. In this study, we designed a biomimetic multilayer composite structure that mimics cartilage. To accurately simulate the structure of natural cartilage, we selected polyether ether ketone (PEEK) as the calcified layer and sulfonated PEEK (SPEEK) for the deep layer. Two hydrogel layers with different moduli were prepared on the surface, achieving a structure consistent with that of natural cartilage, facilitating its practical application. We verified the role of the soft surface and hard deep layers in improving friction performance. The reasons for stable low friction (COF ~ 0.016) and low wear (2.1E-7 mg/cycle) were explained from three aspects: boundary lubrication, interstitial fluid pressurization, and gradient load bearing. Next, we demonstrated its biocompatibility and lack of immunological rejection through cell experiment and subcutaneous experiment in rats. By reconstructing and 3D printing the PEEK joint of a beagle dog's temporomandibular joint (TMJ), we prepared the biomimetic structure on its surface and verified it using an animal model. After six-month, animal experiments showed that the structure exhibited almost no wear and no signs of inflammatory response. This work demonstrates that the designed material and structure exhibit excellent tribological performance and favorable biological evaluation, indicating its potential for practical clinical applications.

Keywords: biomimetic, bone substitutes, artificial cartilage, friction, wear

Contact Mechanics and Edge Loading of UHMWPE Elevated-rim Liner for Artificial Hip Joints

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2. The General Hospital of Western Theater Command of PLA, China

Edge loading (EL) of the liner edge after total hip arthroplasty not only increases the risk of dislocation but also increases frictional wear of the prostheses. The occurrence of EL is highly related to the mounting position of the prostheses, the geometric design, and the patient's movement status. In this study, we developed a finite element analysis model of elevated-rim liner contact mechanics and hip joint EL under gait loading based on a metal-on-polyethylene contact bearing. Four gaits (normal walking, ascending stairs, descending stairs, and deep squatting) common to the patient's daily life were used as kinetic inputs to the finite element model. After finite element mesh sensitivity analyses, mechanical results such as contact stresses, EL, EL duration, equivalent plastic strain, and volume of the equivalent plastic strain of the elevated-rim liner were investigated. The equivalent plastic strain of the elevated-rim liner, the volume in which plastic deformation occurs, and the EL of the elevated-rim liner and its duration all increase with the radiographic inclination and anteversion of the acetabular cup. Compared with the other three gaits, the deep squatting gait is more likely to cause plastic deformation of the liner and consequently the most damage to the liner. Therefore, patients should avoid movements with high flexion after total hip arthroplasty. Placing the elevated rim of the liner on the posterosuperior side of the body and the radiographic inclination of the acetabular cup no less than 50 can avoid EL and significantly reduce the plastic strain of the liner. Total hip arthroplasty should consider not only the patient's postoperative impingement-free range of motion but also the mechanical condition of the patient's postoperative prostheses, thus prolonging the life of the prostheses.

Keywords: contact mechanics, artificial hip joint, edge loading

Track 6: Nanotribology and Superlubricity

KEYNOTE

Progress and Challenges in Atomic Layer Manufacturing

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Chips are the core cornerstone of high-end manufacturing. Carrying out the basic research on the sub-nano precision manufacturing of the chip surface is of great significance for breaking through the "neck" problem of the development of high-end chip. In this talk, the atomic scale manufacturing is proposed. As one of the main contents in atomic scale manufacturing, the mechanism and application of atomic layer manufacturing are discussed. The research team revealed the atomic removal mechanism and energy dissipation mechanism, built the tribochemical energy composite removal model, realized the limit precision fabrication of silicon surface, achieved the controllable fabrication of the edge structures in two-dimensional materials, successfully developed the chip heterogeneous surface chemical mechanical polishing technology. Relevant research has provided effective strategies for the fabrication of two-dimensional nanodevices and development of chemical mechanical polishing equipment.

Keywords atomic scale manufacturing, atomic removal, tribochemistry

KEYNOTE

Origin of H-DLC Superlubricity

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Hydrogenated diamond carbon (H-DLC) is produced as a ‘coating’ through plasma-enhanced chemical vapor deposition. H-DLC is relatively hard and well-known to exhibit superlubricity. Is superlubricity an intrinsic property of the H-DLC? This paper argues that H-DLC is not intrinsically superlubricious; instead, it has the perfect structure that allows transitioning the interface region to a superlubicious structure upon frictional shear in proper conditions. Thus, its superlubricity is an extrinsic property. This argument is made by comparing the friction behaviors of three allotropes of carbon materials – graphite, amorphous carbon, and diamond – and the environment sensitivity and run-in behavior of H-DLC friction.

Keywords superlubricity, diamond-like carbon (DLC)

Establishment and Optimization of Slurry System for Heterogeneous Materials during Advanced Cobalt Interconnects CMP Process

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Metallization scheme of interconnects in middle of the line and back end of the line has become one of the primary limiting factors of performance and yield for the advanced semiconductor manufacturing where technology nodes are lower than 7 nm. Multiple material systems are being considered by the industry as promising candidates to replace the conventional tungsten stack and copper (Cu) wiring metal, where cobalt (Co) presents the most important advantages on scaling contact resistance, thinner barrier layer, and higher electro-migration reliability. Performing a chemical mechanical polishing (CMP) process for Cu interconnect metallization with Co diffusion barrier layer is well developed. However, the research on CMP process and associated polishing slurry system for Co as a novel interconnect wiring metal for sub-7 nm semiconductor device nodes, is still in its infancy.

Generally, the CMP process for Co interconnects can be mainly divided into two steps, consisting of rapid removal of bulk Co at a material removal rate of greater than 2000 Å/min and smooth polishing of heterogeneous materials (Co/titanium/titanium nitride/dielectric) at a low Co MRR with a high removal selectivity between barrier/dielectric and Co. Furthermore, several aspects during Co CMP process demand to be paid attention, involving galvanic corrosion, number of particle residues, and surface qualities.

In this study, the establishment and optimization process of polishing slurry system for advanced Co interconnects have been presented on the foundation of a variety of mechanism analysis, including electrochemical survey, X-ray photoelectron spectroscopy measurement, surface wettability characterization, and adsorption isotherm calculation. As application verification, the final proposed CMP slurries for Co interconnects demonstrate the satisfactory material removal rates, excellent polished surface qualities, minimized particle residues, and flawless microstructures without galvanic corrosion. Furthermore, patterned wafers and 12-inches production-level wafers were employed to validate the performance of our proposed slurries.

Keywords chemical mechanical polishing, cobalt interconnects, heterogeneous materials

Metal Thickness Measurement System with Coaxial Triple-Coil Sensor Based on Eddy-Current Method for Chemical Mechanical Polishing

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The eddy-current method has been employed to realize the real-time measurement of thickness distribution and polishing endpoint detection of metal films during the metal Chemical Mechanical Polishing (CMP) process. However, accuracy and sensitivity in thickness measurement can be significantly impacted by a variation in lift-off distance (about 3.5 mm), attributable to the progressive wear of the polishing pad. This paper proposes a novel triple-coil sensor system, integrated with an alternating current bridge and designed for high-precision metal film thickness measurement. Subsequently, the measurement performance of the bridge output voltage was scrutinized using a theoretical model and a trans-dimensional finite element analysis model of electromagnetic fields and circuit coupling. The correlations between the amplitude, phase, and the ratio of the real part to the imaginary part of the output voltage, in context with film thickness, were determined at assorted excitation frequencies and lift-off distances. Both theoretical equations and simulation results affirmed that the phase and ratio were more resistant to lift-off distance variations than the amplitude, and a linear relationship was identified between the ratio and film thickness. Furthermore, the thickness measurement performance of the amplitude and phase, when the triple-coil was imbalanced, was dissected via numerical simulation. A profound understanding of the proposed system was provided and beneficial for the practical applications in real-time thickness measurements of metal films during metal CMP process.

Keywords chemical mechanical polishing; eddy-current; lift-off distance; triple-coil

Classification of Material Removal Modes in Chemical Mechanical Polishing

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Chemical mechanical polishing (CMP) has been widely used to achieve local and global planarization of wafers for the semiconductor manufacturing industry. With the rapid development of chips, the number of materials needed to be polished significantly increases. Take logic chips for example, with the feature size shrinking to 7 nm and smaller, the number of materials required to be polished reaches more than 10. Moreover, the number of materials needed to be polished simultaneously on the heterogeneous surface can reach 4~5, such as Cu/Ru/Ta/TaN/low-k. Meanwhile, defects need to be stringently controlled, like dishing. However, different materials vary significantly in chemical and mechanical properties, making it difficult to swiftly adapt the CMP performance, especially for the heterogeneous surface containing multiple materials. Accordingly, the study aimed to classify the material removal mechanism from the tribology perspective. Metal CMP can be regarded as a nanoscale corrosive wear process. Two material removal modes were proposed based on the primary wear mechanisms between the abrasive and the sample surface in CMP: mechanical plowing (Cu, Co, and Ni) vs. chemical bonding (Ta, Ru, and Ti). Moreover, the corresponding

regulation methods of the CMP performance were developed. For mechanical plowing, CMP can be regulated by adjusting the synergistic effect of oxidation, complexation, and dissolution. By contrast, for chemical bonding, CMP can be regulated by tuning the synergistic effect of oxidation and ionic strength. The findings provide a guide for achieving equivalent removal of different materials on the heterogeneous surface with CMP.

Keywords chemical mechanical polishing; corrosive wear; heterogeneous surface

KEYNOTE

Superlubricity of DLC Film, a Perspective of Interfacial Tribochemical Kinetics

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Achieving superlubricity is significant for reducing energy consumption. Diamond-like carbon (DLC) films, have demonstrated considerable potential in solid lubrication applications. Especially, a phenomenon known as superlubricity (friction coefficient <0.01) has been reported for DLC films in various environments, which provides the opportunities to achieve near-zero friction and wear, as a prospective solution for energy loss and stable operation of mechanisms. As hydrogenated diamond-like carbon (DLC) film can achieve superlubricity by a rapid running-in process, the fundamental mechanisms governing the friction evolution remain elusive. In this work, we discussed the mechanism of friction evolution toward superlubricity of DLC film at single-asperity level. Combining the ultrahigh vacuum variable temperature atomic force microscope (UHV-VT-AFM), machine learning based molecular dynamics simulation and ab initio path integral molecular dynamics simulations, we proposes a new perspective of interfacial tribochemical kinetics to understand the tribochemical mechanisms of DLC films and proposed a possibility to achieve ultralow-friction with quantum lubricity effect for DLC film via the nuclear quantum nature of hydrogen correlated tribochemical reactions.

Keywords superlubricity; tribochemical; running-in

INVITED

Friction and Wear Mechanism of Graphene-Based Materials at Atomic Scale

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Two dimensional materials have been developed as an ideal candidate of atomically thin solid lubricants or liquid additives for numerous practical applications to render

low friction, wear protection, and adhesion reduction. The friction and wear behaviors of graphene-based materials were found to be determined by the number of atomic layer, step edge structures, chemistry of the counter-face and surrounding atmosphere. Increase in thickness of fluorinated graphene or oxide graphene within few layers results in friction reducing but wear resistance enhancing. Both formation of interfacial bonds between the two contact surfaces and oxidation unzipping facilitate graphene wear initiated from step edge. The wear resistance and the lifetime of graphene-based materials at any length scale can be significantly improved through optimizing the thickness of layered materials, and tuning the atomic structure of step edge or the chemical interactions of the sample/substrate interfaces.

Keywords graphene-based materials; atomic structure; tribological properties

The Mechanism and Control of Nanoscale Friction Behavior on Graphene Surface

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The technology of superlubricity not only can reduce friction by several orders of magnitude, but also can decrease wear and friction noise, and thereby increase the reliability of mechanical equipment. Two-dimensional (2D) layered materials, represented by graphite/graphene, are excellent solid lubricants. Utilizing these materials to create lubricant coatings is considered as an important method for achieving superlubricity in practical engineering. 2D layered material lubricant coatings are composed of numerous thin flakes. Therefore, the coating surface consists of basal planes and step edges with completely different physical and chemical properties. To understand the friction behaviors of different regions, this study investigated the friction mechanism and control methods on both graphene basal planes and step edges with atomic force microscopy. By revealing the friction mechanisms of graphene basal planes and step edges, along with the friction reduction methods, this work is of instructive significance for 2D layered material lubricant coating design and fabrication.

Keywords graphene; friction; atomic force microscopy

Tunable Low Adhesion in Single-Asperity Contact of SP_2 Nanocrystallited Carbon Film with In-Situ TEM Study

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Low and controllable adhesion plays an important role in the precision-driven world of tip-based nanomanufacture. Recent years, the sp^2 nanocrystallited carbon (n-C) film exhibits high elasticity, and promises as an ultra-thin coating to address the adhesion issues on silicon tip. In this work, n-C film, amorphous carbon (a-C) film and original silicon tip were employed as three nanostructures, the in-situ tansmission electron microscope (TEM) nanoadhesion experiment and molecular dynamics (MD) simulation were exploited. The non-contact interractions was investigated with pull-in force, of which n-C film increased with the tip radius, roughly agreed with the attractive van der Walls (VDW) interaction law. While the randomness of top surface atom of a-C and Si tip resulted in the widely distribution range of pull-in force. Only the tip with n-C film exhibited low adhesion behavior with lower load and a better discipline that increased with the load. The a-C film and a-Si layer showed a significant randomness of pull-off force. MD simulation results fitted with the experimental results, and futher analysis shows that n-C and a-C film can effectively reduce the wear of silicon tip. The n-C film had smaller pull-off force even at higher contact stress because the stress on the neighborhood of sp^2 nanocrystallites area was near to zero, which meant the interfacial bonds in sp^2 nanocrystallites area were obviously less than other contact area. And the interfacial bonds in sp^2 nanocrystallites area of n-C film were obviously less than the corresponding area of a-C film. The exploration of controllable adhesion can immensely promote the development of design on nanodevice.

Keywords single-asperity contact, Low adhesion, sp^2 nanocrystallited carbon, in-situ TEM

AFM Studies on Formation and Tribological Properties of Fatty Acid Metal Soaps on Copper Surfaces

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Fatty acids, which are typical organic lubricating additives, form a thick 'metal soap film' on metal surfaces which has a superior friction reducing effect compared to the usual 'adsorbed molecular film'. Therefore, to achieve energy savings using organic additives, it is valuable to evaluate the relationship between friction and the film structure formed by fatty acids, which has various film forms and contribute to low friction. The test specimens used in this study were mirror-polished silicon substrates with copper films deposited by sputtering. Lubricants containing fatty acids added to hexadecane were used and friction tests were carried out using AFM. Linear saturated fatty acids, such as stearic acid, were particularly effective in reducing friction. Furthermore, precise observation under a weak pressing load revealed that the metal soap formed by stearic acid has a crystalline structure and grows to a thickness of over 100 nm. The effect of moisture in the lubricant containing stearic acid on the rate of

formation of the metal soap film was investigated by controlling the humidity around the AFM. When the lubricant had a higher moisture concentration, the formation of the metal soap film started immediately and remained without being removed against higher load friction. The frictional coefficient was found to be equivalent to that of copper stearate pre-deposited on the silicon substrate. When the lubricant had a lower moisture concentration, the metal soap grew gradually and was easily removed by higher load friction before sufficient coverage was achieved. The frictional coefficient where the metal soap has been removed is higher than on a silicon substrate with a dense Langmuir–Blodgett film, indicating that the molecular film of stearic acid under the metal soap is not as dense.

Keywords AFM, matal soap, fatty acid

Energy Harvesting and Sensing at Sliding Interfaces Based on Oil Dielectrics

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Charge separation is usually observed at the sliding interfaces, allowing energy harvesting and sensing, which is also the basis for the emerging device of the triboelectric nanogenerator. Traditional TENGs use air as a fluid dielectric, and contamination of the surfaces usually induces rapid decaying of output performance, limiting their application scenarios, especially for traditional tribology systems. Here, we demonstrate comprehensive investigations of oil dielectrics as an alternative fluid dielectric for TENGs, which enables energy harvesting and sensing in well-lubricated or underwater cases, or other harsh environments, allowing development of smart interfaces in machine elements and systems. Firstly, the contact electrification behavior of different oil droplets is systematically investigated by dropping oil on an oleophobic surface. The electrification trace is clearly imaged using a high-voltage scanning probe approach, and thermally stimulated discharge techniques are adopted for studying the detailed trapping characteristics of charges, providing systematic understandings on oil contact electrification with oleophobic surfaces. Secondly, different oil dielectrics are applied to the sliding interface of TENGs. The lubrication effect and influence on the output performance are investigated in detail, providing comprehensive guidance on how to generate electrical signal in an oil-lubricated sliding interface. Finally, a new mechanism by introducing oil phase into water-solid interface is demonstrated for energy harvesting based on electric double layer (EDL) capacitance. Through squeezing oil droplets on a dielectric surface in water environment, charge transfer is observed accompanying the movement of oil-water-solid three-phase line, which is mainly attributed to the effect that the oil phase sweeps away ions near the dielectric surface in the EDL. As a new working mode relying on EDL, it allows energy harvesting and sensing in severe environments even underwater with low friction and wear.

Keywords energy harvesting; sensing; oil dielectric

Phase Transition Structural Superlubricity

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Structural superlubricity refers to a state with almost vanishing friction and wear between crystalline surfaces in incommensurate configurations. However, thus far, this phenomenon has been observed only at solid-solid interfaces. Here, we constructed an in-situ heterojunction between a crystalline graphene boundary tribofilm and a pressure-induced solid-phase 1–dodecanol molecular layer, achieving structural superlubricity in a liquid phase for the first time. This novel state, termed phase transition structural superlubricity (PTSS), is induced by incommensurate slip at the in-situ heterojunction. Atomic force microscopy (AFM) experiments and molecular dynamics (MD) simulations demonstrated that the friction of solid-phase 1–dodecanol molecular layer exhibits a periodicity of 180°. Notably, the PTSS arises when the molecular axis of 1–dodecanol is oriented 90° to the direction of friction. These findings bridge the gap between liquid and solid superlubricity, shedding substantial light upon achieving structural superlubricity across a broad range of environments.

Keywords structural superlubricity; crystalline tribofilm; phase transition

Quantitatively Obtain the Interface Slip Length Based on Colloidal Probe Atomic Force Microscope (CP-AFM) Techniques

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Recently, with the continuous improvement of micro/nanotechnology, the research on nanofluidics at the micro/nanoscale (1nm-100um) has surged in popularity. Compared with the fluids in the bulk, the fluid at the interface exhibits singularity in structure and mechanical properties. This leads to the gradual failure of traditional no-slip boundary condition in fluid mechanics, especially in the case of weak liquid-solid interactions. The existence of slip can affect the physical properties of fluids under confinement such as M/NEMs. Meanwhile, it can also affect many macroscopic industrial and technological processes. For example, the operation of fluids in certain solid instruments such as rheometers can cause measurement results to deviate and even fail. CP-AFM has become the most popular method for obtaining slip length due to its high accuracy and nN-level sensitivity. Unfortunately, the obtained slip length is equivalent slip and cannot be applied in fluid mechanics. It is only used as a qualitative way to

determine liquid-solid interactions, mainly due to external influences, surface properties, and human operations. This work is based on the CP-AFM techniques and its measurement advantages, testing the hydrodynamic force in a simple fluid (H_2O) environment on hydrophilic and hydrophobic modified monocrystalline silicon substrates at different driving speeds. Combining the concept of non-equilibrium thermodynamics, different fluxes were transformed to obtain different velocity distributions. This is expected to obtain the true slip length, rather than the equivalent slip from an experimental perspective.
In summary, the interaction between AFM colloidal probes and different hydrophilic and hydrophobic substrates at different driving speeds is expected to quantify the slip lengths, which can provide theoretical guidance for the current fields such as M/NEMs and even membrane science.

Keywords interface slip length, CP-AFM techniques, non-equilibrium thermodynamics

Track 7: Tribology in New Energy System

INVITED:

Transistor-Inspired Energy Harvesters

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Harvesting kinetic energies from the ambient environment (raindrops, waves, biomechanical motions, etc.) and translating them into electricity is one of the ideal solutions to solving climate and energy issues. For ambient energy harvesting technology, improving the energy convention efficiency and enhancing the electric power output is important. However, current energy harvesters face challenges such as high output impedance, limited charge density, and significant frictional losses, hindering the attainment of high-power density. Here, we propose a transistor-inspired design to significantly decrease the internal resistance of energy harvesters. We also utilize various approaches, such as electrowetting-assisted charge injection, opposite charge enhancement, and biomimicry, to maximize the charge density and consequently achieve high power and energy density. In this report, I will introduce various transistor-inspired energy harvesters, discussing their design, mechanism, and potential applications.

Keywords: energy harvesting, nanogenerators, tansistor

Liquid Superlubric Triboelectric Nanogenerator

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Solving the wear of triboelectric nanogenerators is a major challenge, which will facilitate their application in areas such as energy harvesting and sensors. Here, we have devised a macroscale liquid superlubric triboelectric nanogenerator, which shows an ultralow friction coefficient (≈0.0025) and ultralow wear rate (≈0.76×10-7 mm3/N·m) from the tribological perspective. Compared with the lubricant-free triboelectric nanogenerator, the maximal open circuit voltage and short-circuit current of liquid superlubric triboelectric nanogenerator increased by 53.0% and 58.4%, respectively, due to the solid-liquid synergistic effect. This huge increase in electrical output performance is accompanied by a 99.1% reduction in friction coefficient and 99.993% reduction in wear rate. Experiments and molecular dynamics simulations demonstrate that the liquid in the contact region forms a lubricant film and the triboelectric charges generated by the friction pair are transferred from solid to the lubricating liquid. Meanwhile, the lubricating liquid plays the "charge bridge and donor" role to exchange electrons with the two friction surfaces. Our work provides an effective solution for the design of long-life and high-efficiency triboelectric nanogenerators.

Keywords: Triboelectric nanogenerator, liquid superlubricity, energy harvesting

Efficient Friction Energy Recovery and Utilization Based on Tribovoltaic Nanogenerator in Industrial System

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According to a survey, almost one-third of energy in global industrial systems is consumed through friction. The tribovoltaic effect is the creation of direct voltage and current by semiconductor interfacial friction, which is regarded as a newly discovered semiconductor effect for electromechanical energy conversion. The emerging tribovoltaic nanogenerators (TVNGs) has garnered considerable attention in recent years owing to its higher power density, but it is still limited by unstable output, mismatched impedance, and lower charging speed. However, there are no related reports on power management of TVNGs so far. It is expected to develop a power management strategy of TVNG to promote its practical application. Herein, a power-managed GaN-based TVNG is first proposed and a self-powered wireless temperature monitoring system is developed. The energy backflow from transition capacitor to TVNG is effectively suppressed by applying a high-voltage-resistant diode. Benefiting from the combination of the maximum power point tracking (MPPT) and the buck converter, an autonomous power management unit (PMU) is designed. After management, not only the internal impedance decreased by ten times and the charging speed of capacitor increased by 7.18 times compared to those before management, but also realizes effective regulation of output voltage and current. Based on the TVNG with PMU, 100 LEDs and six parallel thermos-hygrometers have been demonstrated to be continuously driven. Furthermore, a self-powered wireless temperature monitoring system without external power supply was constructed, enabling the temperature monitoring of industrial environment by the recycling of frictional energy. This work proposes an effective power management strategy for TVNG with high output voltage, which greatly broadens the application scenarios of TVNGs, exhibiting enormous potential to promote the development of self-powered sensors and Industrial Internet of Things (IIoT).

Keywords: Friction energy recovery, Tribovoltaic nanogenerators, Industrial internet of things

Freestanding-Mode Tribovoltaic Nanogenerator for Harvesting Sliding and Rotational Mechanical Energy

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A series of direct-current tribovoltaic nanogenerators (TVNGs) with high current density have been developed for energy harvesting and mechanical sensing recently, but the lead wires that need to be connected to two relatively moving parts have greatly restricted the application of TVNG. Herein, a freestanding-mode TVNG (FTVNG) is proposed based on metal, p-type silicon (p-Si), and n-type silicon (n-Si). As the freestanding part of metal simultaneously rubs against p-Si and n-Si, opposite direct current (DC) outputs can be generated, thus forming a DC output from p-Si to n-Si in the external circuit. Resulting from the distinctive structure, FTVNGs are applicable for harvesting energy from moving objects without attached wires. Additionally, by using steel needles to precisely control the actual contact area, the electrical output characteristics and influence laws of the tribovoltaic effect under different working parameters such as area and speed are studied. Moreover, FTVNG is integrated into the traditional rolling bearing as a triboelectric bearing, realizing energy recovery from the rotational motion of mechanical parts and speed sensing, which demonstrates the great application potential of TVNG in basic components and parts.

Keywords: Energy Harvesting, Freestanding, Direct Current, Rolling Bearing, Tribovoltaic Effect

The Droplet-Luminescence Excited by Contact Electrification on Polymer Surface

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Due to the direct conversion of mechanical force into light, Mechanoluminescence (ML) has been widely investigated in sensors, displays, anticounterfeiting and artificial skin. However, since the duration of luminescence is very short, this presents a great challenge for the visualization of trajectory generated by the motion, resulting in existing trajectory visualization applications frequently require an auxiliary device and extra power supply. With the ML material ZnS:Cu, which also has electroluminescent properties, we have found the interesting luminescence from water droplets flowing through scratches on the surface of a flexible ML composite film, which is called as droplet-luminescence. Contact trajectory visualization can be directly realized by the electric field between polar-liquid droplets and residual triboelectric charges on a rubbed surface without an auxiliary device. This provides an extremely simple but efficient way to store and display motion trajectories.

Keywords: Luminescence, Contact electrification, Liquid-solid interface

Middle Layer Enhanced Triboelectric Nanogenerator and Its Synergistic Regulation Mechanism of Tribology And Triboelectric Properties

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Triboelectric nanogenerators (TENG) have drawn a lot of attraction due to the merging requirement of the Internet of Things (IoT). Tribological materials, such as diamond-like carbon (DLC) films, show great application potential in improving the durability of triboelectric devices, especially for sliding mode. However, the output still needs to be further improved and the outstanding tribological properties should remain simultaneously. In this work, we employed a nano middle layer between Si-DLC films and substrate with plasma magnetron sputtering technology as a charge-blocking layer which can improve the charge density and not influence the tribological properties of DLC films simultaneously. The influence of the middle layer on mechanical properties and triboelectric properties was systematically investigated subsequently, and the experimental results show that the applied intermediate layer can improve the TENG output 4.5 times at the same condition. The mechanism of output enhancement was also discussed and explored. We proposed a theoretical and experimental basis for keeping the surface properties and improving the output at the same time. This research has the potential to give guidance for the durable TENG design and extend the application of

TENG in the domain of mechanical systems which have a strict requirement for durability and reliability.

Liquid-based Fluorinated Nanogenerator with High Charge Density for Energy Harvesting

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Liquid-based triboelectric nanogenerator (L-TENG) is a new type of energy conversion technology that can collect low-frequency mechanical energy from the surrounding environment. Here, a tubular L-TENG (TL-TENG) based on fluoroalkyl monolayer-modified silica was designed and fabricated by the self-assembled monolayer. It exhibited excellent electric output with an output voltage of 101.5 V, peak power density of 43.0 mW m^{-2}, surface charge density of 500.3 μC m^{-2}, and durability of no less than 5.12×10^5 cycles. The electric output could be modulated by the thickness of dielectric layer, types of liquid, and oscillation frequency, which was reasonably explained by our equivalent capacitor model. In addition, the hydrophobic fluoroalkyl monolayer could promote electron transfer at the solid-liquid interface, and the existence of a dielectric layer could inhibit the leakage of the current perpendicular to the surface, both leading to the enhancement of electric output. A wearable TL-TENG was finally demonstrated to harvest body motion energy and power lighting devices efficiently. This work reveals the effect of carrier behavior at the liquid-solid interface on the electric output of TL-TENG, and provides theoretical guidance for TL-TENG's design to help develop its application potential for use in energy harvesting and self-powered wearable devices in the wild.

Keywords: liquid-based nanogenerator, high charge density, energy harvesting

KEYNOTE:

Triboelectrics as Enabling Technology for Sustained AIoT Sensing Systems

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Abundant energy sources of various types are widely distributed in the surrounding environment, which can be converted into electrical energy by micro-nano energy harvesters based on different mechanisms. For vibrational energy sources, including human kinetic energy and kinetic energy existing in the environment, hybrid energy harvesters based on electromagnetic, piezoelectric and triboelectric effects are updated in this talk, respectively. When machine learning (ML) is applied to sensory data analytics at cloud servers for numbers of distributed wireless Internet of Things (IoT) sensor nodes, the emerging ML enhanced IoT is defined as the artificial intelligence of things (AIoT) technology. Having the hybrid transducer mechanisms, we can achieve the energy harvesting and self-powered sensing in one AIoT sensor node. For example, we introduced an AI-augmented walking stick as an all-encompassing, real-time monitoring platform tailored specifically for elderly individuals and people with disabilities, where the realized self-sustaining AIoT system enables comprehensive monitoring of users by tracking their current motion status and locations, and sending out an alert in the event of accidents, offering a holistic caregiving solution. Secondly, we presented the design and characterization of a few self-powered AIoT sensor nodes, aiming at smart mining, factory automation, industry 4.0, transportation, and smart city applications. Given the challenges and advances in materials, fabrication, and system integration, this talk highlights these works which indicate opportunities toward multifunctional, self-sustained AIoT sensing systems.

Keywords: Triboelectrics, Self-powered, AIoT

INVITED:

Triboelectric Spectroscopy for In Situ Chemical Sensing

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Contact electrification has been widely used in the field of energy harvesting and intelligent sensing. In recent years, we have found that the charge transfer at the liquid-solid interface largely depends on the composition of the droplet, including its ion species, concentration and so on. This provides an idea to detect the chemical composition of liquid through the liquid-solid triboelectric signal. In this presentation, I will present our research on the use of contact electrificaiton for liquid chemical analysis. We detect the charge distribution on the solid surface by placing an array and a linear array of metal probes under the solid film. By analyzing the characteristics of charge distribution on the surface of solid in the process of liquid-solid contact electrification, the liquid composition is analyzed. This technique is named as triboelectric spectroscopy (TES). TESprofiles are unique, and through an automated identification, it is possible to match against standard and hence detect over 30 typesof common salts, acids, bases and organic molecules. The qualitative and quantitative accuracies of the TES methodology is close to93%, and the detection limit is as low as ppb levels. Instruments for TES chemical analysis are portable and can be furtherminiaturized, opening a path to in situ and rapid chemical detection relying on inexpensive, portable low-tech instrumentation.

Keywords: contact electrification, chemical analysis, triboelectric spectroscopy, sensing

Boosting the Durability of Triboelectric Nanogenerators

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Triboelectric nanogenerators (TENGs) have attracted great interests in the development of sustainable energies and intelligent society. However, a big challenge for TENGs in practical applications is the unavoidable external mechanical abrasion and/or contaminant adsorption on the triboelectric materials, which leads to the significant decrease of the durability of TENGs and is urgently needed to be addressed. There are already a series of interesting progresses on the topic of the TENGs' durability. In this study, we focus on reviewing the durability of TENGs via both the advanced materials/structure designing and the novel surface/interface engineering, which include choosing basis TENG materials, improving composites performance, optimizing structures and designing triboelectric surfaces and interfaces. Especially, Our group found for the case of solid-solid contact, utilizing lubricants to lubricate the triboelectric interfaces will not only avoid the air breaking and moisture contaminant (resulting in a higher signal output), but also will decrease the friction and wear of TENGs (resulting in a high durability). For the case of liquid-solid contact, we have developed self-cleanable TENGs via designing the solid surface's wetting properties. In addition, to get a better understanding of the durability of TENGs, the quantifiable levels of service life are also summarized including operation cycles, time, fiction coefficient and wear loss of triboelectric materials, where the boosting mechanisms are also discussed and summarized. Finally, the challenges as well as key strategies toward high durable TENGs are presented.

Keywords: triboelectric nanogenerator, durability, friction and wear

Wind Energy Harvesting System Using Polymer Deformation

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Wind, as a valuable and abundant natural resource, predominantly powers large-scale wind turbines for electricity generation. However, conventional wind turbines suffer from drawbacks such as large volume, high cost, and low efficiency. In pursuit of more efficient wind energy utilization, we propose an approach by utilizing polymer deformation for wind energy harvesting. Through experimentation with polymer sheets and films, we investigate the relationship between generated electric potential and material deformation. When polymers undergo bending deformation, compression and tension forces occur above and below the material's midplane, leading to induced electric potential on the upper and lower electrodes of the material, thus generating a

potential difference between the two electrodes. The polarity of the induced electric potential correlates with the tendency of the polymers to charge positively or negatively. Additionally, the potential difference between the two electrodes is directly proportional to the extent of material deformation and the area of contact between the material and the electrodes. Leveraging this characteristic, we develop a new wind energy harvesting unit. this polymer-based generator mitigates issues like wear and short lifespan caused by direct material contact, offering advantages such as simplicity in structure, high power output density, and low cost. Moreover, it can be flexibly deployed with minimal interference from external factors like terrain, presenting a fresh perspective for future wind energy collection and conversion. This innovation paves the way for the development of novel wind power systems.

Keywords: Ploymer, Deformation, Wind Energy

Track 9: Industry Tribology and Instruments

KEYNOTE

From Imaging the trajectory of a single asperity to Colour Atomic Force Microscopy, tip functionalisation and Assisted Reproductive Technology

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The university of Tokyo

Tribology, from the view point of instrumentation is very challenging and rewarding. Various detection and imaging techniques developped in the course of tribological studies have evolved into novel methods and even research fields. The paper will give a brief overview on techniques related to Nanotribology, Colour AFM, and, tip functionalization to achieve "near single floating atom probe" properties. At the end, the paper will introduce multidirectional force detection schemes that are applicable to force and acoustic detection of gametes, which has a potential to give new findings in assisted reproductive technology. Movement and transportation mechanismas of the organs are also subject the techniques developped through instrumentation closely related to tribology.

Keywords: multidegrees of freedom detection, AFM, tip functionalisation, assisted reproductive technology

Acoustic and Haptic - New Challenges in The Automotive & Social Sector

Stephan Henzler
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Automotive trends towards the 3rd place and define new challenges for product development. A fusion between automotive, smart living and public transportation is still in progress, developer and companies must deal with new evaluation criteria.
In addition to the classic tribological result variables such as wear and coefficient of friction, new enablers such as odor, oil separation and many more are becoming increasingly important and can be viewed as 1 or 0 criteria.
Acoustic and haptic perceptions by the end consumer must therefore be made assessable well in advance or within the development phases. The presentation is intended to show the 1 and 0 criteria and their impact on product development especially with lubricants. In addition, the status quo for the tribological characterization of "haptic" and "acoustic" is presented. The current standards are not sufficient for a comprehensive characterization. Solutions are presented as to how this could be possible since load collectives have also been significantly changed by using new materials and technical specifications.

Important aspects here are to recognize tribology as an important aid, to perceive lubricants as a design element and to re-evaluate existing standards regarding their customer needs. Method development and application-oriented testing will play an important role in the future to fulfill all the existing and new market requirements.

Keywords: lubrication, haptic, acoustic

An Accurate Measurement Method for Center Oil Film Thickness in High-Speed Roller Bearing Using Ultrasound

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The ultrasonic reflection methods have been used to measure the film thickness in the contact region of rolling bearings, while the measurements of lubricating film thickness of high-speed bearings are rarely reported. For accurately measuring the center oil film thickness of the contact region in a high-speed roller bearing, a great number of successive ultrasonic pulses are utilized to examine the lubricant film in the roller bearing. A multicycle focal spot mapping method is proposed to design the specific pulse emission frequency and the recorded pulse number to ensure that at least one ultrasonic pulse strikes the center of the contact region. Subsequently, based on the ultrasonic spring model, the minimum reflection coefficient amplitude is selected to calculate the center oil film thickness in the contact region. Statistical test analysis and experimental analysis are performed respectively to validate the proposed method. The statistical test results show that the proposed method overcomes the speed limitation of the existing methods. Its maximum measurable speed could exceed 30,000 rpm, which greatly broadens the application field of this technology. The experimental results of the rotation speed from 500 rpm to 6000 rpm are in agreement with the theoretical film

thicknesses, which also validate the feasibility of this method.

Keywords: ultrasonic, center oil film thickness, high-speed roller bearing

September 18, 2024

Track 1-I: Friction and Lubrication

KEYNOTE:

Measuring Spatial-Temporal Distribution of Contact Stress and Dexterous Grasping

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Human fingers are endowed with unique roughness perception and dexterous grasping abilities relying on its extraordinary tactile perception capability. From the point of view of interface mechanics, the spatio-temporal distribution of the normal and tangential contact stress at the skin-objecct interface is the essential source of tactile perception. This report introduces a dynamic high-resolution measurement method of interface three-dimensional contact stresses based on binocular stereo vision and elastic mechanics mode. The temporal and spatial resolution of the constructed prototypes can reach 10 ms and 10 μm, respectively, which can be readily improved by increasing the camera frame rate and resolution. The excellent performance of the method was used in measurement of adhesion stress on dry adhesive surfaces, visualization of the adhesive resistance and elastic resistance of rolling friction, and revealing the multi-scale suction mechanism of snail crawling. Furthermore, the interfacial contact stress measurement method was used to carry out the researches on the frictional tactile perception mechanism of the human and feedback control strategy of dexterous grasping. Incremental loading strategy and close-loop control based on perceived interfacial micro-slip were clarified. Based on the above control strategy and designed vison-based friction and slip tactile sensing devices, a tactile-feedback control paradigm for robotic dexterous grasping was constructed. It can realize a reliable and dexterous grasping of various objects under dynamic loadings without prior knowledge like a human being.

Keywords: contact stress measurement, biomechanics, tactile sensing, dexterious grasping

INVITED:

Lubrication Condition Monitoring for Multiple Bearings Using the Electrical Impedance Method

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Lubrication condition monitoring of rolling bearings is essential to achieve lower torque and to prevent metallic contact. The Electrical Impedance Method (EIM) can measure the thickness and breakdown ratio of oil films simultaneously by analyzing the complex impedance obtained by applying a sinusoidal voltage to the contact area. This method has advantages in that it can detect surface damage caused by metallic contact in advance and determine whether the lubrication condition is appropriate. However, the EIM is difficult to use on actual machines because it requires a slip ring or carbon brush to conduct electricity to the rotating shaft. To solve this problem, connecting electrodes to outer rings of two bearings and configuring a two-bearings series circuit through the rotating shaft was considered. However, this approach only allows for the measurement of the composite impedance of the two bearings, without providing information on their individual impedances. Therefore, applying the Electrical Impedance Spectroscopy (EIS) was considered, which estimates the equivalent circuit by sweeping the frequency of a sinusoidal voltage. As a result, analyzing the frequency response of the impedance enabled the separation of the composite impedance of the two bearings into their individual impedances. This separation was particularly easy when metallic contact occurred. This is thought to be because the electrical resistance of steel is much lower than that of lubricant, so when metallic contact occurs in one bearing, the time constants of the RC parallel circuit consisting of each bearing will differ.

Keywords: condition monitoring, impedance

A Test Device and Method for Tribological Characteristics of Non-transparent Material Pairs

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The tribological characteristics of kinematic pair under different working conditions have important theoretical and engineering guiding significance for the design and operation of machinery and equipment. Among them, the lubricating oil film thickness and friction coefficient are two important indicators of the tribological characteristics of kinematic pair. However, the existing tribological test machine can only provide measurement of the friction coefficient of kinematic pair. Most of the lubricating film thickness test machine is based on optical interferometry, which cannot achieve the oil film thickness measurement of non-transparent material pairs. To this end, this article proposed a test device and method for tribological characteristics of non-transparent material pairs. Taking the ball-disc as the carrier, based on the ultrasonic spring model and resonance model, the oil film thickness was obtained by the reflection coefficient. Based on the three-dimensional force test technology, the friction coefficient was obtained by the measured pressure and friction. A water immersed ultrasonic probe with a central frequency of 25 MHz, a three-dimensional force sensor and LabView software were used to test the oil film thickness and friction coefficient of different kinematic pairs under different load and slip speed working conditions. The test results were in good agreement with the theoretical values. The relative error was less than 10%. The test device and method can measure the oil film thickness and friction coefficient well.

Keywords: ultrasonic measurement, lubricant film thickness, non-transparent material pair

Study on Tribological Properties and Lubrication Lodification and Nondestructive Testing of Steel Wire Rope in Mine Hoist

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The mine hoist is the throat equipment connecting the ground and the bottom of the well in the underground mine. The hoisting wire rope is the only traction component connecting the hoisting container, and its service performance directly affects the safety of the mine hoisting. With the development of deep mining and large-scale mining in China, multi-rope friction hoisting and multi-rope winding hoisting are mostly used in large-scale mine hoisting, which are prone to complex and changeable friction and wear behaviors between ropes and wires during operation. At the same time, the harsh working environment leads to serious failure of wire rope lubrication protection, and the damage detection is difficult. Therefore, the tribological characteristics, wear mechanism and vibration and wear characteristics between wire ropes and wires under different working conditions were investigated by using a self-made wire rope friction and wear tester. Based on the self-made 19-wire spiral contact friction and wear test

device, the twisting contact friction characteristics between the internal wires of the wire rope under various environmental conditions were explored. The two-stage excitation damage detection device of wire rope is designed, and the accurate detection method of wear characteristics of hoisting wire rope is explored. Based on different solid lubricating additives, a modified wire rope grease for mine hoisting was developed, and the tribological properties of the modified grease were analyzed based on the wire rope friction and wear test system.

Keywords: mine hoist, steel wire rope, friction and wear, lubrication modification, nondestructive testing

INVITED:

Indirect Measurement and Behavoir of Ball Joint Friction Under Real Load Time Series

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For the virtual evaluation of vehicle comfort, it is important to consider the characteristics of the friction properties of ball joints. Since ball joints are only excited monotonically and one-dimensionally in conventional measurements on component test benches, the question arises whether the friction characteristics recorded there also occur in the vehicle axis under real load cases. Against the background that a direct measurement of the friction torque in the vehicle axis is technically not possible, an indirect measurement method is used. In this indirect method, the friction-induced dissipation power is inferred from temperature measurements. The occurring friction torque can then be calculated from the dissipation power with the help of the angular velocities of the ball joint.

This contribution is about conducting an indirect friction measurement through temperature measurements on an axle test bench. It describes how heat flows within the component can be deduced from temperature measurements to subsequently calculate the energy dissipation at the friction contact required to determine the friction torque. In addition, the determination of motion and force quantities in the axle by multi-body simulation is discussed. After the theoretical foundations of the method have been presented, the gained insights from measuring a ball joint under real load time series are discussed. The method is applied to an axle measurement and it is shown which friction characteristics occur in a ball joint in different load situations and excitation signals.

In the measurements it can be shown that increasing angular displacements, angular velocities and loads result in lower friction torques in the ball joint. In measurements with low angular displacements and velocities, high friction forces occur. This suggests that the external excitation of ball joints has an influence on the lubricant distribution in the contact area, and higher loads contribute to a more positive lubrication situation.

Keywords: ball joint friction, indirect measurement, tribological component simulation

The Decoupling of the Complex Stress State of Rough Interface Based on the Model of Mechanical-Electric Contact

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Due to the randomness and complexity of rough interfaces, as well as the opacity of the contact interface, directly observing and measuring the topography and complex stress distribution of the contact surface is a challenge. In this work, based on the volumetric probability representation method, the random contact process is characterized, the theory of mechanical-electric contact is established, and the mechanism of the interaction between force and electricity is revealed. On this basis, combined with potential theory and non-Gaussian distribution function, a method of reconstructing interface topography and stress distribution through unique inversion of macroscopic interface parameters is developed. This method overcomes the difficulties in accurately identifying and decoupling normal stress and tangential stress due to strong randomness of the interface, and provides important technical support for key local performance testing and evaluation of interfaces.

Keywords: mechanical-electric contact model, contact resistance, complex stress decoupling, contact stress distribution

Measurement Method of Superconducting Electromagnetic Device Interface Performance

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Superconducting magnets are core components of the International Thermonuclear Experimental Reactor (ITER), the China Fusion Engineering Test Reactor (CFETR), and the full-service field regulation and measurement devices for superconducting

materials mechanics under high fields of 15 T in China. These magnets operate in extreme environments (extreme low temperatures, high currents, strong magnetic fields, and cyclic loads) and feature multi-turn twisted contacts. The continuous deformation of superconducting magnets under electromagnetic forces leads to random three-dimensional spatiotemporal evolution characteristics of internal interface force transmission, heat transfer, and electrical conductivity. This poses difficulties in determining key interface parameters (contact stiffness, thermal resistance, and electrical resistance), thus limiting magnet design and posing significant hidden dangers to their safe and stable operation. This study starts with a fundamental theoretical model and introduces the concept of "real contact volume" to characterize random interface contacts and friction processes as probabilistic variations in contact volume using a probability density distribution function. This approach overcomes the limitations of existing theories that struggle to consider spatial surface-to-surface contacts and have limited load application ranges. Subsequently, the impact of extreme environmental conditions is correlated through geometric morphology, material state, and performance parameters, and a multi-physics strongly coupled approach is established. This leads to the development of a volume contact theory for electromagnetic solid interfaces under extreme environmental conditions, revealing the multi-field strongly coupled mechanism at the interface. Based on the interface mechanical-thermal-electrical coupling mechanism and interaction laws, a measurement method for electromagnetic device interface contact performance is proposed. This method enables effective measurement of complex stress states at the interface, providing a parametric basis for performance analysis and reliability evaluation of superconducting electromagnetic devices.

Keywords: superconductivity, electromagnetic device, interface contact

Ultrasonic Measurement for Oil Film Thickness Based on Lag Phase Slope

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Ultrasonic reflection technique is widely used in oil film thickness measurement, owing to the non-destructive characteristic. However, the application of the technique in real mechanical components remain a challenge, as the currently available ultrasonic models are suitable only for specific ranges of the oil film thickness. For estimating the oil film thickness at a large scale, a unified model based on the ultrasonic lag phase slope of adjacent waves is proposed. The relation of the lag phase slope with regard to the oil film thickness is established, which is used to effectively determining the oil film thickness. The proposed model is validated by both the finite element analysis and measurement experiments on the oil film thickness. The results show that the oil film

thickness from 0.1 μm to 170 μm can be calculated by using the proposed model, which covers the range from the spring model region to the time of flight model region.

Keywords: ultrasonic measurement, oil film thickness, lag phase slope

Track 1-II: Friction and Lubrication

INVITED:

Tailoring the Tribological Properties of One PEEK-based Composite via High-Quality Nanostructured Transfer Films

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High-performance transfer films generally facilitate the friction and wear properties of the polymer/steel tribological systems. The emerging tribo-sintering theory attributes the tribological performance improvement of fiber/nanofiller synergistic system on the formation of nanostructured transfer films on the steel counterface with impressive lubrication. However, there remains uncertainty regarding their mechanisms, impact factors, and controllability. Further comprehensive exploration of the polymeric tribo-sintering effect is essential, as it not only offers the opportunity to tailor tribological performance by adjusting input load conditions, but also holds potential for industrial applications in prolonging component lifespan.
The present study aims to investigate the effects of load condition induced nanosilica participated tribo-sintering process on the tribological properties of the polyetheretherketone (PEEK)-based composite/steel sliding system. It is verified that high load conditions (pv-products (pressure and velocity) $\geq$ 16 MPa·m/s) are favorable for encapsulating the disengaged nanosilica and promotes the formation of even, thick, and robust tribo-sintered transfer films. For instance, the transfer film tribo-sintered under 8 MPa and 4 m/s reduces the material's coefficient of friction by 27.4% and specific wear rate by 44.2%, improves the friction stability by 74.4%, and possesses outstanding lifetime. Moreover, morphologies of the transfer films are further evaluated by laser scanning microscopes (LSM), scanning electron microscopy (SEM), and energy dispersive X-ray (EDX). The outcomes reveal that high load conditions promote the coating of polymer debris and the crushing of accumulated nanosilica on the steel counterbody's surface, which benefits the embedding of nanosilica into the transfer films. The results of Ramen spectroscopy and chemical composition analysis of X-ray photoelectron spectroscopy (XPS) imply that the transfer film tribo-sintered under high load conditions behaves more ordered graphitic lattice structures, higher C-C sp^2 content and less oxygen content, evidences its significant decrement on the severe friction and wear of the composite.

Keywords: PEEK, nanosilica, transfer film

Tribological Behavior of 3D Printed Nanofluid Reinforced Photosensitive Self-Lubricating Polymer Materials

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Oil-loaded polymer composites have become a research focus in tribology due to the good environmental stability and excellent performance. Usually, it is necessary to endow the polymer with a porous structure to facilitate lubricating oil storage. However, most methods require complex operating steps, making it difficult to control the complex shape of materials, and excessive pores often lead to an imbalance between the oil storage and retention rates. At the same time, the mechanical properties of the material can also be negatively affected. Developing a simple synthesis method to obtain oil-loaded polymer composite materials with good self-lubricating and mechanical properties still faces challenges. Herein, a one-pot synthesis method for oil-loaded self-lubricating polymers was proposed, which embeds the porous silica nanoparticles loaded with lubricating oil into the polymer and uses vat photopolymerization-based technologies to construct the polymer with various complex and delicate structures. After a series of treatments, such as photocuring and cleaning, an oil-loaded polymer-based composite material with good self-lubricating performance was prepared. Benefiting from the rich mesoporous pore structure of mesoporous silica, high specific surface area of 467 m2g-1, and pore volume of 1.06 cm3g-1, the oil content and retention rate of the composite materials are at a high level. In addition, by combining oil-loaded mesoporous silica nanoparticles with 3D printing, controllable preparation of complex shapes of self-lubricating composite materials has been achieved. During the friction performance testing process, the oil-loaded particles in the polymer composite can continuously provide lubricating oil on the friction surface, thus making the friction coefficient and wear rate reduced by 85.7% and 97.7%.

Keywords: 3D printing, self-lubrication, oil-loaded nanoparticles, photosensitive polymer materials

Prediction of Drag Losses of Wet Clutches Using Machine Learning Algorithms

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In wet clutches, load-independent hydrodynamic drag losses occur in the disengaged state and under differential speed due to fluid shearing in the sub-millimeter gaps. The drag torque of wet clutches can be determined accurately and reliably through costly and time-consuming measurements. Alternatively, computing-intensive CFD models can precisely calculate the drag losses in the early development phase. In contrast, simple analytical calculation models allow a rough but non-time-consuming estimation. Therefore, the objective was to develop a data-driven model for predicting the drag losses of wet clutches with low computational effort and, at the same time, sufficient accuracy considering a high number of influencing parameters.

The presentation provides an overview of all relevant steps for developing a data-driven drag torque prediction model. Approximately 300 drag torque measurements obtained from systematic experimental investigations on the drag loss behavior of dip-lubricated wet clutches are used as input. For data generation, mixed-level full factorial test designs were used to provide maximum information for model building. Supervised machine learning algorithms like Gaussian process regression and symbolic regression are used to determine the relationships between the investigated parameters and characteristic values describing the drag loss behavior. The experimental validation of the developed prediction model confirms a high accuracy. From now on, accurate predictions can be made within a split second. The prediction models can be used to design new low-loss clutch systems and can be implemented in full powertrain simulation models.

Keywords: wet clutches, drag loss prediction, data-driven modeling

Track 1-III: Friction and Lubrication

KEYNOTE:

High Temperature Tribology: Current Trends and Future Challenges

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There are many applications such as automotive, aerospace, power generation, and metal working processes where the tribological interaction of contacting surfaces of moving (machine) components occur at high temperatures. The operation of tribological systems at elevated temperature has serious consequences in terms of their efficiency, performance, and reliability. Salient effects induced due to operation of tribological interfaces at elevated temperatures are the tribochemical changes (mainly due to oxidation, diffusion phenomena) in the surface and near surface regions and degradation of mechanical properties of the materials. Also, conventional lubricants become ineffective due to decomposition and degradation at high temperatures. In view of this, new or different approaches in controlling friction and wear at elevated temperatures such as the use of speciality lubricants (including phase change materials), solid lubricant materials (also called self-lubricating materials) must be employed. All these factors make high temperature tribological phenomena highly complex. So far, the key focus of research in high temperature tribology has been on characterisation and understanding of friction and wear mechanisms. A very significant part of research efforts has also been devoted to controlling friction and wear at high temperatures. This talk will discuss some of the recent work and current trends in the field of high temperature tribology. Some research work including those pertaining to tribology issues in hot sheet metal forming and nuclear power generation involving tribological studies in molten (liquid) metal environment will be discussed. The talk will conclude by highlighting the challenges associated with experimentation simulation, modelling and control of friction and wear at elevated temperatures.

Keywords: high temperature, friction, lubrication, wear

INVITED:

Macroscopic Low-Friction via Twinning Assisted Lattice Reconstruction in Magnesium

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Friction causes a huge amount of energy losses annually. Historically, the pioneering work of Bowden and Tabor in the 1950s suggests that the frictional energy dissipation is mostly due to plastic deformation for metallic materials. The friction of hexagonal close-packed (HCP) metals is typically high due to friction-induced dislocation slip and twinning. Here, we find particularly low friction when sliding perpendicular to the a-axis on the basal plane in HCP Mg single crystals. This is in contrast to the common belief that friction is small along the preferred dislocation slip direction (a-axis). This macroscopic low-friction stems from twinning assisted lattice reconstruction sharing a common rotation axis, confirmed by atomistic simulations and strain energy analysis. While sliding along the a-axis and other directions, <c+a> dislocation activity accounts for high frictional resistance. By unambiguously decoupling the contributions of dislocation slip and twinning, this discovery reveals potential opportunities in mitigating the energy dissipation at tribological interfaces of HCP metals, e.g. through crystallographic texture design.

Keywords: friction, twinning, dislocation slip

Study on the Running-in Attractor and Its Evolutionary Law

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In order to reveal the dynamic behavior law of friction and wear process, chaos and fractal theory and wear process experimental methods were used to study the running-in attractor and its evolution law. The staged wear process tests under different operating parameters were conducted, and the friction force, friction vibration signals, and wear surface morphology are collected. Based on the chaotic and fractal characteristics of tribological systems, the phase trajectories evolution in high-dimensional phase space are constructed from friction time series signals and wear surface morphology, and its chaotic and fractal characteristic quantities are calculated. It was found that the phase trajectories and characteristic quantities of the friction system during the running-in process exhibit an evolutionary law of "divergence-convergence-stability", thus proposing the concept of the running-in attractor; Furthermore, it was found that the running-in attractor exhibits an evolutionary pattern of "divergence-convergence-maintenance-divergence" throughout the friction and wear process, which is consistent with the three stages of the wear process. Therefore, the running-in attractor and its evolution law reveal the dynamic behavior law of the wear process. Based on this law, the running-in process can be quantitatively predicted, the running-in state can be identified, the running-in parameters can be designed, and the wear process and working conditions can be monitored.

Keywords: running-in attractor, phase trajectory, chaos and fractal characteristic quality

INVITED:

Wear Properties and Mechanism of Multi-Principal Element Alloys

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Recently, the design concept of multi-principal element alloys makes its alloys have unique microstructure and excellent properties, which has attracted extensive attention and active exploration, and has become one of the hot topics in the field of materials research. This report focuses on the potential application of multi-principal element alloys under complex friction and wear conditions such as low temperature, high temperature, fretting, and poor oil lubrication. The friction and wear properties of several typical multi-principal element alloys under potential application conditions are studied, and the relationship between microstructure and wear mechanism is explored

by combining experimental and molecular dynamics simulation methods. On this basis, the effects of microstructure adjustment based on alloy composition design, composite solid self-lubricating particles, and material surface modification on the friction and wear properties of multi-principal element alloys are explored, which is expected to provide new method for the design and preparation of multi-principal element alloys with excellent friction and wear properties for engineering applications.

Keywords: multi-principal element alloys, complex wear conditions, wear properties and mechanism

INVITED:

Effect of Interaction between Oils, Additives and Thickeners on Grease Tribology Performance

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Response to a reduction of CO_2 emission, there is a rapid increase in manufacture of new energy vehicles worldwide. For EV, noise, vibration and harshness (NVH) during driving become more and more critical in the automotive industry. NVH performance of tripod constant velocity joints (CVJs) is validated using Li grease and di urea greases with same additive package. NVH performance is related to friction of lubricants. Di urea grease shows better NVH performance than Li grease, but both greases show same friction in laboratory reciprocating tests. Observation of grease thickener microstructures, di urea thickener might be slightly thinner than Li soap. Study of greases using extreme dilution method by polar/nonpolar solvents exhibits that grease forms with the primary and the secondary gel systems. Use of polar media, like naphthenic oils and ester oils, could produce high quantity of greases than nonpolar media like paraffinic oils and PAO. Different additives in different thickener systems generate different chemical/physical interaction between additive molecules and thickener molecules that make the primary gel system weak in different levels as a result of different quantities of additives and/or atomic groups of additives remain inside thickener systems during oil separation. It is found that Li soap molecules interacts with atomic group $Mo_2O_2S_2^{+2}$ inside MoDTP and Zn^{+2} ion inside ZDTP stranger than di urea. This kind of difference results in the difference in conditions of forming tribochemical reaction film to achieve low friction during tribology performance which might attribute to difference in NVH tests using Li grease and di urea greases respectively.

Keywords: grease, grease thickening mechanism, interaction between substances of grease

A Novel Nanosecond Laser Irradiation Assisted Chemical Mechanical Polishing (CMP) Process for Promoting Material Removal of Single Crystal 4H-SiC

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Silicon carbide (SiC) is one of the most promising three-generation semiconductor materials owing to its remarkable properties and numerous potential applications, particularly in the fields of satellite communications, integrated circuits (IC), and consumer electronics. Prior to IC manufacturing, SiC substrates should be polished by a nano-manufacturing of chemical mechanical polishing (CMP) for the high surface accuracy. Nevertheless, the polishing efficiency of hard-to-process single-crystal SiC remains a significant challenge due to its high hardness and chemical inertness. A novel approach by employing nanosecond laser irradiation as a pre-process for the CMP process was presented. By irradiating the Si-face, the substrates were processed with CMP for a short time using normal 1wt.% diamond+ 99wt.% deionized water eco-friendly slurry. The performance of nanosecond laser irradiation assisted chemical mechanical polishing (NLIA-CMP), including material removal rate (MRR) and surface roughness (Ra), was evaluated. A significant improvement in the MRR of NLIA-CMP with high surface roughness was confirmed. Besides, the possible effects were investigated. Atomic force microscopy (AFM) was used to observe the morphologies of SiC wafers after NLIS-CMP. The results indicate that a highly efficient SiC-CMP with good surface quality can be realized by employing nanosecond laser irradiation as the pre-treatment and using an eco-friendly polishing slurry. The material removal mechanisms of NLIA-CMP were concluded to be the following perspectives: (a) the formation of the periodic ripples induced by nanosecond-laser extend the contact area between the SiC surface and diamond abrasives, (b) the transition from strongly-bonded SiC on the surface to weakly-bonded species during the nanosecond laser irradiation in air. The present study was a beneficial exploration of expanding the application of nanosecond laser to the CMP process.

Keywords: nanosecond laser irradiation, single crystal sic, material removal, CMP

Stick-Slip Behavior of Galvanized Automotive Steel and Its Suppression

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The stick-slip pheonomenon as a prevalent frictional vibration presents significant challenges to the industry, including machinery wear, reduced precision, and noise generation. This phenomenon is extremely complex because the surfaces of friction pairs have various asperities with different sizes. Therefore, it is important to understand the scale effect of asperities on the stick–slip behavior. Here, we investigated the influence of multiscale asperities on the stick–slip behavior of galvanized automotive steel. Our findings revealed that the stick–slip behavior was primarily dominated by the density of asperities on specific scales. High-density asperities increased the potential energy between asperities of the friction pairs, consequently leading to stick–slip behavior. It was suggested that decreasing the asperity density on the surface could significantly suppress the stick–slip behavior. Therefore, we modified the topography of galvanized automotive steel through temper rolling as a new approach to suppress the stick-slip behavior. Temper rolling effectively suppressed the stick-slip behavior by reducing asperity density. The decrease in stick-slip amplitude affected the motion state of the friction pair and suppressed the frictional vibration and noise generation, as confirmed by the in-situ observation utilizing a digital image correlation method. These findings reveal the scale effect of surface asperities on the stick–slip behavior and highlight the potential of temper rolling as an effective strategy for tailoring the surface topography to suppress the stick-slip phenomenon.

Keywords: stick-slip, frictional vibration, temper rolling, galvanized automotive steel, surface topography

Design, Preparation, and Lubrication Mechanism Study of Lubricating Medium for the Plastic Forming of Titanium Alloys

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Titanium alloys have been widely used in the fields of aerospace, marine engineering, biomedicine and chemical industry owing to their high specific strength and excellent biocompatibility, corrosion resistance. Titanium alloy products (pipes, rods, and sectional materials) are obtained through cutting, rolling, hot extrusion and forging. But their processability is restricted by the low thermal conductivity and high deformation resistance and chemical activities, especially for the processing of sectional materials. As a result, friction and wear are unavoidable occur in the forming process, which result in damage to the equipment and energy consumption. In this work, the design, preparation, and lubrication mechanism of lubricants applied in the plastic forming of titanium alloys has been researched. First, black phosphorus (BP) /TiO2 nanoparticles composite water-based rolling fluid was synthesized by hydrothermal method. The wear rate of rolling fluid was reduced 57% compared with based rolling fluid. Secondly, the glass lubricants have been prepared with controlled softening points and viscosities

through compositional design. The average friction coefficient(COF) of glass lubricants is reduced 66% compared with commercial glass lubricants. Finally, the h-BN/graphite coatings were prepared by fluorination modification method. The high temperature resistance performance of h-BN/ graphite coatings enhanced 50% compared with graphite coating(600°C).

Keywords: lubricating medium, titanium alloys plastic forming, black phosphorus, glass melt lubrication, h-BN/graphite coatings

Track 2: Wear and Fatigue

Research Progress of Polymers in Sliding Friction Pairs

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Polymer materials are widely used as friction parts in aerospace, navigation, new energy and other fields due to their many advantages such as self-lubrication, corrosion resistance and light weight. The tribological properties of Polyoxymethylene (POM) and ultra-high molecular weight polyethylene (UHMWPE) engineering plastics under the conditions of high concentration of H2O2 solution, ultraviolet light irradiation and thermal and oxidative aging were studied. The results indicated that POM was susceptible to aging in these environments, which was manifested by an increase of surface microcracks, a decrease of hardness, and an increase of crystallinity. UHMWPE demonstrated better aging resistance. During the aging process, the wear rate was reduced for POM and increased for UHMWPE. Molecular simulations had revealed that H2O2 solutions were more likely to penetrate into POM and thus lead to its aging. Furthermore, the blending properties of PI with UHMWPE could be enhanced by the addition of the compatibilizer MAH-g-LDPE, which improves the properties of the composite. The research results provide an important reference for the design of high-performance polymer materials, and have been applied to military products such as underwater equipment, thus supporting the national deep-sea strategy.

Keywords: engineering plastics, aging properties, tribological properties, molecular simulation

Analysis and Research on Thermal Accumulation Temperature Field of Friction Surface under Cyclic Action

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Aero-engine main shaft bearings have been working under severe working conditions such as high speed and heavy load for a long time. They also face complex and harsh working conditions such as rapid start and stop, variable speed and load, and oil cutoff. When the bearing is working and the heat generated cannot be dissipated, it may cause thermal damage or even jamming of the bearing. In order to explore the heat generated by sliding friction in the bearing contact area and its diffusion process, the study of the temperature field of the friction surface under cyclic action is carried out. The moving frictional heat flux as a function of the time-dependent contact pressure is applied cyclically on the contact surface. The convectional heat boundary is considered in non-contact region. The transient temperature rise of the friction interface and the cumulative temperature rise of the substrate under the same sliding speed and contact load and different cycle frequencies were analyzed, and verification tests were carried out using UMT. The study found that as the cycle frequency increased, the specimen with damage to the friction interface shortened. The test data was brought into the heat accumulation analysis model for analysis. The results showed that the instantaneous temperature rise exceeded the phase transition temperature of the material. The test specimen was detected and analyzed and found that A plastic deformation layer appears on the wear scar interface, which verifies the calculation results of the cyclic friction heat analysis model.

Keywords: frictional heat accumulation, transient temperature rise, friction and wear test

Numerical Wear Simulation and Wear Coefficient Prediction Using Fully Coupled Conjugate Gradient Method

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Wear is a phenomenon of plastic deformation of surface asperities during contact between two relatively moving surfaces. Because wear-induced deformation of machine components can affect the life of the machine system, wear prediction is crucial for reliability of machines. Traditional wear experiments are time-consuming and prone to significant variations in results as subtle changes in parameters such as temperature, humidity, and surface roughness. To overcome these limitations, wear prediction is carried out through the implementation of numerical wear simulation analysis.

In this study, numerical wear simulation is performed using the minimum wear particle size criterion proposed by Rabinowicz, and then wear coefficients are predicted using Archard's wear equation. Elastic energy is stored in asperities due to normal pressure and shear stress, and when the stored elastic energy exceeds a certain threshold, called “work of adhesion”, asperities undergo detachment resulting in wear. For using the Rabinowicz criterion, accurate calculation of normal pressure and shear stress arising on rough surfaces is essential. In particular, when surfaces of dissimilar materials

contact, the normal pressure and shear stress at the interface are generated in a fully coupled form. Furthermore, the tendency for partial slip in the contact region can be observed and vary depending on the ratio of the applied shear force to the frictional force. To compute those efficiently, Conjugate Gradient Method (CGM) is employed, an optimization technique minimizing residual value; gap and slip distance. The surface deformation required during the pressure optimization process is calculated using the DC-FFT method. The volume of wear particles obtained from the wear simulation, along with normal load, sliding distance, and material hardness, is used to predict the wear coefficient. Finally, the wear coefficient is estimated by applying linear regression to Archard's equation and verified with prior wear experiment results.

Keywords: wear coefficient, rabinowicz Criterion, conjugate gradient method (CGM)

Mechanism and Evolution of Polycrystalline Diamond Compact Back Rake Angles by Experiment and Simulation on Impact Mechanical Response

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Polycrystalline diamond compact (PDC), a vital composite for drill cutter, excels in geological drilling. However, enhancing the durability and efficiency of PDC amid complex impact disturbances becomes crucial as the increasing demand for ultra-deep drilling and directional wells. To address this, this study investigates PDC under diverse back rake angles by Finite Element Simulation, dynamic impact response, and cumulative impact wear tests under different cycles. The shifts in impact force, energy absorption patterns, and wear mechanisms were unveiled through SEM and EDX analyses. Notably, it is found that the lowest energy absorption rate between the back rake angles of -20° to -30°, with reduced fracture failure during lower impact cycles. As back rake angles decrease, the wear mechanism shifts from adhesive wear to the combination of adhesive and abrasive wear due to combined impact and friction wear. This transformation arises from different elastic-plastic deformation stages caused by varying impact forces. This study aims to establish a robust evaluation system for PDC impact toughness, optimize the back rake angle of PDC cutters at different locations on the drill bit, and paving the way for enhanced PDC performance. Meanwhile, the periodic wear of PDC composites under different stress modes and the adhesion mode between tungsten carbide are of great significance to our understanding of the wear process.

Keywords: polycrystalline diamond compact, accumulative impact wear, dynamics response

The Damage Behaviors of Wheel/Rail Materials under Complex Environments

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With the development of the railway transit, the lines are constructed in areas with complex environments, such as the cold environment in the north and high altitude areas, windblown sand environment in the desert areas, and erosion environment in the coastal areas. Wheel and rail are a rolling contact pair which is crucial to the operation of trains. Under the above environments, the wear and rolling contact damage behaviors of wheel/rail materials are complex, which directly influences the running safety of wheel/rail system. Therefore, the experiments are conducted to reveal service damages under the cold, windblown sand and erosion environments.
The results show that under the cold environment of -15°C～-40°C, the wear rate of wheel and rail materials, the angle of surface cracks and the length of the subsurface cracks are increased. The oxidization of the wear debris is decreased. Under the windblown sand environment, the wear rate of the wheel and rail materials and the depth of cracks are decreased. The sand particles are compressed into sheets and then broken into small powder at the wheel/rail contact, which have a lubrication function. Under the NaCl corrosion environment, the wear rate of wheel and rail is increased, but the density of cracks is decreased. The rusty scale formed on the surface is easy to be worn, leading to the increased wear.
In order to improve the wear resistance of wheel and rail, the material microstructure is optimized using the heat treatment, and the correlation between the microstructure size and the wear rate is constructed. It is found that with the decreased of the perlite size and the interlamellar spacing, the wear rate is decreased.

Keywords: wheel and rail; wear; rolling contact fatigue; corrosive wear; microstructure optimization

INVITED:

How Does Tribology Contribute to the Development of Healthcare Devices and High Tech Systems?

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Tribology, being the science of interacting surfaces in relative motion, is ubiquitous in all industrial applications involving surfaces that are in contact and moving relative to each other. Through friction and wear, tribology determines the lifetime performance of products and mechanical systems and is often essential to meeting their primary functional requirements. An everyday example is an electric shaver: wear of the moving cutters against the shaving cap or foil determines how quickly the shaving elements

need to be replaced, but the friction against the skin and hairs govern the shaving effectiveness and the perceived comfort during shaving, which are primary functions of the shaver. In this talk, I will use a number of practical examples to illustrate and explain how tribology principles have contributed to the (pre)development of a variety of healthcare devices and high tech systems.

Keywords: friction, wear, lifetime performance, healthcare devices, high tech systems

Reducing Thermal Gradients and Improving Brake Pad Durability with Architectural Copper Structures

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The high and repeated thermal stresses during the braking of high-speed rails result in thermal fatigue cracks, leading to braking material failures. So improving the heat dissipation capacity of brake pads is crucial to the reliability of the braking system. In addition, the emission of copper (Cu) particles is not only environmentally polluting but also biologically harmful. Therefore, the diminution of Cu in braking pads is becoming an obligation. Optimizing the microstructure is an effective way to improve thermal properties of braking pads. It is proposed in this work to minimize Cu structures architecture with a continuous network in the form of a repeated representative elementary volume enabling better control of heat flow and then increasing the Cu specific efficiency. Bimetallic pads were produced by a co-mixed process of additive manufacturing (AM)-assisted investment casting and a hot-pressing technology. The tribological behaviors were observed and analyzed by a reduced-scale tribometer with an infrared camera. The results show that the pad with a Cu lattice structure can significantly decrease the thermal gradients on the rubbing surface between braking pads and discs. The new architecture shows stable friction and a better wear resistance of braking pads. The decrease in temperature on rubbing surfaces contributes to a more stable third body compared to that of a reference sintering pad.

Keywords: braking pad, lattice structure, thermal dissipation

Quantitative Identification of Rope Damage Based on Three-Dimensional Magnetic Leakage Detection and Magnetic Focusing Technology

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According to the difficulty in detections of coupled damage such as wear, corrosion pits, and wire breakage in steel wire rope, quantitative identification of rope damage based on magnetic leakage detection and magnetic focusing technology was presented. The detection of wire breakage in steel wire rope based on three-dimensional magnetic leakage and focusing technology was carried out. The finite element analysis of broken wire in steel wire rope based on magnetic focusing technology was conducted. The signal research on coupled magnetic structure under different wire breaking modes was performed. The denoising processing of broken wire signals in steel wire ropes based on wavelet transform was presented. The feature value extraction and quantitative identification of magnetic flux leakage signals from broken ropes were carried out. The results show that the quantitative identification results coincide well with the rope damage conditions.

Keywords: quantitative identification of steel wire rope damage, three-dimensional magnetic leakage detection, magnetic focusing technology

Regional Morphological Difference and Evolution of Tread Rubber and Its Formation Mechanism Under High-Speed Sliding Friction

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The tribological behaviors of tread rubber were gradually changed by the worn surface morphologies during friction. The high-speed sliding friction test was conducted by self-developed friction apparatus to investigate the tribological behaviors of the tread rubber. The fan-shaped rubber specimen was tangent to a grinding wheel to simulate the tread-road contact. A clear abrasion pattern can be observed on the rubber surface after sliding friction, which was further captured by the optical digital microscope and scanning electron microscopy for morphological analysis. The worn surface can be divided into three areas, which were mainly formed by the effects of stretching, abrasion, and compression, respectively. The morphological evolution of the worn surface was contributed by frictional force-promoted horizontal expansion and abrasion-promoted vertical expansion. The horizontal and vertical expansions were inhibited and accelerated by high friction speeds, which reduced friction coefficient and caused severe abrasion, respectively. Therefore, increases in specific mechanical properties and moderate acceleration processes were recommended for ideal tribological performance.

Keywords: tread rubber, abrasion pattern, morphological evolution

Study on Fretting Behaviour of Ti-10V-2Fe-3Al Titanium Alloy and 1Cr17Ni3A Alloy Friction Pair and Polymer Coating Protection

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Owing to good mechanical properties and processability, Titanium alloys have been widely used in aerospace, mechanical equipment and other fields. Titanium alloy is often used in fastening structures, such as blade dovetail, lugs, etc., and thus prone to fretting wear and fatigue. And fretting wear and fatigue greatly reduces the service life of the key components, therefore, in recent years, extensive experimental and theoretical studies have been carried out to understand the tribological properties and fatigue properties of Titanium alloys, and to improve the fatigue life of Titanium alloy through the surface treatment technology. In this work, we first conducted fretting wear experiments on Ti-10V-2Fe-3Al titanium alloy and 1Cr17Ni3A stainless steel friction pair. The damage of the friction pair materials under different loads and displacement amplitudes will be explored, and the running condition maps will be used to determine which operating conditions are prone to crack initiation and expansion. Wear patterns will be observed using a three-dimensional white light interferometer and then wear rates will be calculated. Nanoindentation, scanning electron microscopy/transmission electron microscopy (SEM/TEM), X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy will also be used to analyze the mechanical properties, surface morphology, chemical composition and micro-structure at the wear marks of the friction pair. The damage mechanisms and protective measures for friction pairs in the mixed fretting regime will also be discussed.

Keywords: fretting wear, fretting fatigue, titanium alloy

Track 3-I: Coatings and Surfaces Engineering

INVITED

A Decoupling Sensing Method of Separating Temperature Component from The Nano-Scale Metal Film Thickness Measurement Output by Using Eddy Current Effect

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The eddy current method has been widely applied in the field of nano-scale metal film thickness detection. The output signal of an eddy current sensor is generally tiny in practice, and it is easily affected by the temperature variation, which results in a decrease in the measurement accuracy. How to separate the temperature effect on in-situ film thickness measurement for achieving a high precision is a major problem. Based on the eddy current effect, a film thickness detection model is established by coupling an electromagnetic field and a temperature field, and the influence of the film thickness and temperature on coil impedance is revealed in this study. It is found that the inductance and resistance of the coil vary monotonically as thickness and

temperature with a measure of linearity in a certain range, as well as the real part and imaginary part of the output voltage which is converted by an AC bridge. Then a film thickness-temperature decoupling method is proposed, and a group of linear calibration intervals are divided considering the linearity and measurement accuracy. According to a series of calculation and experiment results, it is confirmed that the method can decouple the two variables well, and improves the measurement accuracy and temperature stability. At the same time, it is feasible to achieves a synchronous sensing of metal film thickness and temperature in a certain range, by establishing a fitting relationship between the output voltage and the two variables. In addition, the proposed decoupling sensing method can also be applied to the synchronous multi-parameter detection of lubricating oil film state, which has been verified by the experimental testing.

Keywords film thickness measurement, eddy current sensor, temperature

Superhydrophobic ER Composite Coating for Excellent Wear and Corrosion Resistance

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Marine equipment in the ocean splash zone is subjected to the harsh wear-corrosive environment of high humidity and salinity accompanied by wear from wave and sand impacts, resulting in a severe reduction in the service life of marine equipment. The development of superhydrophobic coating technology has become a new approach to enhancing the corrosion resistance of marine equipment, but there is a lack of research on the wear-corrosion synergistic behavior of superhydrophobic coatings. In this study, a superhydrophobic epoxy resin (ER) composite coating was designed based on surface texture technology and low surface energy treatment technology, which obtains an ideal contact angle of 154°. The superhydrophobic ER composite coating has good robustness and still maintains a high contact angle under mechanical wear and acid-base environments. Excellent wear and corrosion resistance of the superhydrophobic ER composite coating were revealed experimentally. These properties are synergistically enhanced by polymorphic fillers and hydrophobic surfaces. The multi-morphic fillers (fly ash microspheres-graphene oxide, FACs-GO) in the ER base fill the internal voids and strengthen the texture, resulting in a low coefficient of friction and abrasion loss. Under wear-corrosion conditions, the superhydrophobic ER composite coating showed a 10% reduction in coefficient of friction and a 20% reduction in abrasion loss, demonstrating excellent wear resistance. The stabilized air layer captured by the superhydrophobic surface effectively prevents electrolytes from penetrating the coating, and the FACs-GO hybrid filler also enhances the corrosion resistance of the coating by prolonging the penetration path of the corrosive medium.

The impedance modulus of the superhydrophobic ER composite coating was increased by 1 order of magnitude as measured by an electrochemical workstation. This superhydrophobic ER composite coating has great potential for application in the field of wear and corrosion resistance of marine equipment.

Keywords surface texture, superhydrophobic, ER composite coating, wear, corrosion resistance

Bioinspired Design of Multifunctional Solid-Repellent Coatings

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Sticky problems on surfaces from various solid foulants inhibit us from the access to clean toilets, hygiene medical ware, and high-efficient energy transfer. They vastly exist in most industrial, medical, and household interfaces, and they dramatically dysfunction the well-designed surface structures by sticking on them. In contrast, nature has provided us abundant examples of keeping surfaces clean, from duck feather to lotus leaf, to springtail skin, to pitcher plant rim, and to many other insect/animal surfaces. These examples share some common materials design principles for antifouling, particularly for solid repellency. With complex fouling conditions on surfaces for various applications, it is critical to explore the mechanisms of solid-repllent natural surfaces and create effective antifouling coatings.

Herein, we have developed a new design principle for developing solid-repellent coatings through advanced nano-manufacturing methods. In particular, we fabricated partially crosslinked omniphobic coatings that can repel a broad range of foulants, comprised of both liquid and solid phases. The fabricated coatings are an order of magnitude more resistant to cyclic abrasion than current state-of-the-art slippery surfaces. Furthermore, through the integration of classic wetting and tribology models, we introduce a new material design parameter for abrasion-resistant polymeric coatings. More importantly, a magnetic responsive anti-icing coating is developed and demonstrates significant anti-icing capability towards large-scale icing. This combination of mechanical durability, broad antifouling properties, and stimuli-responsibility enables the implication of such coatings to a wide variety of industrial and medical settings, including wind turbine blades, heat exchanges, and antifouling robotics.

Keywords anti-icing, bioinspired design, mechanical robustness, surface science

KEYNOTE

Abnormal Tribological Properties of Graphite and Molybdenum Disulfide at Cryogenic Temperature

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Ultra-low temperature is a particular extreme environment. Tribology involves a lot of friction and wear problems of materials in extreme environment, and the research of cryogenic tribology is becoming more and more urgent and important nowadays. Therein, the movement of atoms at the cryogenic temperature is greatly inhibited, resulting in a series of abnormal phenomena, such as superconductivity, superflow and others. We studied the tribological behavior of graphite and molybdenum disulfide (MoS2) at ultra-low temperature under ultra-high vacuum, and found that the two materials showed opposite phenomena at cryogenic temperature compared with that at room temperature. With the decrease of temperature, the friction coefficient and wear rate of MoS2 reduce. At room temperature of 300 K, the friction coefficient is the lowest (about 0.02), and the wear rate is 7.36×10-7 mm3/N·m. While at cryogenic temperature of 50 K, the friction coefficient is the highest (about 0.07), and the wear rate is 2.15×10-6 mm3/N·m. This is due to the formation of ordered (002) basic plane parallel to the sliding direction at 300 K. However, at 50 K, the hardness of MoS2 increases, and thus ordered basic plane and transfer films are not easily formed at the friction interface, showing typical brittle spalling wear. On the contrary, the graphite wears out rapidly at 300 K, the friction coefficient fluctuates between 0.25 and 0.45, while the friction coefficient decreases to 0.05 at 50 K, and the wear rate is 1/83 of that at 300 K. It is attributed to the fact that the temperature difference between the upper and lower surfaces of the graphite nanosheets promotes the formation of graphite nanorollers during the cryogenic friction process, showing the rolling lubrication effect. Our work will provide guidance for the selection of lubricating materials under cryogenic temperature service conditions.

Keywords tribological properties, cryogenic temperature

Effect of Laser Shock Peening on Tribological Properties of 55SiMoVA Bearing Steel

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Wear is an important factor limiting the service life of 55SiMoVA bearing steel. Laser shock peening (LSP) is a new surface strengthening technology that enhances materials' friction and wear properties by refining the grains, generating residual compressive stresses and increasing hardness. In this work, a Y09-N04 series LSP system with laser

energy of 7J, spot diameter of 3mm and pulse width of 10ns was applied to prepare the LSP specimens of 55SiMoVA bearing steel. Meanwhile, the surface morphology, phase transformation, mechanical properties and wear behavior of 55SiMoVA bearing steel prior and after LSP treatment were investigated. The results showed that the XRD diffraction peaks were broadened, and no new phase was formed after the LSP treatment. A residual compressive stress layer was constructed on the subsurface surface with a maximum residual compressive stress of -793.1MPa. The microhardness was increased by 17.4%, and the volumetric wear rate was reduced by a maximum of 36%. Due to the high pressure effect of the laser shock wave, the overall kurtosis and roughness angle of the surface profile was reduced, resulting in a lower coefficient of friction. Simultaneously, the hardness enhancement limited micro-cutting on the wear surface, the residual compressive stress inhibited crack formation and expansion, and the resistance to abrasive and delamination wear was improved.

Keywords laser shock peening, 55SiMoVA bearing steel, surface morphology, coefficient of friction, wear characteristic

Microstructure and Fretting Wear Performance of FeCrAl Coating on Ferritic/Martensitic Steel after Lead-Bismuth Corrosion

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The fretting wear of fuel cladding caused by fluid-induced vibration is a key issue to be considered in the design of lead-cooled fast reactors (LFRs). The fretting wear of fuel cladding As the most important candidate fuel cladding, the fretting wear behaviour of FeCrAl coatings on Ferritic/Martensitic (F/M) steel need to be studied. Considering the effect of lead-bismuth corrosion on the fretting wear, the FeCrAl coatings was subjected to the lead-bismuth solution at 550 ℃ for 1000 hours in this study. The morphology, microstructure, phase composition, and element distribution of FeCrAl coatings on F/M steel after corrosion were studied, and the fretting wear behaviour and damage mechanism were analyzed. The results show that the outer FeCrAl coatings has a loose and porous microstructure feature, leading to a relatively low hardness value. The FeCrAl coatings after corrosion present a weaker ability of fretting wear resistance because the LBE-filled holes locating at the FeCrAl coatings interfaces has many microcracks, which strongly reduce their bonding strength. The wear mechanism of FeCrAl coatings after corrosion is delamination and abrasive wear.

Keywords FeCrAl coating, lead-bismuth corrosion, microstructure, fretting wear

Effects of Ultrasonic Surface Rolling Processing on the Surface Properties of 4Cr13 Stainless Steel

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Uitrasonic surface roling processing (USRP) was applied on 4Cr13 stainless steel. Microstructure observations of the USRP sample surface indicate that the processing can exhibit significant plastic deformation, with a maximum depth of about 253.4 um, and refine the average surface grain to 0.5 um. In contrast to the untreated sample, the USRP sample has a minimum surface roughness Ra of 80.1 nm, which is 93.1% lower. Tests of mechanical properties showed a 37.0% increase in the maximum surface microhardness for USRP samples. The residual compressive stress can be as high as -484.4 MPa. lt has also been found that USRP can enhance tribological properties under different normal loads. Adhesion oxidation wear dominate in the process of dry-sliding friction based on the surface/interface analysis. The improvement in antifriction and wear resistance is mainly attributed to the reduction in surface roughness and the increase in mechanical properties afte USRP treatment.

Keywords ultrasonic surface rolling processing, surface roughness, microhardness, residual stress, tribological properties

INVITED

Adhesive Contact for Elastic Systems and Structures Based on Johnson-Kendall-Roberts Formalism

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Adhesive contact plays a pivotal role in modern engineering systems, especially at both micro and nano scales, encompassing various applications such as depth-sensing indentation, micro-electro-mechanical systems (MEMS), and artificial adhesive surfaces. Among the multitude of theories applied to address adhesive contact problems, the Johnson-Kendall-Robert (JKR) theory stands out as a classical, elegant and widely utilized approach. The JKR formalism integrates two fundamental concepts: (1) the Derjaguin balance energy approach and (2) the superposition of solutions to two non-adhesive contact problems, namely, the Hertz-type and the Boussinesq-type problems. The effectiveness of the JKR formalism could be further underscored by harnessing the characteristics of slopes in force-displacement diagrams of non-adhesive cases. This enhancement facilitates explicit transformations of force-displacement curves from non-adhesive to corresponding adhesive cases. The resultant condition could be

expressed through a set of formulas, which proves to be a valuable extension of the JKR theory. The explicit transformations demonstrate practical applicability across a myriad of adhesive contact problems in diverse elastic structures expanding the utility of the theory across a broad spectrum of engineering scenarios, such as layered substrates, transversely isotropic materials, monomolecular membranes, and so on.

Keywords adhesion, JKR theory, adhesive layers

Preparation and Characterization of Wear Resistant TiO layer on Ti Alloy

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Titanium monoxide (TiO) is golden in color, and of good chemical inertness and high hardness, making it a potential candidate for decorative and protective coatings. In this study, a TiO layer was coated on Ti alloy substrate through a combination of cathode plasma electrolysis (CPE) and comproportionation between the Ti substrate and Ti4+ from the electrolyte. The thickness of the obtained TiO layer was around 500 nm, with a hardness of 11 GPa, a modulus of 220 GPa and a critical load of 55 N. The coefficient of friction of the CPE-treated sample vs. ZrO2 ball was decreased from 0.4 to 0.6 to around 0.2 when the Hertz pressure was less than 885 MPa. The wear rate of the CPE-treated sample was reduced by ~450 times compared with that of the untreated Ti alloy. Correspondingly, the wear rate of the ZrO2 ball was reduced by ~170 times. In addition, wear resistance of the CPE-treated samples was also significantly improved for common metallic materials (such as stainless steel, carbon steel, or copper alloy) as the counterpart. The surface morphology evolution and the mechanical properties of the TiO layer can avoid the severe abrasive wear as well as adhesive wear, and contribute to the excellent antiwear effects. CPE demonstrates a technologically relevant capability, especially in forming a TiO antiwear layer on Ti alloy.

Keywords TiO layer, titanium, surface treatment, antiwear design, cathode plasma electrolysis

SiC-DLC Composite Coating for Low Friction under Boundary Lubrication in Water Friction System

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SiC (Silicon carbide) exhibits ultra-low friction under water-lubricated condition, but it shows relatively high friction in boundary lubrication. DLC (Diamond-like-carbon) coating has high load capacity in water-lubricated condition. Thus SiC-DLC coating

which is a composite of SiC and DLC has a potential of low friction and high load capacity under water boundary lubrication. Therefore, this study aimed to demonstrate the possibility of stable, low friction in water boundary lubrication using SiC-DLC coating.
Ball-on-disk friction tests were conducted using SiC as the ball specimen and SiC-DLC coating on SiC substrates as the disk specimen. SiC and DLC coating are also used as the disk specimen for comparison. All the experiments were performed under 0.01 m/s and 10 N. SiC-DLC coating used in the experiments was deposited by simultaneously deposition of DLC coating by the CVD method and sputtering SiC by the PVD method. The Si concentration in the SiC-DLC coating was varied from 10 at.% to 28 at.% by increasing the sputtering voltage from 500 V to 700 V. Raman spectra analysis are used to analyze carbon structure of SiC-DLC coating.
friction coefficient of SiC was more than 0.2, while DLC shows low friction coefficient less than 0.1. At the same test conditions, SiC-DLC coating exhibited a low friction coefficient less than 0.05 and stable friction behavior. Therefore SiC-DLC coating has both the excellent friction characteristics of SiC in water lubrication and the high load capacity of DLC. When the Si concentration was less than 20%, the friction coefficient tended to decrease as the Si concentration increased. On the other hand, when the Si concentration was above 20 %, the friction behavior became unstable and showed high friction coefficient higher than 0.1. According to Raman analysis, G peak position of SiC-DLC coating before experiments shifted to lower wavenumbers when Si concentration increased.

Keywords boundary lubrication, tribochemical, SiC-DLC composite coating

Fabrication of 3D Porous Oil-Filled Coating Integrated with Oleophilic MXene Nanoflakes for Exceptional Anti/De-Icing Performance

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The accumulation of ice on the surfaces of equipment/facilities can lead to energy wastage, substantial economic losses, and even pose a threat to personal safety. In this work, A three-step method was employed to fabricate a three-dimensional (3D) porous oil-filled coating doped with oleophilic MXene nanoflakes (POG-PDMS-EM@MXene), featuring a pre-coated oleogel sealer layer. The results suggested a reduction of approximately 99.1% in ice adhesion strength (~4.66 kPa) compared to the sandblasted aluminum plate. Moreover, the coating consistently maintained ice adhesion strength below 10 kPa for 70 days (~210 cycles of ice accretion and de-icing tests). The ice adhered to the coating surface through freezing could easily detach at an inclination angle of 11° without the application of external force under simulated solar radiation power of 96 mW/cm² (1 sun) at an ambient temperature of −10°C. The superior anti/de-icing performance of the POG-PDMS-EM@MXene coating can be primarily attributed to its low interfacial modulus and low surface energy, the exceptional retention of silicone-oil, which remains liquid at even low temperatures, and the excellent photothermal effect. The 3D porous oil-filled coating, possessing extremely low ice adhesion and remarkable de-icing stability, demonstrates substantial potential for practical applications that require sustained anti/de-icing performance.

Keywords ice adhesion, 3D porous oil-filled coating, expandable microsphere

Wear Resistant, Transparent and Antifouling Diamond Coatings via Electrostatic Self-Assembly Seeding

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Biofouling is a worldwide problem from healthcare to marine exploration. It is challenging to achieve anti-biofouling coatings with high stability such as abrasion, corrosion, and flawed film adhesion. Here, bio-inspired micro- and nanostructured hierarchical diamond films were developed to simultaneously achieve self-cleaning, high transparency, and marine antibiofouling, combined with mechanical and chemical robustness. These coatings were designed and successfully constructed on various commercial substrates, such as titanium alloys, silicon, and quartz glass via self-assembly seeding and chemical vapor deposition growth. The topography of the diamond nanofilms was determined by initial nanodiamond seeds distribution, which was adjusted by nanodiamond colloidal stability. The unique surface structure of diamond films reduced bacteria attachment by 90−99%. In the marine environment, these biomimetic diamond films significantly reduced more than 95% adhesion of green algae. The structured diamond films retained mechanical robustness, superhydrophobicity, and antibacterial efficacy under high abrasion and corrosive conditions, exhibiting at least 20 times enhanced wear resistance than the bare commercial substrates even after long-term immersion in seawater. For the transparent nanodiamond films, UV-Vis transmittance achieved max. 90 %, while IR transmittance was between 85% and 90%, which is close to the bare quartz (95%). The bio-mimicking nanostructured diamond film represent a potent solution for achieving highly transparent, anti-biofouling and highly durable optical coatings for biomedical and marine optical instrument.

Keywords diamond coating, nanostructure, self-cleaning, bacterial adhesion, marine biofouling, wear resistance, transparency

Investigation on the Pitting Fatigue Properties of Diamond-like Carbon Film Under Rolling Friction Contacts

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Electric vehicles (EVs) are attracting attention due to growing interest in environmental issues. However, in EVs, the trend towards high-speed rotation of motors leads to an increase in the contact frequency per unit time, thus demanding an improvement in the pitting resistance of components such as gears and bearings.

Diamond-like carbon (DLC) film is amorphous carbon film with a mixture of sp2 and sp3 carbon bonds. It has excellent properties such as high hardness and wear resistance. It is known that crack propagation can be suppressed due to high hardness. Therefore, the application of DLC film is expected to improve pitting resistance. However, there are still many uncertainties regarding the causes of micropitting in DLC film. In this study, we applied ta-C film to the ball, and two types of the balls were used: uncoated steel and ta-C coated. To investigate the pitting fatigue properties of DLC film, ball-on-disc tests were conducted for 40 h and 96 h in base oil lubrication under pure rolling contacts.

After 40 h test, micropitting occurred on the uncoated ball, but no micropitting was observed on the ta-C film. This indicates that ta-C film has an excellent property of pitting resistance due to high hardness. However, when the test duration was extended to 96 h, micropitting occurred on the ta-C film, with a depth of 0.5 μm. In the worn track, we observed the decrease in hardness and the change of sp3 bonds to sp2 bonds were confirmed by nano-indentation and Raman spectroscopy. Furthermore, XPS depth analysis revealed that this structural change extended to a depth of 0.5 μm within the ta-C film. This corresponds to the depth of micropitting observed on the ta-C film. In our presentation, we will report the results of rolling-sliding friction tests and the micropitting mechanism on ta-C film.

Keywords DLC, micropitting, MTM

Track 5: Biotribology and Biomimetics

INVITED:

Fabrication of Lubricating Nanoparticles and Their Application in the Treatment of Early-Stage Osteoarthritis

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Osteoarthritis (OA) is a chronic degenerative joint disease affecting hundreds of millions of people worldwide. It is primarily characterized by the gradual degeneration of joint cartilage, leading to pain and functional impairment. Current treatments mainly focus on symptom management and slowing disease progression rather than providing a cure. Recently, the application of nanotechnology in the biomedical field has opened new possibilities for developing novel therapeutic strategies. This study aims to develop a novel treatment method based on lubricating nanoparticles, utilizing the hydration lubrication mechanism, for early-stage osteoarthritis intervention.

Phosphatidylcholine, one of the main components of articular cartilage, exhibits good biocompatibility and the ability to form hydration layers, which can enhance lubrication and reduce wear through the principle of hydration lubrication. We employed innovative chemical synthesis methods to successfully fabricate various nanoparticles with enhanced lubricating properties, as well as anti-inflammatory and targeting functionalities. These nanoparticles can effectively integrate into the articular cartilage surface, significantly improving joint lubrication and thus reducing cartilage wear and degeneration. Cell experiments demonstrated that the nanoparticles possess good biocompatibility and safety, while animal experiments showed that joints treated with lubricating nanoparticles exhibited better biomechanical performance and lower inflammation levels, highlighting their potential in delaying the progression of early-stage osteoarthritis.

In summary, our research has opened a new avenue for the treatment of early-stage osteoarthritis, providing a novel strategy. These findings not only enhance our understanding of the potential of nanotechnology in medical applications but also lay the foundation for future clinical applications.

Keywords: Hydration lubrication, Osteoarthritis treatment, Nanotechnology

Investigation of Frictional Characteristics of the Knee Joint of the House Cricket by Pendulum Friction Test Simulating Limb Movements

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Orthopterans are a group of insects that includes grasshoppers, crickets, and katydids. With remarkably long hindlimbs, they leap much longer than their body length. During this leaping motion, the hindlimbs extend from a folded position in about 0.04 seconds. This characteristic movement requires low friction at the knee joint. It is also considered necessary to have abrasion resistance to withstand the repetition of violent jumping movements.

In a previous study of the katydids, it was reported that the friction coefficient of the hindlimb knee joint was 0.053 and that little wear was observed on the joint surface after several thousand sliding movements. However, in this report, the hindlimb was disassembled and slid in a straight-line direction, it is different from the actual jumping motion.

In this study, we constructed a pendulum friction tester that can simulate the bending and extending motions of the limbs and investigated the frictional characteristics of the knee joint in House crickets. In order to compare the frictional properties by sex and limb sites, we used male and female hind and middle limbs for the experiments. In addition, to investigate the relationship between frictional properties and surface structure, the contact surfaces of the knee joints were observed with the electron microscope.

As a result, the friction coefficient of the knee joint was smaller in the middle limbs than in the hindlimbs, in contrast, no sex differences were observed. In addition, microscopic observations revealed that the contact surfaces were smooth on one side on the hindlimbs, whereas both sides were uneven on the mid limbs.This suggests that the middle limb, which had an uneven contact surface, exhibited lower friction due to a decrease in the contact area of the knee joint and a weakening of the adhesive force.

Keywords: Biotribology, Crickets, Pendulum friction tester

A Multi-scale Simulation Model for Blood Flow and Oxygen Diffusion in the Artificial Capillary Network

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Capillary networks serve as the primary sites for oxygen and nutrient exchange in organs, playing a critical role in function and metabolism due to their high exchange efficiency and low flow resistance. Drawing inspiration from the alveolar capillary network (ACN), this study introduces a novel three-dimensional artificial capillary network. A multi-scale simulation model was developed to evaluate and optimize this design. The model, based on the Navier-Stokes equations, takes into account the non-Newtonian behavior of blood, the nonlinear oxygen diffusion, and the phase separation effect at diverging micro-bifurcations. The simulation across multiple scales—from the overarching structure down to the minutiae of its smallest branches—focusing on optimizing design parameters for enhanced oxygen exchange efficiency and reduced pressure drop. A comprehensive analysis compared oxygenation efficiency under various design parameters and flow rates, identifying the optimal configuration for superior performance. To demonstrate the potential of this novel oxygenator, we compared it with standard extracorporeal membrane oxygenators (ECMOs) using hollow fiber membranes and microfluidic oxygenators. The results showed that the new design reduces flow resistance significantly under similar conditions. Furthermore, we also confirm the manufacturability of the ACN-inspired oxygenator, laying the groundwork for its development towards practical use.

Keywords: capillary networks, gas transfer simulation, bioinspired design, membrane oxygenator

Simulation and Microfluidic Observation of The Microscale Dynamic Process of Clot Formation at the ECMO

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The membranous lung is the core component of extracorporeal membrane oxygenation (ECMO), playing a crucial role in partially or fully replacing lung function during extracorporeal circulation. Clotting and blockage of the membranous lung are among the primary reasons for its failure.Firstly comprehensive research on the overall flow field of the oxygenator is essential. However due to the opacity of blood, it is impossible to directly observe the flow field at the inlet, outlet, internal microstructure and contact boundary of the membrane fibers within the blood oxygenator. In this study, we conducted simulations and modeling using the turbulent k-epsilon model to assess and predict the actual flow field within the designed oxygenator,also obtained the boundary conditions at the entrance of the microscale fluid film.A microfluidic chip was designed by us to simulate the velocity field and shear rate distribution between membrane fiber gaps and between membrane fibers and microchannels. To address the issue of clotting in actual membrane fiber gaps, we constructed a simulated microscale clotting model. The occurrence of clotting within the membrane fiber gaps, which typically happens during actual extracorporeal perfusion processes, was simulated by us. This was achieved by adjusting the perfusion flow rate of blood to control the shear rate in the microchannels. Based on this, we performed real-time observation and analysis at the microscopic level using the simulated microfluidic chip with membrane fibers and studied the actual occurrence of clotting in membrane fiber gaps and membranous lung microstructures under different shear rates, aiming to identify the flow rate range with minimal impact on shear-induced clotting.Finally for the study of continuous anticoagulation therapy in animal experiments with ECMO, this study will provide reference concentrations for different anticoagulant agent pretreatments of blood corresponding to perfusion flow rates of 1 L/MIN (low flow) and 6 L/MIN (high flow).

Keywords: membranous lung, blood clotting, shear rate, microscale, anticoagulation

Investigation of Pain Sensation Induced by Friction at The Lower Limb/Prosthetic Socket Interface

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Below-knee prostheses are important rehabilitation assistant devices for restoring walking function in lower limb amputees. However, skin injuries and pain caused by long-term friction and compression between the residual limb and prosthetic socket seriously affect the rehabilitation and life quality of patients, which greatly reduces the clinical application of the prosthesis. Pain sensation is a complex neurophysiologic process, and little research has systematically elucidated the formation mechanisms of pain sensation from skin friction and compression to the cognition of the brain. Therefore, this investigation systematically studied pain sensation based on subjective assessment, skin friction, and the neurophysiological response of the brain. Friction tests between the skin of the lower limb and the prosthetic socket were carried out, and electroencephalography methods and subjective assessment were employed to determine the key physical stimulation that contributes to the pain sensation and obtain the frictional pain thresholds for different regions of the human lower limb. The relationships between the friction contact characteristics and the physiological response of the skin, and the formation mechanisms of pain sensation induced by friction and compression were revealed. The results can help in understanding the pain sensation induced by skin friction and provide data support for the design of comfortable below-knee prostheses. It is also helpful for providing the technical support for the rational use of prosthesis sockets.

Keywords: Skin friction, Pain sensation, Electroencephalography, Prosthesis socket

Effects of Lubricating Squalene on The Early Wear of UHMWPE – Insights from Molecular Dynamics Simulations

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Ultrahigh molecular weight polyethylene (UHMWPE) stands out as a popular artificial joint material, but its service life is limited by unfavorable biodegradation and wear caused by friction in body fluids. The accumulation of plastic deformation on the surface of UHMWPE at the initial frictional stage is a precursor to the development of wear, and thus the reduction in the service life of UHMWPE. In order to investigate the microscopic wear mechanism of UHMWPE under the participation of squalene, a typical component in the body fluid, the friction process of UHMWPE lubricated by squalene were constructed by using molecular dynamics simulation under the United-Atom force field. The diffusion behavior of squalene into UHMWPE and its influence on the tribological properties of plastic deformation of UHMWPE were discussed. The results show that the squalene lubricating film gradually diffuse into UHMWPE's subsurface during the frictional process. Meanwhile, polyethylene chains on the surface of UHMWPE present paralleled alignment along the frictional direction, resulting in the generation of plastic deformation on the surface layer. The conformational

rearrangements of polyethylene chains bring the generation of cavities between them, which eventually facilitates the diffusion of squalene into UHMWPE. On the other hand, in the mixed model, the squalene in the UHMWPE substrate could increase the plastic deformation of the surrounding polyethylene chains, and this phenomenon was strengthened with the increase of squalene. Finally, the conformation analysis shows that the paralleled distributions of polyethylene chains also induce similar molecular orientation of squalene, which in turn reduces the internal stress and interaction strength of adjacent polyethylene chains, which causes further accumulation of plastic deformation of UHMWPE. Therefore, the absorption of squalene from body fluids leads to the increase of plastic deformation on the surface of UHMWPE, while the continuous accumulation will further induce the biodegradation and wear of UHMWPE.

Keywords: Plastic deformation, UHMWPE, Squalene

A Skin-Inspired Triboelectric Sensor with Normal-Shear Stress Perception

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A comprehensive sensing of normal and shear stress is highly desired by the study of contact and friction mechanics. However, the constraints of the external power supply have impeded the miniaturization, portability and continuity of tactile sensors. Triboelectric nanogenerator (TENG), an emerging technique for mechanical-to-electrical energy conversion, opens a new avenue for self-power sensing[1].

Inspired by human skin[2] (Figure 1), we reported a biomimetic soft tactile sensor, consisting of four TENG units with single-electrode-mode triboelectrification to generate asymmetry electric outputs among them, which enables the decoupling of multidimensional loads including pressure and friction. Simulating the spinosum layer in the finger skin, we designed an elastic hemisphere structure of polydimethylsiloxane to amplify mechanical stimuli and transmit them to the sensitive layer. The sensitivity reached 10.15 mv N^{-1} with the resultant load ranging from 0 N to 8 N and the angle ranging from 0° to 30°. As a biological laboratory automation application (Figure 2), our sensor was installed on a robot manipulator to realize an automatic pipetting operation based on force feedback, solving the problem of droplet residue. Further, a self-powered sensing insole with a TENG sensing array was developed for a comprehensive mapping of normal and shear plantar stress (Figure 3). The insole can dynamically capture plantar stress variations to distinguish between different states during a standing long jump, thereby enabling sports performance evaluation and rectification. Moreover, with the assistance of artificial intelligence in signal processing, our insole can precisely identify different abnormal gaits, highlighting its potential for disease diagnosis and rehabilitation.

Keywords: triboelectric nanogenerators, multidimensional force, biomimetic

INVITED:

Stick-Slip Friction Triggered Wear in the Articular Cartilage

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Articular cartilage is a smooth, white tissue that covers the ends of bones where they come together to form joints. Its primary function is to provide a low-friction, load-bearing surface, facilitating smooth and pain-free movement. The lubrication of articular cartilage is crucial for maintaining joint health and function, as it minimizes wear and tear, reduces friction, and prevents joint degeneration. The lubrication process involves a complex interplay of biological and mechanical factors, including the secretion of synovial fluid, which contains hyaluronic acid, lubricin, and other molecules that create a slippery layer on the cartilage surface. Understanding the mechanisms behind articular cartilage lubrication is essential for developing treatments for joint disorders such as osteoarthritis, which is characterized by the breakdown of this vital tissue.
In this work, we observed stick-slip friction in articular cartilage for the first time under mild conditions. To visualize the load and speed regimes of stick-slip friction occurrence, we introduced a 'Dynamic (Friction) Phase Diagram.' Prolonged exposure of pristine cartilage surfaces to stick-slip sliding increased surface roughness, similar to HA and GAGs digested cartilages. This suggests that stick-slip motion can induce severe morphological changes in the cartilage superficial zone, which may trigger the initiation of osteoarthritis.

Keywords: Cartilage, Biolubrication, Osteoarthritis

Development of A New Anisotropic Wear Prediction Model of Articular Cartilage Based on An Experimental Study

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The tribological behaviour of articular cartilage is likely to be anisotropic due to the unidirectional alignment of the superficial fibres in the tissue, which yet remains insufficiently explored. The aim of this study was to investigate the effect of fibre orientation of the cartilage on its wear behaviour using in vitro wear tests, a new anisotropic wear law accounting for the angle between the fibre orientation and sliding direction was proposed, and a finite element (FE) wear model considering the anisotropic and biphasic properties of the cartilage was developed based on the experimental results. There was a significant correlation between the wear depth under different testing periods and the product of the solid stress and the sliding distance. The wear depth of the cartilage specimens was minimal when the sliding was in the same direction with the fibres and gradually increased with the increase in the fibre-sliding angle until the sliding direction was perpendicular to the fibre alignment. The FE model offers accurate prediction of anisotropic wear of the cartilage. The anisotropic wear behaviour of the cartilage is marked and subject to the unidirectional orientation of the superficial fibres in the cartilage. A new and effective wear modelling framework is developed, accounting for the anisotropic and biphasic properties of the cartilage. The wear model can be used to study the wear of joints.

Keywords: articular cartilage, anisotropic wear, wear prediction model

Multimodal Tactile Sensor Aiming at Smart Space Extravehicular Multi-Finger Operations Based on Finger Tribology

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Tactile sensing of skin, an important component of biotribology, shapes the interactions between hand and the surrounding world, owing to the remarkable natural sensory system. But for astronauts, tactile feedback cannot be obtained biologically due to the very thick protective gloves, which seriously hinders the flexibility of the extravehicular activity. In this work, inspired by human skin, we develop a biomimetic multi-layer tactile sensor (BMLTS) that can work like the fast adaptive and slow adaptive receptors of fingertip to achieve the multimodal tactile perception based on the fusion of thermosensitive, piezoelectric, triboelectric and piezoresistive materials. Based on the BMLTS, the tactile perception for temperature, surface roughness discrimination and smart object grasping is successfully achieved by the tribological behavior between BMLTS and surrounding world. Furthermore, by the combination of BMLTS and deep learning, a biomimetic intelligent perception system (BIPS) that can make decisions is constructed. Intelligent real-time object material identification, writing and recording are conducted using BIPS, reaching the recognition accuracy rate higher than 95%. This work lays the foundation for the systematization and integration of tactile sensors, and paves the way for the development of dexterous tactile perception for extravehicular activities of astronauts

Keywords: Biotribology, Surface topography, Machine learning / AI, Multimodal tactile perception

Track 6: Nanotribology and Superlubricity

KEYNOTE

Hydration Lubrication: The Mechanism and Applications

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The water molecules are attracted by ions or polar groups to form a hydrated layer, due to the strong polarity of them. When two surfaces with hydrated layer are approached to each other to a distance of several nanometers or even less than 1 nm, a strong repulsive force, named hydration force, can be found. Theoretically, the hydration force can be as large as several Giga Pascal. Considering two surfaces separated by the hydration layer slide mutually, the friction between the two surfaces should be very low due to the low shear strength of water. Such phenomenon is called hydration lubrication. The hydration lubrication has been proved by the experiments of surface force apparatus (SFA) and atomic force microscope (AFM). The friction coefficient between two mica surfaces in salt solution can be as low as 0.0001. Recently, hydration lubrication was achieved with tribometer in macro scale. In such case, a Si3N4 ball slid on a sapphire disk lubricated with salt solution. The friction coefficient in the 0.001 order of magnitude was obtained after a running in period. The lubricating mechanism were discussed in details. In addition, we proposed a method for the purpose of enhancing hydration lubrication by improving negative charge density of the material in water. Such material can be employed in the water lubricated bearing and artificial joint.

Keywords superlubricity, hydration force, hydration lubrication

INVITED

Exploring Macroscale Superlubricity in Diamond-Like Carbon Coatings and Ceramics: From Model Testing to Practical Applications

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Tribological contacts contribute significantly to global energy consumption, accounting for 23% (119 EJ). Graphite layers have emerged as effective agents in achieving ultra-low friction in dry friction scenarios, paving the way for superlubricity. Previous studies

have showcased superlubricity in fluids (friction coefficients < 0.01) using mesogenic fluids, igniting interest in practical applications. The challenge lies in sustaining superlubricity under specific conditions for prolonged lubrication.
To address this challenge, we conducted tribological tests on various model lubricants (e.g., glycerol), materials (e.g., ceramics), and coatings (e.g., a-C:H and ta-C) using a model test setup. Promising candidates underwent application tests on a plain bearing tribometer. Integrating experiments with surface analyses and molecular dynamic simulations enabled the identification of tribological mechanisms and promising tribosystems.
Results indicate that selecting suitable friction partners and an appropriate intermediate medium can surpass the performance of reference oils, showcasing superlubricity across boundary, mixed, and hydrodynamic friction ranges, albeit inconsistently across all speeds. Plain bearing tests demonstrated superlubricity across a wide speed spectrum. However, further optimization of model lubricants and coating systems is essential to meet specific application requirements.

Keywords superlubricity; DLC; ceramic

Harnessing Boundary Slip for Achieving Friction Reduction: An Experimental Study on Oleophobic and MoS2 Coatings

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ABSTRACT: Superlubricity refers to achieving an extremely low coefficient of friction (COF) between two sliding surfaces, typically defined as less than 0.01, which is crucial for reducing energy loss and improving mechanical efficiency. There is an inseparable relationship between boundary slip and superlubricity. Theoretically, boundary slip can reduce the velocity gradient of the lubricant, thereby lowering the friction coefficient and even achieving superlubricity. However, the boundary slip is extremely difficult to observe, and the slip length cannot be accurately measured. Inspired by theoretical analysis, experiments were conducted using oleophobic and MoS_2 coatings. Optical interferometry was employed to measure changes in film thickness to determine the occurrence of boundary slip, and a method was proposed to indirectly measure slip length through changes in film thickness. The research found that both oleophobic coatings and two-dimensional material coatings facilitate the occurrence of boundary slip, with varying slip lengths at different positions within the contact area. Boundary slip occurring on static surface did not significantly affect film thickness, whereas boundary slip on moving surface led to a notable decrease in film thickness. Under elastohydrodynamic lubrication (EHL), boundary slip effectively

reduced the coefficient of friction, marking an important step forward in utilizing boundary slip for friction reduction.

Keywords boundary slip, coatings, friction reduction, film thickness, EHL

The Evolution Mechanism of Graphene-Like Structure During Superlubricity Achievement of Si_3N_4/ta-C Friction Pairs

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Superlubricity holds ample potential for energy dissipation and surface protection, which has attracted wide attention over the past years. The superlubricity of Si_3N_4/ta-C lubricated by fatty alcohol has attracted wide attention owing to its novel mechanism depended on graphene-like structure. The present work studied the graphene-like superlubricity mechanism of Si_3N_4/ta-C lubricated by fatty alcohol. The ultralow friction was obtained after a pre-running-in operation that performed under lower-velocity/higher load conditions. Results showed that boundary lubrication is more beneficial to the growth of graphene-like structures, while mixed or elastohydrodynamic lubrication (EHL) are conductive to the superlubricity achievement. Microscale characterization revealed that such graphene-like structure covered the entire surface, which is primarily composited by the aromatic structure of $C_xH_yNO_n$. In the case of Si3N4, the graphene-like structure formed on the tribofilm with a thickness less than 2.7 nm, and it disappeared when the thickness of tribofilm further increased. The tribofilm formed on the ta-C surface had a loose structure when compared to that on Si_3N_4, and mmore graphene-like structure could be observed obviously. The present work revealed the evolution mechanism of graphene-like structure, which can provide theoretical guidance and new paths for superlubricity achievement.

Keywords liquid superlubricity, ultralow friction, graphene-like structure, ta-C

KEYNOTE

Ambient Thermo-Superlubricity on Ultra-Thin Metals

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Achieving superlubricity for dry sliding contact on metals under realistic loading conditions is highly desirable yet remains a grand challenge. In this talk, we will show that that, by transforming the bulk material into ultra-thin sheets through extreme compression, friction on silver can be reduced to an ultra-low state with a coefficient

of friction below 0.001 in ambient conditions. The unusual phenomenon is also accompanied by a stable, liquid-like state of the metal at room temperature. Revealed by atomistic simulations and diffraction experiments, such behavior has been attributed to the emergence of disordered and highly mobile atoms in the ultra-thin metal. We further demonstrate that the superlubric sliding is also applicable for other metals with high diffusivity, suggesting a novel route for realizing intrinsic superlubricity on metals.

Research on the Friction and Wear Mechanism in the Electronic Perspective

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The intrinsic mechanisms of friction and wear are core scientific issues in fundamental tribology research. The frictional contact at solid interfaces ultimately traces back to the interactions between atoms across the interface. The electronic coupling behavior is closely related to friction and wear behavior and their mechanisms. However, research in this area is currently lacking. This report focuses on the behavior of electrons and their evolution, attempting to explore the mechanisms of friction and wear at the microscopic level. This includes the electronic-level origins of frictional sliding barriers and the mechanisms of mechanochemical wear. Using density functional theory (DFT) calculations, we studied the evolution of energy and electronic behavior along the sliding path from van der Waals interfaces, metal interfaces, ionic bonds, and covalent interfaces. We established a quantitative analysis method describing the energy evolution along the sliding path based on electron density changes with contact conformation. We found that the energy changes during the friction process synchronously evolve with the charge density along the sliding path, reflecting a significant linear dependence of friction dissipation on electron evolution. This linear coefficient indicates the extent to which energy dissipation in the friction process responds to electron density, explaining the physical essence of the concept of shear strength. Furthermore, this idea was extended to the understanding of wear mechanisms. Starting from the behavior of electron transfer under stress and combined with AFM experiments, we conducted a physicochemical analysis based on electronic behavior for key models of microscopic wear, such as the stress-modified Arrhenius equation. This helps to understand the mechanisms of wear at the electronic level. The related results can deepen the understanding of ultra-low friction and ultra-low wear behaviors in engineering materials and have been published in journals such as JACS, AFM, and Nano Letters.

Keywords origin of friction; microcosmic wear; mechanochemistry; charge transfer

Modeling and Designing the Electrical Contact of Sliding Interfaces

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Sliding electrical contacts refer to the interface that transfers current between the moving and stationary parts in a mechatronic system. To achieve low friction wear and low contact resistance of sliding electrical contact, we investigate the basic scientific problems from the perspectives of friction and electrical transmission. The details are as follows:

First, we investigate a unique friction tuning effect induced by an electric current in a conductive atomic force microscopy experiment and uncover two main tuning mechanisms of friction by the fluctuation of electronic properties during sliding: (1) electric-field-induced electron density redistribution and (2) current-induced electron transfer. We put forward an electronic level friction model unraveling the relationship between the friction tuning and the electronic property fluctuation (EPF) under electric field/current, which is applicable to tribosystems ranging from conductors to semiconductors and insulators, including two-dimensional material interfaces [1].

Second, we measure the atomic-scale local electrical contact conductance instead of local electronic surface states in graphene/Ru(0001) superstructure, via atomically resolved conductive atomic force microscopy. By defining the "quality" of individual atom–atom contact (ACQ) as the carrier tunneling probability along the interatomic electron transport pathways, we establish a relationship between the atomic-scale contact quality and local interfacial atomistic structure. This real-space model unravels the atomic-level spatial modulation of contact conductance, and the twist angle-dependent interlayer conductance between misoriented graphene layers [2-4].

Finally, according to the ACQ model and EPF model, we propose the Ti-MoS1.5-Gr-Ti superlubricating electrical contact. The first-principles transport calculation shows that the conductivity of this electrical contact is increased by about 78% compared with the traditional Cu-MoS2-MoS2-Cu contact, and the sliding barrier is reduced by more than one order of magnitude, which provides a way for engineering to achieve low friction and low resistance sliding electrical contact [5].

Keywords nanotribology, physics of friction, electrical contact

Moiré Pattern Based Interfacial Superlubricity in Two-Dimensional Materials

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With the development of advanced manufacturing, superlubricity, with a friction coefficient smaller than 0.001, is highly expected at the contacting surfaces. It has been revealed that the Moiré pattern formed between two crystalline surfaces could take a crucial effect on structural superlubricity. Whereas how to tune tribological properties by manipulating the Moire patterns is still not well studied and understood. In this work, a misfit interval statistical method (MISM) is developed to identify the geometrical characteristics of a Moiré pattern quantitatively, in which the distribution of lattice misfits can act as a good indicator to demonstrate (non-)superlubricity at the interfaces. Both the contact size (D) and the twist angle (q) substantially affect the distribution of misfits and hence play a dominant role in affecting frictional properties. Furthermore, a parameter-free model is suggested to distinguish the regimes between non-superlubricity and superlubricity in the D-q diagram. For the case of twisting bilayer graphene, the prediction made by this model are in good agreement with molecular dynamics (MD) simulation results. The model is generic to the other homogenous and heterogeneous interfaces, and the results in this work provide a new perspective on tuning interfacial superlubricity based on the Moiré patterns. [Carbon 191 (2022) 28-35]. Furthermore, the strain solitons propagate along the armchair sliding direction dynamically, while fission and fusion are repeatedly evidenced along the zigzag sliding direction. The MISM is applied to characterize the atomistic misfits at the interface and strain soliton pattern. During sliding along both armchair and zigzag directions, the lateral force depends on the ratio of graphene flake length (L) to strain soliton spacing (Ls) and becomes nearly zero when L is an integer multiple of 3Ls [JPCL, 2022, 13, 7261−7268].

Keywords structural superlubricity, moiré pattern, molecular dynamics simulations

In-Situ Observation of Orientation-Controlled Atomic-Scale Wear Behavior of Metal Re

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For purposes of revealing the atomic wear behaviors, high resolution in-situ TEM has been introduced to investigate the effects of the misorientation of interfacial atomic arrangement on adhesion wear of the metals. Experimental results severe adhesion wear with the formation of wear debris mediated by the mechanism of the large angle twins and the rotation of the crystal band axis, at the angle of the misorientation of ~0 °. As the angle of the misorientation is 1~8 °, slight adhesion wear occur, which is owing to dislocations and twins. Adhesion wear cannot be found in the metallic Re interface with an angle of the misorientation of 15°.

Keywords adhesion wear, misorientation of interfacial atomic

Ethyl lactate Triggers Macroscopic Superlubricity on Silicon-doped Diamond-like Carbon Film without Corrosion of Friction Pairs

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The acid solution can achieve superlubricity in the diamond-like carbon (DLC) film, but the acid solution will aggravate the corrosion of the friction pairs, which making it difficult to increase the contact pressure. In this work, adding ethyl lactate into ethylene glycol as lubricant for the friction pairs of silicon-doped diamond-like carbon (Si-DLC)/steel ball was investigated. Compared to adding acid into ethylene glycol, the stable friction coefficient (COF=0.002) can be reduced by 50%, and the maximum contact pressure can be increased by 100% without corrosion of friction pairs. The characterization experiments demonstrated the steel could catalyze the triboreaction, which induced partial hydrolysis of ethyl lactate into lactic acid and chemically adsorbed on the surfaces of friction pairs. Subsequently, formed a hydrated layer through hydrogen bonding with ethylene glycol molecules, which leading to a significant reduction in friction coefficient. A mechanically enhanced structure was also formed in the worn track of Si-DLC, which could further reduce wear and friction coefficient. This work presents a novel approach to achieve superlubricity on Si-DLC without corroding the friction pairs. It significantly increases the contact pressure and providing support for industrial applications of superlubricity on the DLC.

Keywords superlubricity, ethyl lactate, Si-DLC；

Phytic Acid-Modified Black Phosphorus Nanosheets Achieve Ultra-High Load Bearing and Ultra-Fast Running-In Liquid Superlubricity on Engineering Steel Surfaces

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The realization of superlubricity on engineering steel surfaces is of great importance for their applications and economics. However, achieving superlubricity on steel surfaces usually requires a long break-in period, which may lead to severe wear of the friction pair. Herein, a novel lubricant with superlubricity performance was designed by introducing phytic acid-modified black phosphorus into a mixed solution of polyaspartic acid and ethylene glycol, which shortened the running-in period for achieving macroscale superlubricity ($\mu \approx 0.0048$) on the steel-to-steel contact to 26 s. Meanwhile, the maximum contact pressure could reach up to 710 MPa. In addition, it was demonstrated by a combination of surface analyses and molecular dynamics simulations that the phytic acid-modified black phosphorus is easily adsorbed on the surface of the friction surface to form a phosphorus oxide film, which reduces the

interaction energy between the lubricant molecules and the substrate. This work provides new insights into the lubrication mechanism of black phosphorus and contributes to the design of water-based liquid superlubricants with ultra-fast running-in and high load-bearing capacity for engineering steel surface applications.

Keywords black phosphorus, superlubricity, engineering steel

Ultralow-friction of Hydrogenated Carbon Film at Cryogenic Temperature Induced by Hydrogen Correlated Quantum Effect

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Temperature is one of the governing factors affecting friction of solids. Undesired high friction state has been generally reported at cryogenic temperatures due to the prohibition of thermally activated processes, following conventional Arrhenius equation. This has brought huge difficulties to lubrication at extreme low temperatures in industry. Here, we uncover a hydrogen correlated sub-Arrhenius friction behavior in hydrogenated amorphous carbon (a-C:H) film at cryogenic temperatures and a stable ultralow-friction over a wide temperature range (103-348K) has been achieved. This is attributed to hydrogen-transfer induced mild structural ordering transformation, confirmed by machine-learning-based molecular dynamics simulations. The anomalous sub-Arrhenius temperature dependence of structural ordering transformation rate is well-described by a quantum mechanical tunneling (QMT) modified Arrhenius model, which is correlated with quantum delocalization of hydrogen in tribochemical reactions. This work reveals a hydrogen correlated friction mechanism overcoming the Arrhenius temperature dependence, and provides a new pathway for achieving ultralow-friction under cryogenic conditions.

Keywords ultralow-friction, cryogenic temperature, quantum mechanical tunneling

Track 7: Tribology in New Energy System

INVITED:

Enhanced Charge Density of Triboelectric Surfaces through The Multi-Physical Field Coupling Strategy

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Triboelectric nanogenerator (TENG), as a disruptive energy harvesting technology, have demonstrated unparalleled output performance and cost-effectiveness, making it an effective mean for efficient acquisition and conversion of environmental energy. However, the issue of insufficient power output has progressively emerged as a bottleneck in the realm of engineering application. The surface charge density plays a crucial role in determining the output power of the triboelectric nanogenerator (TENG). In order to construct high-performance triboelectric nanogenerators, this study proposes several mechanisms, including coupling the ferroelectric effect, surface plasma effect, and photogenerated carrier effect, to establish charge trapping sites within the triboelectric layer. This approach aims to enhance the triboelectric surface charge density. A novel approach was developed to enhance the charge density of triboelectric surfaces through multi-physics coupling, leading to the development of a diverse range of hybrid triboelectric materials and exploration of new applications for self-powered triboelectric nanogenerators.

Keywords: Triboelectric nanogenerators, charge density, multi-physical field coupling

Effect of Temperature on Tribology of PTFE Seals in Hydrogen Application

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Liquid hydrogen, due to its high energy density and zero carbon emission, stands as a promising alternative fuel, especially for ultra-high-speed and long-distance aircraft. Selecting the right tribological materials for liquid hydrogen application is challenging. With its broad temperature operation range, PTFE emerges as the most promising seal material for liquid hydrogen storage. However, the friction mechanism between PTFE and steel in hydrogen or at cryogenic conditions remains unclear, necessitating an investigation of their performance and mechanism under these conditions.

This study is divided into two parts. Firstly, we will investigate the influence of oxygen in a hydrogen environment at room temperature at various humidity levels. The effect of other gases, such as ammonia and methane will also be explored. The second part will involve cryogenic experiments to examine differences in the tribological properties of the same atmosphere at low temperatures. Surface chemical analysis will be carried out to study the relationship between the formation of tribofilms and wear under hydrogen atmospheres. This work will reveal the operational principles of PTFE seals and propose methods to reduce wear in hydrogen, which will be critical for the future development of new energy applications

Keywords: Hydrogen application, PTFE tribology, Cryogenic conditions

Research on Friction and Wear Properties of New Energy Logistics Vehicle Brake Materials under Different Ambient Temperature and Humidity Conditions

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With the rapid advancement of new energy logistics vehicles in China and the significant enhancement of transportation efficiency, the safety of brake systems has garnered widespread attention. As an environmentally exposed system, the performance of disc brake systems is significantly influenced by ambient temperature and humidity. This study explores the friction and wear performance of brake materials for new energy logistics vehicles under different temperature (3 °C, 23 °C, 43 °C) and humidity conditions (35 %, 65 %, 95 %) using pin-disc experimental device. The findings reveal that at 3 °C, the friction coefficient exhibits extreme sensitivity to changes in humidity, with a significant reduction as humidity increases. Simultaneously, the increase of humidity leads to the transition from adhesive wear to abrasive wear and fatigue wear. At room temperature (23 °C) and 43 °C, humidity has minimal impact on the friction coefficient;however, higher humidity promotes oxidation film formation on the friction surface leading to dominant oxidation wear. Notably, in low-humidity environments, temperatures at 3 °C and 43 °C cause severe brake pad wear.The severity is greater at 43 °C because the resin-based components within the brake pad material decompose at elevated temperatures. Under such circumstances, increased humidity helps mitigate brake pad wear rates. The research findings provide valuable insights into ensuring vehicle safety, stability, and reliability for new energy logistics operations across diverse environmental conditions.

Keywords: New energy logistics vehicle brake materials, Ambient temperature, Ambient humidity, Pin-disc test, Wear mechanism

Effect of Local high temperature on Tribovoltaic Effect at Semiconductors Interface

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The tribovoltaic effect is a new physical phenomena be found in the frictional behavior of semiconductor material systems. The influence of temperature is particularly important, because the local high temperature is inevitably generated during the friction process. The most of the existing experiments are done by heating at the macro level. However, the friction temperature rise is a microscopic problem, and its influence on the tribovoltaic effect is more suitable to be discussed from the microscopic perspective.

Here, the pulsed infrared (IR) of AFM-IR equipment is used to microzone heat the sample to simulate the friction local temperature rise, and the influence of friction local temperature rise on the tribovoltaic effect is studied. The results show that the friction local temperature rise has an obvious enhancement effect on the tribovoltaic effect, and there is a good linear relationship between the instantaneous temperature rise and the tribo-current increment. This has important guiding significance for future research, improve the output of the tribovoltaic effect, and develop new applications of the tribovoltaic effect.

Keywords: tribovoltaic effect, local temperature rise, AFM-IR

Numerical and Experimental Investigations on Thermoelastic Hydrodynamic Performance of Planetary Gear Sliding Bearings in Wind Turbine Gearboxes

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The application of planetary gear sliding bearings (PGSBs) in large wind turbine gearboxes (WTGs) has become an important development trend for high-power wind turbines due to the advantages of improving power density and reducing failure rates. However, the working characteristics of operating at heavy-load conditions and using helical gears to mesh will induce large deformation, axial misalignment, and non-negligible temperature rise in PGSBs. In this paper, a comprehensive analysis model taking into account the influence of axial misalignment, thermal effects, and thermoelastic deformation was presented for the PGSB in WTGs. A full-size test rig for PGSBs was built and simulation experiments were conducted to verify the model. Both the measured oil temperature and film thickness agreed well with the numerical results. The predictions from the model were compared with the results of the isothermal-EHD and rigid-THD models. The comparison results indicated that the pad deformation and temperature rise had obvious effects on the bearing performance and could not be ignored. The effects of bearing clearance and aspect ratios on thermoelastic hydrodynamic performance were analyzed. The numerical results showed that both a lower clearance ratio and a higher aspect ratio could help to reduce the maximum pressure at the bearing edges.

Keywords: Planetary gear sliding bearings, Wind turbine gearboxes, Thermoelastic hydrodynamic performance

Recent Tribological Challenges of Electric Vehicles

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Electric vehicles (EVs) have recently attracted significant global attention as a feasible way to achieve net-zero emissions by 2050 and decrease greenhouse gas emissions, which aids in the reduction of the carbon footprint of the modern transportation sector. EVs encounter a primary issue related to the leakage of electric current from the electric motors to the powertrain. This is known as shaft current, which has a negative effect on the tribological performance of mechanical components. Hence, bearings and gears tend to fail faster than other components due to increased fatigue, corrosion, and wear, which reduces their durability and reliability due to the electrical environment. This presentation summarizes the key tribological challenges of EVs. Furthermore, this presentation offers recent advances in novel tribological techniques for electric mobility systems to improve the performance and durability of EV components.

Keywords: Shaft Currents, Electrified Conditions, Lubrication Mechanisms

Research on The Effect of Water Contamination on Lubricating Oil Properties In Premixed Hydrogen Engine

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Hydrogen is gathering attention as a clean fuel because of its zero carbon dioxide emissions, ease of combustion, and straightforward manufacturing process. On the other hand, hydrogen produces water during combustion, but limited research has investigated the effects of this water on lubricating oil. Saturated water vapor pressure depends on pressure and temperature, but in a high-pressure combustion chamber, water vapor can condense into liquid water and mix with the lubricating oil. Water in the lubricating oil increases the risk of wear and severe damage due to reduced lubrication performance. In addition, condensate water formation is also assumed to be strongly influenced by liner wall temperature. Therefore, this study focused on investigating the effects of hydrogen combustion and condensate water formation on lubricating oil performance. Based on these reasons, this study used a single-cylinder engine that can use both hydrogen and diesel as fuel. The engine was run with different fuels and the amount of condensate entering the oil was investigated at different wall temperatures (from 40°C to 80°C).
An engine motoring test was conducted excluding fuel injection with different wall

temperatures. After this test, the water volume in the lubricating oil did not increase, hence water was not mixed in simply by lowering the liner wall temperature with a chiller. Engine ignition tests were conducted using hydrogen and diesel fuel. For diesel combustion, temperature changes had no significant effect on the water in the lubricating oil. However, with hydrogen combustion, the liner wall temperature change affected the water content of the lubricant to a large extent, especially at 40°C.In addition, after 30 hours of engine operation under this condition, the water percentage in the lubricating oil exceeded 10%. These results show that the water generated by the combustion of hydrogen enters the lubricating oil and affects the lubricant.

Keywords: hydrogen engine, lubricating oil, water contamination

Competitive Mechanism between Interfacial Electric Fieldand Built-In Electric Field for Silicon-Based Tribovoltaic Effect

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The tribovoltaic effect raises an emerging semiconductor energy technology and silicon-based tribovoltaic nanogenerator (Si-TVNG) has aroused great attentions. However, the electrical output of Si-TVNG is extremely unstable due to its complicated mechanism. Here, a competitive mechanism between the built-in electric field (BEF) and the interfacial electric field (IEF) is proposed to determine the current direction and magnitude of the Si-TVNG. The results indicate that the natural oxide layer, load pressure, and resistivity of Si significantly affect the IEF and BEF. The natural oxide layer can store surface charges by contact electrification, resulting in a IEF dominant carriers transport process. Conversely, lower resistivity and higher load pressure can reduce the contact resistance, thereby decreasing the surface charges caused by contact electrification and leading to a BEF dominant carrier transport process. This work contributes to deeper understandings of the tribovoltaic effect and further clarifies the theoretical mechanisms of carrier excitation and directional transport.

Keywords: dielectric layer, direct-current friction, semiconductor effect, single crystal silicon

PEG-based both mechanically and electrically modified flexible tribovoltaic nanogenerator for human joint movement monitoring

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Organic semiconductor based tribovoltaic nanogenerator (TVNG) pose a significant challenge in terms of mechanical strength and electrical response for human kinetic energy harvesting and intelligent sensing. In this work, we proposed a direct current flexible TVNG based on Al and blended film, which is composed of poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate) (PEDOT: PSS) and polyethylene glycol (PEG). The dependency relationship between the conductivity and electric output performance of TVNG is investigated by modifying the conductivity of PEDOT: PSS, which offers an effective approach to simultaneously improving mechanical and electric output performance. Contrasting with undoped PEDOT: PSS, the open-circuit voltage (0.8 V) and short-circuit current (0.6 mA) are increased by 4 times and 2 times, respectively. The peak power density (0.26 $W \cdot m^{-2}$) is increased by 6 times and the elongation at break is improved 10 times. The tribovoltaic textile is fabricated by weaving conductive yarn and Al wire with warp and weft braid method for physical exercising sensing. It has demonstrated its capability to detect bodily joint movement and recognize gesture, highlighting the promising applications of wearable TVNG in medical diagnostics and sports health.

Keywords: Tribovoltaic effect, PEG dopped, Conductivity advancement, Tribovoltaic textile, Wearable electronics

The Effect of Friction on Bonding in Chemical Reactions

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Friction excites pairs of electron holes in a semiconductor material, causing them to separate and transition to higher energy levels. These by friction excitation of non-equilibrium carriers, in the interface to a combination of electric and built-in electric field mobile, produce direct current.In 2023, Adam B. Braunschweig et al. used needle arrays to investigate possible mechanisms by which friction affects chemical reactions. Due to uniaxial stress and needle tip array close to the surface, the surface distortion, conformation distorted, thereby lowering the activation energy of the reaction and the reaction along a different path.We hope to investigate whether friction-excited hole electron pairs can be used to drive chemical reactions.

Keywords: Friction, Chemical reaction

Poster

Group A

Track 1: Friction and Lubrication

Track 5: Biotribology and Biomimetics

Track 6: Nanotribology and Superlubricity

A-01

Numerical and experimental investigation of patterned liquid film thickness in the surface energy-directed assembly process

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Patterned metal oxide thin films constitute crucial components of numerous electronic devices. Conventional fabrication process of patterned metal oxide films exhibits high manufacturing cost due to requirements for expensive vacuum system. In contrast, surface energy-directed assembly (SEDA) process which utilizes contact line friction to drag liquids from certain solution and then forms solid film in specific regions of substrate by post process is vacuum-free, addictive in nature and low-cost, demonstrating extensive applicability in cutting-edge electronic devices. Here, a lubrication-theory-based model is developed to reveal parametric dependence of entrained liquid film thickness during SEDA process. A precursor film is assumed in the dry substrate regions and a two-term disjoining pressure relevant to local wetting property is utilized to characterize the motion of three phase contact line with finite contact angle. In addition, a full-curvature correction is adopted to improve accuracy under large slope conditions. Numerical results shows a power-law dependence of maximum film thickness on nondimensional capillary number, which is consistent in trend with experimental results. The power-law dependence can be identified into two region: when capillary number is lower than about 10-3, the exponents associated with capillary number are remarkably smaller than previous researches, which is

attributed to lateral and longitudinal confinement of the liquid; when capillary number is higher than about 10-3, the exponents shows an obvious increase due to excess liquids brought by liquid bridge break-up. Besides, numerical and experimental results confirm that the ratio of longitudinal and lateral dimensions of the pattern (denoted with R) can alter the exponent of the power-law relationship in low capillary number region: when the ratio deviate from 1, the exponent will increase. In high capillary number region, the ratio R shows no remarkable influence on the exponents.

A-02

Fabrication of Flexible and Transparent Metal Mesh Electrodes Using Surface Energy-Directed Assembly Process

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Transparent conductive electrodes (TCEs) are indispensable components of various optoelectronic devices such as displays, touch screen panels, solar cells, and smart windows. To date, the fabrication processes for metal mesh-based TCEs are either costly or having limited resolution and throughput. Here, a two-step surface energy-directed assembly (SEDA) process to efficiently fabricate high resolution silver meshes is introduced. The two-step SEDA process turns from assembly on a functionalized substrate with hydrophilic mesh patterns into assembly on a functionalized substrate with stripe patterns. During the SEDA process, a three-phase contact line pins on the hydrophilic pattern regions while recedes on the hydrophobic non-pattern regions, ensuring that the assembly process can be achieved with excellent selectivity. The necessity of using the two-step SEDA process rather than a one-step SEDA process is demonstrated by both experimental results and theoretical analysis. Utilizing the two-step SEDA process, silver meshes with a line width down to 2 μm are assembled on both rigid and flexible substrates. The thickness of the silver meshes can be tuned by varying the withdraw speed and the assembly times. The assembled silver meshes exhibit excellent optoelectronic properties (sheet resistance of 1.79 Ω/□, optical transmittance of ≈92%, and a FoM value of 2465) as well as excellent mechanical stability. The applications of the assembled silver

meshes in touch screen panels and thermal heaters are demonstrated, implying the potential of using the two-step SEDA process for the fabrication of TCEs for optoelectronic applications.

A-03

Study on interface modification and its effect on the tribology properties of PTFE/Cu self-lubricating materials

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Henan University of Science and Technology

PTFE/Cu composities as a typical self-lubrication materials have the problems of weak interfacial bonding and high interfacial thermal resistance, which will affect its friction and wear properties. In order to solving the interface problem of PTFE/Cu composities, in this study, the interface between PTFE coating and Cu alloy have been modified by using the polydopamine (PDA) and metal nanoparticles-PDA (NPs-PDA). Then, the effects of different interfacial modified layers on bonding force, thermal conductivity and tribology properties of PTFE/Cu coating materials have been investigated. The results showed that the affinity groups in the PDA both bond with PTFE coating and with Cu alloy by chemical bonding, then it forming good interface bond between PTFE coating and Cu alloy, and make the interface bonding force of the PTFE/Cu coating materials which modified by PDA show 3.5 times higher than that of the PTFE/Cu coating materials without interface modification. The AgNPs-PDA and CuNPs-PDA interfacial modified layers not only improved the interface bonding force of PTFE/Cu coating materials, but also significantly improved the interface conductivity by forming good thermal conducitivity channels at the interface. In particular, the thermal conducitivity of PTFE/Cu coating materials modified with CuNPs-PDA interfacial modified layers is best in this work. Comparing with the samples without interface modification, the durability of PTFE/Cu coating materials modified with PDA, AgNPs-PDA and CuNPs-PDA interfacial modified layers have increased 4.3, 11.4 and 13 times, and their wear resistance have increased 3.2, 11.7 and 17 times, respectively. The relevant research results are expected to providing technical support for long life and high reliability service of high performance self-lubricating materials.

A-04

Tribological mechanism of molybdenum trioxide nanoparticles synergized with water-based sulfur-containing additives

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Henan University

Water-based lubricants are widely used in industry as hydraulic fluids and metalworking fluids because of their environmental, safety and reduced cost advantages. However, there is an urgent need for high-performance water-based additives due to the disadvantage of poor lubricity of water-based lubricants. In this paper, we designed a novel and facile hydrophilic modification method for MoO3 nanoparticles, and outlined the structural defect-mediated grafting pathway of oleic acid diethanolamide (ODEA) on the MoO3 surface: the unsaturated d orbitals of Mo coupled with the electron-rich oxygen centers of ODEA on the oxygen vacancies of the MoO3 surface generated the ODEA-functionalized MoO3 nanoparticles (ODEA-MONP). The prepared ODEA-MONP and water-based sulfur-containing additive (4770) were used as water-based additives, and the tribological performance of the two composites in H2O were evaluated by the UMT-2 friction tester. The results showed that ODEA-MONP and 4770 have excellent frictional properties in H2O, with a friction coefficient as low as 0.04, and synergistically generated MoS2 in water-based lubrication systems. Therefore, this work provides an avenue for in situ vulcanization of molybdenum-containing materials in water-based lubrication systems.

A-05

Relation between bulk viscoelasticity and friction of semi-crystalline polymer using molecular dynamics simulation

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2. Kyushu University

Polymer are good friction materials due to the low weight, self-lubricity, and flexibility of molecular design. Polyethylene is a typical polymer material higher-order structures such as lamellar and spherulites. Due to the difficulty of molecular simulations on semicrystalline polymers such as polyethylene, amorphous-phase

polymers are mostly used for tribological analysis. In our previous study, we succeeded in creating a model of lamellar structure consisting of amorphous and crystalline layers and clarified the stretching process and frictional behavior. In this study, we analyze the viscosity and elasticity of the lamella and discuss the relation between the friction properties and viscoelasticity. The coarse-grained molecular dynamics method based on the United Atom model is used to reduce the number of particles by considering the methyl group monomer as a single particle The Lennard-Jones interaction is used to represent the interaction between coarse-grained particles. Non-equilibrium MD simulations are performed, where steady shear deformation is applied to the system We obtain shear viscosity for different shear rates. Then, the equilibrium Green-Kubo linear response theory is applied to clarify the relationship between stress relaxation and friction in the system for small perturbations based on an integral evaluation of the autocorrelations. Finally, we discuss the relation between viscoelasticity and sliding friction results. We found that not only the elastic but viscosity is important to understand the friction of polymers .

A-06

a study on fully decoupling property in frictional contact based on modified direct method

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Deployment of protective coating is an efficient way to reduce the impact of wear and friction between transmission parts. The fatigue life of such layer-substrate structures is then a key concern in optimization design. In mechanical analysis perspective, integrity of the structures is completely dependent on the stress sates of the surface and sub-surface. Development in efficient numerical algorithms is therefore of great significance for stress field calculation, and furthermore the study of potential physical properties in structural optimization design. In the present work, a frictional sliding contact problem of a cylindrical indenter and layer-substrate structure is modeled. By applying the Fourier transform and convolution theorem, the governing equation in the form of a singular integral equation of the second kind (SIES) is obtained. To liberate the mathematical foundations of the direct solution, which is presented by F. Erdogan for SIES, from Riemann boundary value problem theory, a method in the name of CP is proposed. It is verified that the method is a successful improvement in operability and efficiency. By applying the CP algorithm, a normal-

tangential fully decoupling property in frictional contact is detected. Contact pressure of non-Hertzian type would be symmetric, and the position of tensile peak remains locked. This kind of in-plane surface stress state may imply that, the position of potential crack could stay at the trailing end of the contact area, which would not be affected by variation of friction coefficient.

A-07

Investigation of Coarse-Grained Molecular Dynamics Simulation for Nanoindentation of Amorphous Carbon

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The mechanical behaviors of materials vary depending on scale, with continuum models being applicable for assessing materials at large macroscales, while discrete models are employed to describe behaviors at smaller scales. One of the main problems for simulation is computational costs. In molecular dynamics (MD) simulations, computational costs can rise exponentially depending on the size of the model, even within the nanoscale range. This limitation leads researchers to perform simulations on a much smaller scale and time frame compared to the conditions of the actual experiment. Therefore, the application of MD simulations to investigate tribology-related problems have been limited to a very small material system over a very short time. To overcome this issue, coarse-grained molecular dynamics (CGMD) simulation has been developed and widely used. Although CGMD has been studied for a long time, there have been only a few studies on its applications in modeling amorphous materials. In this study, a CGMD model of amorphous carbon was established to simulate nanoindentation. The nanoindentation problem was chosen since it is widely utilized in assessing the mechanical properties of thin films. The simulation parameters needed to be investigated systematically to stabilize the material system. Particularly, the parameters of potential functions were modified to better describe the interaction between coarse-grained carbon beads. The model was verified by comparing the mechanical behavior results of the CGMD model to the results of a conventional MD model. Further optimization of the CGMD model will be sought through a comparison of the results to the nanoindentation experiment data. The findings of this study are expected to contribute to the development and design of CGMD models for amorphous materials.

A-08

The seal performance transformation of compliant foil gas seals with various microchannels during instantaneous start-stop

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Compliant foil gas seal technology is an advanced non-contact gas film sealing technology. This can meet requirements of hydrogen fuel circulation pumps under variable high speed. However, with the high-frequency variation and vibration requirements of circulation pumps during instantaneous start-stop operations, smooth compliant foil gas seal can't meet the performance requirements of circulation pumps. Through analysis of the design characteristics of face seal microchannels, it is found that the microchannel morphology on dynamic ring or floating ring surface is advantageous for enhancing the gas film force, stiffness and the adaptability. Therefore, this paper evolves a new type of variable angle microchannel on cylindrical surface. On the basis of coupled interface deformation, the performance of variable angle, stepped, helical, and T-shaped microchannels are compared with a new periodically numerical method. The results show that the arrangement of microchannel can increase the compressibility of the gas seal. The variable angle microchannel has a significant impact on the gas compressible. Secondly, the force leakage ratio decreases with the increase of pressure differential and film thickness. This phenomenon indicates that the impact of Poiseuille pressure flow dominates the seal performance. The increase in axial pressure differential increase the leakage rate and decease the gas force. As the same time, the leakage rate of variable angle, T-shaped, and stepped microchannels increase with speed. However, helical microchannel decreases slowly with increasing rotational speed. Variable angle microchannel is the lowest leakage rate of and the highest gas film force. Futhermore, the friction torque of helical microchannels is the highest, and stepped microchannels is the lowest. Compared with the characteristics of different microchannels, this paper provide theoretical guidance for t design of compliant foil gas seal.

A-09

Hierarchical Microtextures Enhance the Stability of Friction Reduction

yayong wang

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Research has shown that textured surfaces can significantly enhance the tribological properties of sliding interfaces. However, the instability of the friction-reducing effect during the wear process of microtextures has become a limiting factor for their technological application. In light of this, the present study proposes a hierarchical microtexture design approach aimed at enhancing the stability of the friction-reducing effect of microtextures. This paper describes the process of fabricating hierarchical microtextured surfaces using femtosecond laser technology. Through ball-on-disk tribological tests, this study thoroughly investigates the impact of the area density and the depth-to-diameter ratios of various levels of hierarchical microtextures on the coefficient of friction. The experimental results demonstrate that hierarchical microtextures not only significantly enhance the stability of the friction-reducing effect but also effectively reduce the coefficient of friction at the contact interface. This research provides valuable insights into improving the stability of the friction coefficient and extending the lifespan of microtextures, offering significant guidance for industrial applications.

A-10

Surface interface modification of synthetic smectite and its properties as thickener

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Smectite grease is excellent high temperature grease. However, the quality of natural smectite is unstable due to its complex composition and uncontrollable properties. The pure smectite with high cation exchange capacity was prepared by hydrothermal method. The thickening ability and rheological properties of smectite were investigated by using octadecyl trimethyl ammonium chloride (OTAC) and octadecylamine (OA) as modifiers. The OTAC-modified smectite (OTAC-smectite)

showed greater basal spacing, organic content and hydrophobic ability than OA-modified smectite (OA-smectite). Obviously, organic matter has a significant effect on the surface interface properties of organic smectite. Grease was prepared by using organic smectite as thickener and polyalpha-olefin 8 (PAO8) as base oil. The storage modulus of OTAC-smectite and OA-smectite grease was 20450 Pa and 15546 Pa, respectively. Compared to natural smectite (N-smectite) grease, OTAC-smectite grease and OA-smectite grease exhibited excellent mechanical stability, colloidal stability, thermal stability and water resistance, which was due to the factor that OTAC-smectite grease can form a stable grease structure with PAO8. Through the tribological performance evaluation, the grease was prepared by synthetic smectite and showed excellent anti-wear and anti-friction performance. Due to the convenient synthetic method and superior rheological and tribological performances, synthetic smectite as a grease thickener has promising potential for use in demanding advanced precision instruments, as well as pharmaceuticals, food, and other industrial fields.

A-11

Analysis of frictional behavior factors of lubrication structure in graphite embedded spherical contact friction pairs

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China Three Gorges University

Solid inlay lubrication is gradually being applied to the bottom pivot bearing of the herringbone gate in hemispherical contact. In order to explore the influence of solid lubricant composition, inlay hole shape and distribution on its friction performance under solid inlay lubrication of the bottom pivot. Firstly, a solid lubricant was prepared by mixing graphite with phenolic resin of different particle sizes, and then its mechanical properties were tested. Based on this, combined with the actual operation of the herringbone gate of the Three Gorges Dam, using the principle of equal contact area, four types of embedded hole shaped bearing shells, namely cylindrical, conical, quadrilateral conical, and spherical crown, were constructed. Static and dynamic analysis was carried out using finite element software, and friction and wear tests were carried out on bearing shell samples in a ratio of 1:20 using similarity principles. The friction coefficient, wear amount, and surface morphology were analyzed, The lubrication performance of the cylindrical hole bearing is better. Finally, EDS equipment was used to analyze the surface composition after wear, and the influence of inlay hole diameter, hole depth, and distribution on the transfer of C element during friction process was studied. The research work in this article provides a theoretical method for the optimization design of embedded lubrication structures in the future.

A-12

Research on the friction and wear performance of a Cr composite coating for high-temperature and high-speed mechanical seals.

An Liu,Shuangxi Li,Haichao Yang,Renyi Cheng

Beijing University of Chemistry Technology

The development of the aerospace industry has resulted in an increase in high-temperature and high-speed working conditions for bearing cavity seals. This has resulted in higher demands for the friction and wear performance of mechanical seals. This paper presents the preparation of chromium coatings with varying thicknesses and carbon nanotube contents using laser cladding on a 38CrMoAlA substrate. The effects of the coatings on the friction and wear performance of the end face of the moving ring and the performance of the seals were verified through simulation analyses and friction and wear tests. The results indicate that the chromium/carbon nanotubes composite coatings (Cr/MWCNTs) exhibit better performance than the chromium coatings (Cr) alone. The study demonstrates that the chromium coating exhibits superior surface hardness and finish. Additionally, the high-temperature end face produces chromium oxide, which creates a self-lubricating effect on the end face. The sealing performance has been verified through simulation analysis and experiments. A coating thickness of 0.15 mm is considered the most suitable. The performance of the end face of a chromium/carbon nanotube composite coating is affected by the carbon nanotube content. If the content is too high, the hardness of the end face decreases, and wear resistance is reduced. Through simulation analysis and experimental verification, it has been determined that an optimal carbon nanotube content is around 10%. The preparation of composite coatings results in a high level of hardness and enhances the friction and wear resistance of the carbon nanotubes at the end face. This enhances the self-lubrication effect. The analysis and test results have theoretical significance for seal design.

A-13

Analysis of the wear characteriztics of dynamic pressure seals during start-up based on 3D fractal end-face characterisation

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In order to analyze the end face wear characteristics of the dynamic pressure seal start-up process, this paper establishes a dynamic pressure seal start-up process wear characteristics analysis model based on Archard wear calculation method, and analyses the change rule of end face wear characteristics in the start-up process. It is found that: the contact state in the start-up process through the low-speed and heavy -load stage, the mid-speed and mid-load stage, the high-speed and light-load stage, the intermittent-contact stage and the non-contact stage, the wear rate ratio of each stage is 4.82:5.95:2.20:1.00:0. With the increase of the operating pressure, the wear rate of the low-speed and heavy-load stage and the mid-speed and mid-load stage increases by 7.4%, and the wear rate of the high-speed and light-load stage decreases by 33.67%. In order to reduce the end-face wear of the dynamic pressure seal during start-up process, the operating pressure is kept low in the low-speed and heavy-load stage and the mid-speed and mid-load stage, and the operating pressure is gradually increased in the high-speed and light-load stage.

A-14

Analysis of friction and wear performance of dry friction mechanical seal end face weave and irradiation-modified HDPE material

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For the friction and wearproblemsof mechanical sealsinreactionkettles,the end face of the hard seal ring istextured,and the high-density polyethylene (HDPE) material,suitable for useas the soft seal ring, is irradiated andmodified. Bothmethods can effectively reduce the coefficient offriction on the seal end face, enhance the wear resistanceof the end face, and improve thewear-resisting ability of the end face and thesealing performance. Based on the Archard weartheory of friction, awear rate simulation modelfor themechanical seal end face fabric wasdeveloped

usingANSYSsoftware. The model was based onthe characteristic parameters of thematerial,with SiC as the dynamicring oftheAPDLcommand flow was insertedinto the contactpairtoachievethewear calculation, and the wear laws under different fabric distribution and different sizeswereanalysed;a high-speed friction and weartester was adopted to validate the results of the simulation,and the wearresultsof irradiation modification wereconfirmed. A high-speed friction and wear tester was used tovalidatethe simulationresults, and theirradiation-modified HDPE materialunderwentnon-lubricated friction and wear tests atvarious PV values. Subsequently,the surface microstructure and wearrate were compared and analyzedbefore and after thetests. The results show that the weaving grooves on the end face of the seal dynamic ring can store the abrasive debris generated by friction and reduce abrasivewear; comparedwith the unirradiated HDPE material, the friction coefficient of the irradiated HDPE material is reduced by33%~55% and the wear rate is reduced by 12.5%~25% under the same working conditions. The obtained results provide guidance for the optimal design of mechanical seal end faces and the extension of seal life.

A-15

Influencing Factors Analysis and Experiment Verification of Friction Coefficient between the End Faces for Mechanical Seal under Gas-Liquid Two-Phase Variable Working Condition

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Aiming at the different friction states of drones and other aircrafts operating in gas phase and liquid phase, friction coefficients between the end faces for mechanical seal under the two operating conditions are studied respectively. Based on the friction coefficient fractal model of the end face, this paper carries out theoretical simulation calculations to study and analyze the influence of operating parameters such as medium pressure, rotational speed, spring specific pressure and the surface topography fractal parameter on friction coefficient between the end faces under the two conditions of the gas phase and the liquid phase, and carries out the variable parameter experiment to validate the theoretical calculation results. The results show that: in the gas-phase condition, there is no pressure difference, the friction coefficient decreases with the increase of rotational speed, and increases linearly with the

increase of the spring specific pressure; in the liquid-phase condition, the friction coefficient decreases parabolically with the increase of medium pressure, and increases slightly when the rotational speed is small, and then decreases slightly with the increase of rotational speed after it reached a certain value; the friction coefficient increases linearly with the decrease of characteristic length scale factor of the soft ring and parabolically with the increase of fractal dimension. The experiment results are the same as the theoretical calculation results of the change rule, and the error is relatively small, which can provide some guidance and basis for the design, optimisation and application of mechanical seal for equipment operating under two-phase conditions.

A-16

Effect of Cr doping on mechanical and tribological properties of MoN coatings

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MoN coatings possess excellent mechanical and tribological properties, making them a promising option for foil air bearings. However, the presence of MoO_3, which exhibits high volatility above 500 °C, limits the application of MoN coatings at high temperatures.The advantages of Cr doping in improving the antioxidant properties of MoN coatings are significant.However, the impact of Cr doping on the mechanical properties, organizational structure, and tribological properties of MoN coatings, particularly at medium and high temperatures, remains insufficiently explored and warrants further investigation. Based on this, MoCrN coatings with varying Cr contents are prepared by high power impulse magnetron sputtering (HiPIMS) combined with direct magnetron sputtering (DCMS) on different substrate surfaces. And the microstructure, physical phase composition, mechanical properties and tribological properties of the coatings were systematically investigated. The results show that the MoN coating consists of a single Mo_2N phase and the MoCrN coating consists of Mo_2N and CrN. Due to the decrease of Mo_2N content and compressive stress with the increase of Cr doping content, the hardness and toughness of the coatings decreased monotonically, and the bonding force increased firstly and then decreased. The highest bonding force was found in the sample with Cr content of 10.4 at.%, which increased by 29 N compared to the pure MoN coating.Tribological experiments revealed that the room temperature friction coefficient and wear rate

increased monotonically with the increase of Cr doping content due to the decrease of the toughness of the coatings, the disappearance of the scaled friction layer, and the change of friction products; when Cr doping content was 19.9 at.%, the coating has the best wear resistance at 550 °C due to the significant enhancement of the oxidation resistance of the MoN coating.

A-17

Effect of laser surface texture characteristics on the interfacial toughness of hydrogel layer on the titanium alloy

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For hydrogel-on-titanium alloy hybrid architecture, the interface toughness is an essential performance parameter when it is used as soft-hard artificial cartilage material. The interfacial toughness of hydrogel-on-titanium alloy configuration is directly related to the surface modification of the titanium alloy. In this study, the surface texture was fabricated on the titanium alloy by pulse laser. Then the polyvinyl alcohol (PVA) was casted on the modified titanium alloy after laser surface texturing and chemical modification (hydroxylation and silanization). The interfacial toughness between PVA hydrogel and titanium alloy was detected by the 90° peeling test. Otherwise, the tribological properties of PVA hydrogel-on-titanium alloy configurations were investigated by a ball-on-disk tribometer. The texture parameters, such as dimple density and dimple diameter on the bonding toughness and the tribological properties were discussed. It was found that the interfacial toughness increases with the textured dimple density, while the influence of the diameter of textured dimple is not so significant. The higher interfacial toughness is obtained for the samples with dimple density of 30% and the dimple diameter of 150μm. The influence of the texture dimple parameters on the frictional properties is not regular.

A-18

Automated high-throughput screening of low-bioadhesion hydrogels

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Hydrogels are typical bioactive soft materials that play a crucial role in tissue engineering, drug delivery, and biosensing in the life sciences field. In response to scientific research and practical engineering needs, efforts have been made to develop hydrogels with low bio-adhesion properties. Among these, the biological adhesion properties of proteins and cells are particularly crucial. However, the high-dimensional nature of hydrogel synthesis poses a challenge for high-throughput screening. For instance, in the case of acrylamide hydrogels, a polymer material, performance optimization can be attained through formulation adjustments. However, the formulation presents a typical n-dimensional characteristics, where n is on the number of monomers. Traditional manual testing is inefficient and unstable, acting as the bottleneck for high-throughput screening of hydrogels.

We proposed an automated screening system for the low-bioadhesion hydrogels. Building upon the principles of hydrogel photopolymerization, we have designed a liquid handling workstation for the mixing, distribution, and dispensing of monomers, crosslinkers, and initiators. Additionally, a light-curing module was built to achieve stable curing of hydrogels, enabling high-throughput synthesis and preparation. Furthermore, we have achieved high-throughput automated bioadhension testing by integrating the bioadhesion property testing module into the system using a collaborative robot, allowing for the rapid and accurate screening of hydrogels with excellent low-bioadhesion properties.

A-19

A superelastic coating with bionic lamellar structure for improving drag reduction and wear resistance prepared by laser directed energy deposition

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Complex friction service environment leads to premature failure of mechanical surfaces and excessive energy consumption, which has become a key bottleneck restricting the progress of automotive, aerospace and other industries. Traditional hard friction surfaces are difficult to effectively achieve energy buffer, premature plastic deformation is the root cause of failure. Therefore, to improve the adaptability of friction surfaces to external complex working conditions, so that the friction surfaces have better self-defence, self-absorption and self-regulation under the action of multi-physical fields, is a key issue that needs to be solved urgently. Natural organisms have evolved over billions of years to create the ability to adapt to a variety of friction conditions and develop excellent drag reduction and wear resistance, which provides new ideas for exploring the friction of artificial surfaces actively adapting to complex environments. NiTi alloy not only has a unique shape memory effect, but also can be used as a super elastic metal material, providing a feasible material coupling and method path for the design and manufacturing of biomimetic elastic surfaces. This study is based on the elastic functional mechanism of the natural biological surface, designing a bionic layered structure, and preparing a soft hard alternating NiTi/NiTiNb coating through laser directed energy deposition. Microstructural characterisation and mechanical testing show that NiTi/NiTiNb surfaces with biomimetic structures achieve alternating soft and hard structures across scales and enhance drag-reduced wear resistance under multiple wear conditions. This study formed a rigid-flexible coupled bionic structure on the friction surface enriched with Ni-Ti alloy superelastic phases, and prepared a superelastic coating with friction behaviour similar to that of the surface of living organisms in complex environments, which provides a theoretical basis for designing and fabricating new friction surfaces with a bionic superelastic structure.

A-20

Counterion Distribution in the Stern layer on Charged Surfaces

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Counterion adsorption at the solid-liquid interface affects numerous applications. However, the characteristics of the adsorbed ion layer in the electrical double layer remains poorly evaluated. Here we report the direct determination of surface charge density at the shear plane between the Stern layer and the diffuse layer. By the Grahame equation extension and streaming current measurements for different solid surfaces in different aqueous electrolytes, we are able to obtain the counterion adsorption density in the Stern layer, which is mainly related to the surface charge density but less affected by the bulk ion concentration. The charge inversion concentration is further found to be sensitive to the ion type and ion valence rather

than the charged surface, which is attributed to the ionic competitive adsorption and ion-ion correlations. Our findings offer a framework for understanding ion distribution in many physical and chemical processes where the Stern layer is ubiquitous.

A-21

Molecular design of superlubricating materials based on the inorganic-organic hybrid structure

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Due to the periodic arrangement of inorganic and organic components, the inorganic-organic hybrid structure can combine the advantages of inorganic materials and polymers, so as to show different tribological behavior from that of conventional materials. Moreover, the inorganic-organic hybrid structure have rich adjustable parameters, so that the physico-chemical property can be greatly regulated, for example, its band gap can span the huge range of insulators, semiconductors and conductors. The rich functionality makes it have great potential in the field of multifunctional superlubricating materials. In this paper, the surface friction properties and interlayer sliding behavior of metal-organic frameworks (MOFs), a typical inorganic-organic hybrid structure, are investigated by experiments and theoretical simulations. Firstly, the structure-function relationship between structural components and tribological properties is established by designing the same crystal structure with various components. Then, based on surface control strategy, the influence mechanism of surface microstructure on tribological properties is revealed by designing the same MOFs with different surface chemical property. Finally, by developing the technology of highly oriented crystalline film, the interlayer sliding behavior of 2D MOFs is investigated. The research results show that the tribological properties of the inorganic-organic hybrid structure, include the surface friction, interlayer sliding resistance and friction anisotropy, are dominated by its coordination stability. The above conclusions provide the fundamental guidance to the molecular design of superlubricating structure, that is, to design the structure with high coordination stability based on the crystal field theory (CFT).

A-22

Nanofriction properties of alkane molecules on graphite surface : Effect of alkyl chain length

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Graphite is a two-dimensional material with excellent tribological properties, and graphene nanoflakes are often incorporated into oil to be used as nanoadditives to improve the lubrication properties of alkane-based oils. The nanotribological properties and superlubricity mechanism of n-alkane molecules with different alkyl chain lengths (C9, C12, or C16) sliding on graphite surface were investigated using atomic force microscopy, and it is found that the friction coefficient decreases with the growth of the alkyl chain, n-nonane achieves a friction coefficient of about 0.008 for superlubricity, while n-hexadecane can achieve a friction coefficient apprpximate 0.001.The boundary slipping of the oil molecules on the graphite crystals, which has a smaller energy barrier, results in the boundary slip of oil molecules on graphite crystals with small energy barriers leads to shearing at the interface of oil/graphite crystals with extremely low shear strength. As the chain length of alkane molecules increases, the sliding energy barriers at the interface of oil/graphite crystals become smaller, so the n-hexadecane molecules can realize a superlubricity statement with an ultralow firction coefficient. This boundary slip of oil molecules on graphite can be extended to the macroscale of friction reduction, providing a basis for the lubrication mechanism of graphene nanoflakes in oil, which is potentially applicable to the design of efficient lubrication aspects.

A-23

Interfacial charging performances of electrode coated silicon nitride in aqueous solution for self-sensing composites based on zeta potential investigation

Anqi Huang,Ying Liu,Jia Cheng

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The lubrication condition of friction pairs in water or aqueous solutions is crucial to the performance and lifespan of key mechanical components in engineering applications. Our previous research proposes a promising in-situ self-sensing method based on the liquid-solid triboelectric signals generated from the rotation-induced streaming current. However, the zeta potential investigation for self-sensing composites with electrodes to convey perceived signals is deficient for the comprehension of the interfacial charge mechanism and the enhancement of the signal outputs. Besides, the influence of convergent channel on zeta potential needs further investigation, which fits most engineering conditions for seals or bearings due to the hydrostatic or hydrodynamic effect. Herein, electrode-coated silicon nitride (Si3N4) composites are prepared by laser machining and magnetron sputtering. The interfacial charging mechanism is proposed based on the comprehensive investigation of electrode ratio, surface roughness, and liquid ion concentration on zeta potential. The apparent zeta potential originates from the combined efforts of the dissolution of metallic electrodes and hydration effect of Si3N4, as well as the charge absorption capacitance caused by uneven surfaces and massive ions in the liquid phase. Moreover, samples with convergent profiles along the fluid flow exhibit a higher absolute value of zeta potential than divergent ones. A negative relationship between zeta potential and convergent slope indicates that counter electrodes should be positioned at surfaces with significant differences in the gap between the friction pair to produce a remarkable fluctuation in signal outputs. Finally, design criteria for self-sensing friction pairs are proposed for enhancement of interfacial charging performances: optimal electrode ratio of 40%, surface roughness of 0.1-0.2 μm, and aqueous solution with moderately hydrated ions. This work fills in the void between the interfacial charging mechanism for self-sensing applications of liquid-solid triboelectric behaviors based on streaming current input.

Group B

Track 2: Wear and Fatigue

Track 8: Aerospace and Ocean Tribology

Symposium Posters

B-01

Enhancing Triboelectrical Output Performances of Triboelectric Nanogenerators via Lubrication of TiO2-doped oleic Acid at Interface

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Abstract Content：

Over the past decade, triboelectric nanogenerators (TENGs) have attracted significant attention across various fields due to their compact size, light weight, high output voltage, versatile shapes, and strong compatibility. A multitude of researchers have dedicated their efforts to enhancing the structure and efficacy of TENGs. However, substantial wear at solid-solid contact interfaces presents a major obstacle to the electrical output stability of TENGs. The objective of this study was to investigate the impact of TiO_2 nanoparticles as an additive in oleic acid lubricant on the tribological characteristics and electrical output performance of TENGs. The findings suggest that the increase in load and frequency conditions has a significant positive impact on the electrical output performance of the TENG, with different materials demonstrating varying levels of electrical output performance. Additionally, it has been observed that the addition of oleic acid has been shown to significantly reduce wear on PI film in TENG. Particularly, when 0.1wt% TiO_2 is added to oleic acid, the electrical output performance of TENG in the experiments of this study is improved. The incorporation of TiO_2 nanoparticles in oleic acid alters the surface characteristics of the friction pair during the friction process, thereby impacting the electrical output performance of the TENG.

B-02

Research on Energy Capture and State Intelligent Monitoring for Bridge Random Vibration Based on Triboelectric Nanogenerator

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By collecting environmental energy and self-powered sensors to solve the problem of power supply of traditional bridge structural health monitoring sensors has become a research focus. Based on triboelectric nanogenerator technology, a series of devices for random vibration energy capture and state intelligent monitoring of bridges are designed in this paper. The low-frequency, micro-amplitude and random vibration energy of bridges can be used to power low-power sensors, thus forming a self-powered sensing system. The coupling design of energy capture, energy storage and energy control mechanisms is carried out to develop the prototype, and the output characteristics are tested under random vibration excitation to verify its feasibility. The research results of this paper will provide a new idea and method for the development and utilization of vibration energy capture and vibration state monitoring of bridges, which has important scientific research significance and practical application value.

B-03

Bladeless Wind Turbine Triboelectric Nanogenerator for Effectively Harvesting Random Gust Energy

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In the environment, there is an abundance of gust energy which is challenging to harvest with conventional rotating wind turbines, such as the gusts generated by passing vehicles along roadsides. Addressing the irregular and low-frequency characteristics of gusts, a bladeless wind turbine triboelectric nanogenerator (BWT-TENG) with enhanced aerodynamic performance is proposed, enabling effective harvesting of random gust energy. Firstly, a bladeless wind turbine with a cylindrical bluff body shape is designed, and its aerodynamic principles under gust-driven

conditions are elucidated through the computational fluid dynamics method. Subsequently, parameter optimization is conducted for the multilayered TENG. Systematic experiments demonstrated that the BWT-TENG achieved a peak power density of 4 W m^{-3} driven by gust of 10 m s^{-1}, and could even operate at frequencies as low as 0.1 Hz. Finally, experiments showcased the BWT-TENG powering a warning light in a simulated rainfall environment, and harvesting gust energy from vehicles passing by real roadside to power wireless gyroscopic sensor, thereby achieving self-powered structural health monitoring of roads or bridges. This work provides a novel strategy for utilizing TENGs in the harvest of environmental gust energy and demonstrates the vast potential of TENGs in the field of self-powered structural health monitoring.

B-04

Friction and Wear Digital Twin: In-Situ Surface Information Acquisition

Haoran Liao,Ying Liu,Hongju Li

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The deterioration of surface conditions is one of the primary causes of wear-induced failure in critical components. Constructing a mapping simulation of the friction system within a virtual space and forming a digital twin model is an effective approach to achieving in-situ prediction of wear and failure in key components. However, due to the current requirement to disassemble components for surface information acquisition, it is hard to measure and reconstruct the rough surface in its working state in situ, leading to a lack of essential mapping conditions for the twin system. This paper investigates the relationship between in-situ measured macroscopic parameters and topographical parameters. The Majumdar and Bhushan contact model has been modified to develop a fractal contact model in multi- contact stages. From the perspective of microscopic contact, the dynamic relationship between the friction coefficient and fractal parameters is derived, and wear stages are determined based on the dynamic changes in fractal parameters. The derived friction-fractal formula, based on mechanical deformation, provides a universal method for in-situ acquisition of friction coefficient information, avoiding assumptions based on specific wear mechanisms. Experimental validation shows that the topographical parameters obtained through the friction-fractal formula exhibit good consistency with experimental results. The friction-fractal formula provides a theoretical foundation for predicting and analyzing the wear status of friction pairs in critical

equipment and supports real-time surface condition characterization of friction pairs within digital twin systems.

B-05

Cloud Maps Highlighting Dynamic Characteristics of Surface Signal to Improve Time-varying Wear Evaluation Accuracy

Hongju Li,Ying Liu,Haoran Liao

Tsinghua University

This paper proposes a high accuracy time-varying wear evolution method with cloud maps highlighting dynamic characteristics of surface signal. Firstly, the cloud map method is established by arrangement of measured data, thus time-varying wear evolution process is visualized on a series of plane figures for preliminary qualitative analysis. Then, high accuracy recognition of time-varying wear states is realized by cloud map shape parameters, including kurtosis and 1-D kernel density function highlighting distribution information of surface signal. The relative recognition degree by cloud map shape parameters is higher than those of friction coefficient, Root-Mean-Square (RMS) deviation and fractal dimension. Finally, high accuracy time-varying wear life prediction is realized by cloud map size growing speed highlighting waviness information of surface signal. The relative prediction error is reduced from more than 20% to less than 10% compared with friction coefficient and roughness.

B-06

Wind aggregation enhanced triboelectric-electromagnetic hybrid generator with slit effect

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It is of great significance to establish a low-cost, high-efficiency self-powered micro-meteorological monitoring system for agriculture, animal husbandry and transportation. However, each additional detection element in the meteorological monitoring system increases the power consumption of the whole system by about 0.7 W. As a renewable energy technology, triboelectric nanogenerator has the advantages

of low price and self-powered sensing. To reduce the power consumption of the micro-meteorological monitoring system, this work introduces an innovative solution: the wind-gathering enhanced triboelectric-electromagnetic hybrid generator (WGE-TEHG). Coupling the thin-film vibrating triboelectric nanogenerator (TENG) and electromagnetic generator (EMG), the TENG is used to monitor wind direction, the EMG is used to monitor wind speed and provide energy needed by the system. In particular, the TENG can be used as a self-powered sensor to reduce the power consumption of the sensing system. Besides, the TENG is used to produce slit effect to enhance the output performance of EMG. The experimental results show that the WGE-TEHG can build a self-powered natural environment micro-meteorological sensing system. It can monitoring the wind direction, wind speed, temperature, and relative humidity in the environment. This research has great application value for the self-powered sensing implementation of hybrid TENG and EMG.

B-07

A strong, wear- and corrosion-resistant, and antibacterial Co–30 at.% Cr–5 at.% Ag ternary alloy for medical implants

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A Co–30 at.% Cr–5 at.% Ag alloy was fabricated using a combination of mechanical alloying and spark plasma sintering. The microstructure of the alloy consisted of an ultrafine-grained ε-Co solid solution matrix with an average grain size of 167 nm and uniformly dispersed Ag particles with an average size of 72 nm and a minor amount of nanoscale σ-precipitates with size of 23 nm. Such particular microstructure enabled high hardness of 650 HV and compressive strength of up to 2.3 GPa. Pin-on-disk dry sliding wear tests show that the present alloy exhibited superior wear resistance, with wear rate in the order of 10^{-5} $mm^3/(N \cdot m)$ upon sliding against alumina. The wear-induced microstructure extended only ~500 nm from the sliding surface, with elongated Ag particles. The alloy also demonstrated high resistance to corrosion in artificial saliva solution, due to the formation of a protective passive film. Moreover, the addition of Ag also significantly enhanced the antibacterial activity of Co–Cr alloys, with antibacterial rates against *E. coli* and *S. aureus* of 90.5% and 72.6%, respectively. The present alloy with a combination of high strength, superior wear- and corrosion-resistance, and excellent antibacterial activity offers a promising candidate for medical implants.

B-08

Analysis of Wear in Boundary Lubrication Using Smoothed Particle Hydrodynamics

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In recent years, the use of boundary lubrication is expected to increase due to the increasing demand for higher efficiency, higher functionality, and longer life for power trains and generators used in automobiles, and seizure has become a problem. Understanding seizure requires simulation techniques that can handle the process in which solid-state friction in metallic materials which increases ambient temperature and causes plastic flow, not only in atomistic level but also in mesoscopic level. We proposed applying smoothed particle hydrodynamics (SPH) to tribology. This makes it possible to express mesoscale surface roughness and handle heat generation, heat transfer, and large deformation. In this study, we made a microscale model of a solid metal consisting of aluminum (Al) on the top and titanium (Ti) on the bottom using an aggregate of hundreds of thousands of particles investigated changes in frictional heat. As a result, Ti tends to have a higher upper temperature limit than Al. This indicates that the temperature of Ti particles increases more easily than that of Al. Since Al has a low maximum temperature, it is thought that heat will diffuse over a wide area, increasing the temperature of the entire sliding part and increasing the average temperature. These results are thought to be largely related to the differences in specific heat and thermal conductivity between Al and Ti. It is thought that heat was transferred to the entire Al surface, raising the average temperature of Al to the same level as that of Ti. Heat conduction is thought to occur at the contact area between Ti and Al, and the analysis results regarding the possibility that heat generated in Ti is transferred to the Al side will be also shown.

B-09

Investigation of Acoustic Emission under Friction Condition Using Discrete Element Method

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Recently, acoustic emission (AE) technique has received great attention due to its high sensitivity in condition monitoring. However, AE signals can easily be influenced by background noise during mechanical system operation, which results in difficulty accurately diagnosing the contact surfaces. Therefore, it is highly required to understand the behavior of AE to develop a condition monitoring system based on AE technique. In this work, sliding simulations were conducted using discrete element method to investigate behavior of AE in relation to material failure caused by frictional work. The elements of model tip and flat substrate were coupled by massless parallel bonds. Ductile and brittle materials were selected as substrates, and the tip was set as rigid. Sliding simulations were conducted under various normal loads and sliding speeds. The acoustic emission was analyzed based on material failure observed during the simulation. The simulation results were investigated by comparing with experimental data conducted with same friction condition. The findings of this study are expected to aid in the development of condition monitoring systems.

B-10

Observation of Failure Behavior of Multilayer Coatings

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Multilayer coating is widely used due to its advantages such as multifunctional character, moderate residual stress, good adhesion, proper mechanical properties, low friction coefficient, and high wear resistance. These advantages originate from the layer structure of multilayer coating with nanoscale thickness of each layer. In general, the high wear resistance mechanism of multilayer coatings is known to interrupt crack propagation at the interface and adjust the mechanical properties of the applied surface. However, there are not enough studies to visualize the wear mechanisms of multilayer coatings because nanoscale layer thickness makes it difficult to observe wear behavior. Therefore, in this study, the wear mechanisms of a multilayer coating which is widely used as a wear-resistant coating were analyzed and visualized. Multilayer coatings were manufactured using the sputtering system, and microscale wear mechanisms according to the number of layers were analyzed by nano-scratch tests and SEM. As a result of nano-scratch tests, it was found that the fracture behavior was different depending on the number of layers. The friction tests performed inside the SEM showed that the onset of the wear of the multilayered coating was delayed compared to the single-layer coating. The results of this work could provide insight into the design and production of functional multilayer coatings with high wear resistance.

B-11

The influence of drilling technology on the wear evolution process of impregnated diamond bits

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The diamond exposed on the surface of the impregnated diamond bit (IDB) is the key to breaking the rock. The exposed condition of the diamond affects the drilling efficiency and the life of the bit. In this study, the drilling experiments were conducted on granite under rotary and rotary-percussive drilling conditions using a self-developed drilling test platform. The evolution of diamond emergence on the surface of the IDB under two drilling technology conditions was investigated, and the typical characteristics of diamond wear and its causes of formation were discussed. The experimental results show that under rotary drilling conditions, the main evolution process of diamond on the surface of the sliding IDB is Emerging-Whole-Blunt (Flat). The exposed diamonds are mainly blunt and fractured, and a slippery IDB cannot be re-sharpened by increasing the weight-on-bit (WOB). Under the conditions of rotary-percussive drilling, the main evolution process of diamond involves Emerging-Whole-Fractured-Pull out, and the diamond on the surface of the bit is mainly fractured diamond. Diamond emerges from the matrix in the form of points, lines and planes, and different emergence states affect the wear and failure mode of the diamond. The main form of diamond wear is mechanical wear, dominated by abrasive wear and fatigue wear, and the proportion of fractured diamonds is significantly higher under rotary-percussive conditions than rotary drilling conditions. The tail of diamond under rotary-percussive drilling conditions is shorter than that of rotary drilling conditions. The impact effect enhances the contact between the bit and the rock, which is conducive to the wear of the matrix and the emergence of the diamond. The results are useful for optimising the design of IDB and optimising drilling technology.

B-12

Study on the erosion and wear performance of fracturing sliding sleeve baffle ring structure based on FLUENT-EDEM coupling

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The structure of the baffle ring in infinite-level fracturing sliding sleeves, along with the solid phase content and particle size parameters of the fracturing medium, are crucial factors affecting the erosion and wear performance of the tool, directly determining its operational efficiency and lifespan. To address this, a coupled fluid-solid erosion simulation model of the baffle ring structure in fracturing sliding sleeves was established using the FLUENT-EDEM coupling method. The correctness of the model was verified by conducting fluid-solid erosion tests during baffle ring replacement. A study was conducted to investigate the erosion and wear patterns at the baffle ring of sliding sleeves under different geometric parameters of baffle ring width and diameter, as well as solid phase content and particle size physical parameters. The results indicate that, under the tested simulation conditions, the inner diameter of the baffle ring is the primary parameter affecting erosion and wear performance compared to baffle ring width. As the inner diameter of the baffle ring increases, the degree of erosion and wear of the tool also increases. When the inner diameter is 51.76mm, the tip area of the baffle ring experiences the most severe erosion and wear due to its penetration into high-velocity regions. Under the same baffle ring structural parameters, the erosion rate of the baffle ring increases with the increase in solid phase content and particle size. This study provides valuable insights into the impact of fluid erosion on downhole tools.

B-13

Research on Disc Brake Noise and Control Measures Based on Bidirectional Friction Coupling Vibration-Induced Mechanism

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This work details research on the formation mechanism of disc brake noise in railway vehicle and its effect factors by numerical modeling in order to prevent the increasingly prevalent problem of brake noise. Firstly, a vehicle-track system dynamic model is established based on the actual situation on site. The vibration characteristic of the wheel axle end under the wheel surface out-of-roundness is obtained by dynamics analysis. Then, the disc brake system finite elements model under multiple vibration inducements is carried by combining the self-excited vibration of brake system and feedback vibration of wheel-rail system. Finally, the correlation between brake system friction coupling vibration characteristic and brake noise characteristics under self-excited and feedback couple vibration is investigated by using complex eigenvalue analysis and instantaneous dynamic analysis. Results show that the disc brake noise is affected by the self-excited and feedback vibrations of the system. The frictional self-excited vibration of the braking system is the root cause of brake noise, whereas feedback vibration of the wheel-rail system can exacerbate the unstable vibration of the braking system. Wheel polygonal wear has a significant effect on the frictional contact pressure of the braking system when the vehicle is braked. When the polygonal wear amplitude reached 0.1 mm, the maximum magnitude of the contact force increased by 30.6% compared to the result without polygonal wear. Higher order wheel polygon wear (17 ~ 21 order) affects the braking system more significantly than lower order (1 ~ 4 order).

B-14

Tribological characteristics of rotary vane steering gear seals under the oil with different abrasive particle sizes

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Wuhan University of Technology

The abrasive particles often cause the wear of the rotary vane seals during the operation process, and lead to seal failure and mechanical fault. Focusing on the wear mechanisms and extracting the tribological information during the friction are the prerequisites for extending the service life and carrying out the fault diagnosis prediction of the rotary vane seals. Four different sizes of iron particles were selected to mix with the same volume of hydraulic oil to explore the effect of lubricating oil containing abrasive particles on the wear behaviors of the seal. The tribological behaviors during friction were comprehensively analyzed, including the coefficient of friction (COF), wear volume, surface topography, vibration, noise, and other

information. The results demonstrated that the wear characteristics of the seal's contact surfaces changed obviously. The wear morphologies, coefficients of friction, surface roughnesses, and vibration signals increased with the increase of the abrasive particles' size, which indicated that the wear state was gradually worsening. When the iron particle size reached 160 μm, the COF increased by 0.047, and the peak vibration signal increased from 4.31 to 36.97 m/s^2 , compared with pure hydraulic oil lubrication. This tribological information could disclose the wear mechanisms of the thermoplastic polyurethanes polymer material (TPU) and reveal the TPU's wear states. Sensing the tribological information between the rubbing pairs was a potential and effective way for evaluating or predicting the rotary vane steering gear seals' wear states or failure modes. This study lays the foundation for understanding the wear mechanisms and the fault diagnosis of steering gear seals.

B-15

Friction and wear analysis and life prediction of long-life reciprocating spring energized seal for aerospace application

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The spring energized seal has the advantages of good corrosion resistance,vibration impact resistance,wide temperature range and so on.Therefore,it is widely used in the aerospace industry.Low wear and long-life have always been the key topics in the field of sealing,so it is vital to study the friction and wear life characteristics of the spring energized seal.In this paper,a friction analysis model is established to analyze the sealing contact characteristics of the spring energized seal.Considering the influence of friction coefficient and wear rate on the seal,the life of the spring energized seal is predicted.The friction and wear test device was designed,the friction and wear test was carried out on the three kinds of fluorine plastic shell(polytrifluorochloroethylene,fluorinated ethylene propylene and polytetrafluoroethylene)of the spring energized seal,and the analysis model was compared and analyzed.The results show that the effect of fluorinated ethylene propylene material is the best,and the requirements of low wear and long life are best achieved on the basis of meeting the sealing conditions.

B-16

Simulation study on fretting wear behavior of high strength alloy steel induced by plasma nitriding and post-oxidation

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Fretting wear refers to the small wear caused by the relative movement of the material surface on a small scale. Finding ways to reduce fretting wear is of great significance for extending equipment life and reducing maintenance costs. With the increase of load, the fretting wear adhesion effect of the same surface treatment material becomes more obvious. The materials treated with post-oxidation have stronger wear adhesion than those treated only with plasma nitriding, but the total wear volume is reduced. The fretting wear of high strength alloy steel with different surface treatment is simulated by finite element method. The friction coefficient and wear volume can be obtained from the experimental results, and the wear coefficient is calculated using the wear energy model. The two dimensional predicted wear profile curves (U-shaped and W-shaped wear profiles) under different wear conditions are compared with the experimental results. The W-shape wear profile is used to describe the adhesion state of the worn surface. In addition, the influence of single-sided wear, double-sided wear and increasing adhesive effect on the wear profile is analyzed by simulation. The simulation results show the importance of double-sided wear and the addition of adhesive layer to wear prediction.

B-17

The Improved Model of Contact Deep Groove Seals Based on Partition Model and JFO Boundary Condition

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Unlike nuclear main pump seals, deep groove seals in aero-engines operate on a contact basis. However, the precise working mechanism and accurate quantitative methods for assessing their sealing performance remain elusive. This research introduces a fluid-solid-thermal coupling model for contact deep groove seals, utilizing a partition model and considering JFO boundary condition, mixed

lubrication, and detailed heat calculations. The model significantly enhances accuracy compared to original approaches. It comprehensively accounts for contact effects, thermal deformations, convergence wedges, radial waviness, hydrodynamic pressures, groove drainage, and convection, revealing characteristics of contact deep groove seals such as high stiffness, effective heat dissipation, wear resistance, and prolonged service life. The proposed model and working mechanism provide theoretical guidance for designing diverse deep groove seal structures.

B-18

Study on the dynamic characteristics, friction, and wear of constant gap air film floating ring seals

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Beijing University of Chemical Technology

In high-temperature, high-speed working conditions, air film floating ring seals face challenges such as significant eccentricity, poor stability, weak vibration and shock resistance, and insufficient reliability. By establishing a dynamic model for the fluid-solid-thermal coupling analysis of the air film floating ring seal, this study discusses the stability and followability of the floating ring under various structures and operating parameters of the floating ring seal. Additionally, it analyzes the frictional wear of the primary and secondary sealing surfaces of the floating ring seal. The analysis results show that the static pressure has a certain opening effect on the floating ring under eccentric conditions. As the whirl motion amplitude of the rotor increases, the floating ring lags behind the rotor, exhibiting a whirl of the same frequency. The axial pressure has little effect on the eccentricity, but small axial forces have better followability and contribute to improved frictional wear on the end faces of the floating rings. The conclusions of the study offer theoretical support for floating ring seals to meet the design objectives of high stability and extended lifespan.

B-19

Research on an Active Supplementary Oil Supply Technique for Long-life Lubrication Systems of Space Actuators

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The high-speed shafts of spacecraft attitude control actuators, like flywheels and CMGs, require stable operation for over 10-15 years in orbit. Achieving precise and minimal lubrication is crucial. However, the current passive centrifugal oil supply technology for long-life lubrication systems has limitations: (1) Inability to actively adjust oil supply rate on orbit; (2) Significant oil supply rate decay at the end of life.

To address these issues, this paper conducted research on active supplementary oil supply methods for the existing long-life lubrication system. This encompassed exploring the principles of lubricating oil storage and precise supply utilizing thermally deformable materials, optimizing the performance of lubricating oil transportation and desorption under operational conditions, and experimentally validating the active supplementary oil supply technology on spacecraft actuator components. The findings reveal that, through rational optimization of oil supply path parameters, an active supplementary oil feeder leveraging thermally deformable materials can controllably replenish lubricating oil in situ, building upon the existing oil supply system. Notably, the power consumption required for a single oil replenishment is less than 2W. This study offers a viable approach to mitigating on-orbit faults such as abnormal increase in resistance torque of space high-speed bearings, thus providing technical support for enhancing the high reliability and longevity of spacecraft actuators in orbit in the future.

B–20

Frictional wear characteristics of magnetic seals in aero-engine bearing cavities

Renyi Cheng

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Due to the continuous advancement of aero-engine technology, the sealing performance of aero-engine bearing cavities must be more stringent, and the working conditions of temperature and speed are also more demanding. Therefore, friction and wear tests were conducted on the magnetic sealing of the bearing cavity of the aero-engine to select the material combination that can meet higher requirements. The test compares the friction coefficients of various friction materials, magnetic materials, and surface treatment processes, and selects the combination with the best

performance in terms of wear and friction. This ensures that the magnetic seal has optimal friction and wear performance. Once the materials are selected, a typical working condition test of the magnetic seal in the bearing cavity of an aero-engine is conducted to measure wear and leakage. The experimental study revealed that the choice of frictional sub-material significantly affects wear. Specifically, the study found that MAT4000 material exhibits superior wear resistance compared to the commonly used impregnated phosphate graphite (M234AO) in aero-engines. Additionally, the surface spraying process significantly affects the amount of leakage in magnetic seals. The research presented in this paper has significant implications for the design of seals in aero-engine bearing cavities, the selection of magnetic materials for magnetic seals, and the machining process of end faces.

B-21

Study on the frictional properties of sliding electrical contact materials with low wear in space

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The Solar Array Drive Assembly (SADA) is used to drive the solar array of the spacecraft to achieve the orientation of the Sun, and to realize the transmission of electrical energy and signals through the slip ring. In order to meet the requirements for the use of large communication payloads and space stations, the new generation of space vehicles has put forward higher requirements for the whole star energy. With the increase of transmission voltage and power, the requirements for safety and reliability of SADA electrical transmissions have increased dramatically. Abrasive debris, as an unavoidable product in the friction process of the slip ring , is not only an important factor for the stability of the ring-brush contact, but also a risk factor for triggering arc discharge.Therefore, it is crucial to reduce the amount of slip ring abrasive debris and stabilize it within a certain range. Currently, self-lubricating composites are one of the most used brush materials in space, due to their high current-carrying capacity, low electrical noise and good wear resistance. This paper takes the self-lubricating composite brush block material as the research object, the self-lubricating performance of brush block can be significantly improved by optimizing the material composition and microstructure. The results show that the average wear rate of the optimized composite brushes is less than 2.5×10^{-13} $m^3/N\cdot m$, which is more than 50% lower than the existing level. At the same time, the stability and quality consistency of the optimized composite brushes are greatly improved due to the optimization of the material preparation process using acoustic resonance hybrid technology. The research results provide technical support for the long-term stable and reliable service of space high-voltage and high-power rotary electric transmission mechanisms, which have important scientific values and space application prospects.

Group C

Track 3: Coatings and Surfaces Engineering

Track 9: Industry Tribology and Instruments

C-01

Strengthening mechanisms of laser cladding TiC/FeCoCrNiCu high-entropy composite coatings: Microstructure evolution and wear behaviors

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Central South University of Forestry and Technology

The HEA-TiC high-entropy composite coatings with TiC (5, 10, 15 and 20wt.%) reinforced FeCoCrNiCu matrix were fabricated by laser cladding to investigate their tribological performances and wear behaviors at RT and 600 °C. As the percentage of TiC particles elevated, the microhardness was progressively enhanced to 531.65 $HV_{0.5}$ and its surface energy weakened to 24.29 mN/m. Fine-grain strengthening of high melting point and high hardness TiC acting as a heterogeneous nucleation site, precipitation strengthening of the Laves phase and diffuse strengthening of re-solidified carbides. These reinforcing behaviors synergize to confer the desired

tribological properties on the 15wt.% TiC coating, with outstanding wear resistance (7.6×10^{-6} $mm^3/N\cdot m$) at RT, and the friction process is dominated by slight abrasive wear. The highly dense oxide film composed of TiO_2 and the friction film reconstituted by Cr_2O_3 act synergistically on the coating surface at 600 ℃, which effectively provides lubrication and resists friction. Compared to TiC-free coating, the wear rate (2.76×10^{-5} $mm^3/N\cdot m$) and COF (0.23) controlled by oxidative wear were reduced by 88.7% and 28.1%, respectively. Whereas the excess TiC particles added into the coating internally appeared serious agglomeration caused by strong van der Waals gravity between the ceramic particles, resulting in performance rebound.

C-02

Preparation of Epoxy Resin Based Ultra-Low Friction and Anti-Corrosion Composite Coating

Zheng Wang,Liguo Qin,Guangneng Dong

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The new two-dimensional material MXene has exhibited excellent mechanical, electrical, optical and electrochemical properties in many applications. Based on its graphene-like structure, in order to further study the corrosion resistance and tribological properties of MXene under lamellar structure characteristics, an epoxy resin composite coating containing MXene was prepared in this paper. The corrosion resistance, anti-friction and wear resistance of the composite coating under simulated seawater environment and lubrication conditions were investigated. The results of friction and wear experiments showed that the addition of MXene can improve the mechanical properties of the coating and form a lubricating transfer film during friction. Under the synergistic lubrication of oleic acid, the friction coefficient can be reduced to 0.008, and the wear rate can be reduced by 99.73%. At the same time, benefitted by the micro/nano size of MXene and the corrosion inhibition, the electrochemical corrosion test results show that the anti-corrosion efficiency of the coating can reach 99.38%. This work provided a strong support for the anti-corrosion and anti-friction applications of MXene, and provided a new idea for the long-term protective coating of Marine equipment.

C-03

All-Solution-Processed Electronics with Sub-Microscale Resolution and Nanoscale Fidelity Fabricated Via a Humidity Controlled Surface Energy-Directed Assembly Process

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Tsinghua University

Solution-based processes have received considerable attention in the fabrication of electronics and sensors owing to their merits of low-cost, vacuum-free, and simple in equipment. However, the current solution-based processes are either absence of patterning capability or have low resolution (> 20 μm) and low pattern fidelity in terms of line edge roughness (LER).

Here, we present a surface energy-directed assembly (SEDA) process to fabricate metal oxide patterns with high resolution and low LER, in this process, we use plasma treatment and self-assembled monomolecular layers, respectively, to make the surface hydrophilic or hydrophobic, and then combine them with photolithography to complete functionalized substrate preparation, after withdrawing the functionalized substrate from the precursor solution, the metal oxide solution was selectively entrained on the hydrophilic pattern regions, forming metal oxide patterns after dried. Experiment results show that high pattern fidelity can only be achieved at low relative humidities of below 30%. The reason for this phenomenon lies in negligible water condensation on the solution droplet. At a high relative humidity, the final metal oxide patterns shrink, resulting from water condensation-induced increase of the surface tension of the solution droplet. Employing the SEDA process, all-solution-processed metal oxide thin film transistors (TFTs) are fabricated by using indium oxide as channel layers, indium tin oxide as source/drain electrodes and gate electrodes, and aluminum oxide as gate dielectrics. TFT-based logic gate circuits, including NOT, NOR, NAND and AND are fabricated as well, demonstrating the applicability of the SEDA process in fabricating large area functional electronics.

C-04

Development of a human signal detection sensor based on conductive film through multi-layer coating

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Chosun University

The human-machine interface plays a central role in the current era of technology, where sensors hold paramount significance. As crucial components of these interfaces, sensors detect and interpret human signals, thereby enhancing the efficiency and usability of devices. Despite substantial advancements in sensor technology, there is a persistent demand for the development of more reliable, efficient, and adaptable sensors. This demand is driven by the escalating sophistication and complexity of modern devices, which necessitate the sensitive and accurate detection of human signals. In response to this research gap, this study introduces a novel conductive film sensor for human signal detection, offering a solution that merges innovative material utilization and practical fabrication processes. The sensor was fabricated through a multilayer coating process involving carbon nanotubes and an acrylic adhesive. This process enables the production of a thin conductive film through the alternate layering of carbon nanotubes and acrylic adhesives. This study fabricated films of various thicknesses and conducted comprehensive evaluations of their durability, thereby determining the optimal thickness that ensures stable durability. All fabricated conductive films exhibited excellent adhesion properties, facilitating their attachment to a wide range of substrates. Furthermore, this study investigated the potential application of the optimally conditioned conductive film as a sensor for human signal detection. The results indicated the successful and stable detection of human signals, underscoring the potential utility of this conductive film sensor in human-machine interfaces. The findings of this study significantly contribute to the field of sensor technology by providing a novel, efficient, and reliable method for human signal detection. Moreover, they lay the groundwork for further advancements in the development of sensors for human-machine interactions, anticipating a revolution in future technology.

C-05

Enhanced friction and wear properties of dual-phase

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A gradientnanostructured surface layer is synthesized on a dual-phase Cu-10Ag alloy bymeans of surface mechanical grading treatment (SMGT) at liquid

nitrogentemperature, in which a single-phase Cu-Ag nano-laminated (NL) structure with alamellar thickness of 30 nm is formed at the top surface, and a dual-phasegradient nano-laminated (DGNL) structure composed of Cu- and Ag-rich lamellaeis formed in the depth range of 70-210 μm. A DGNL surface layer on Cu-10Agalloy is obtained by removing the NL layer from the SMGT surface. The DGNLsamples exhibits significantly lowered COF and enhanced wear resistance underdry sliding in comparison with the coarse-grained (CG) sample. Within the loadrange of 30 to 90 N, the wear rate is ~3.11×10^{-7} mm3·N^{-1}·$m^{-1}$and the COF is ~0.27, being ~5% and ~44%, respectively, of those of the CGcounterpart. The wear resistance improvement of DGNL sample in this work (~20times) is higher than wear resistance improvement of nanostructured metalscompared to the CG counterparts in available literatures. The analysis showsthat the excellent friction and wear properties of DGNL sample are related tothe unique deformation mechanism of multiple structural characteristics duringthe friction process. The gradient nanostructure can suppress strainlocalization during sliding, thereby, effectively suppress the formation ofsurface roughening and brittle tribo-layer. The semi-coherent interface with lowershear strength and high resistance to normal loads in dual-phase nano-laminatedstructure can reduce the COF, and inhibit the formation of vortical deformationstructure, which can improve the structure stability in the surface layer. In addition,the transition of dual-phase nano- lamellae to single-phasenanocrystalline with high hardness inhibits the shear instability of thesubsurface layer and the formation of brittle tribo-layer, which is beneficialto further improve the friction and wear properties of the DGNL sample.

C-06

Design and build of layer-by-layer heparin antithrombotic coat-ing for Poly(4-methyl-1-pentene) hollow fiber membrane

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Study Objective: Oxygenator with Poly(4-methyl-1-pentene) (PMP) hollow fiber membrane as the core component needs to be in constant contact with blood during operation, which is lead to thrombosis and other problems, seriously affecting the safety. building a heparin coating for the surface of PMP membranes is an effective method to address this issue, but the method is still challenging in terms of antithrombotic stability and durability.

Methods: In this study, several heparin anticoagulant coatings with partial differences were built on PMP membranes using layer-by-layer (LBL) method, after which the coatings were tested and characterized by staining agent staining, SEM, optical microscopy, Fourier infrared spectrometry (FTIR), and blood experiments.

Results: cross-linking with aldehyde after the first coating Polyethyleneimine (PEI) allowed more heparin sodium to be grafted onto the PMP membrane, while glutaraldehyde had a better cross-linking effect than crotonaldehyde. However, cross-linking with aldehyde cannot be used after the second PEI coating, otherwise it will adversely affect the grafting effect of sodium heparin on the surface of the PMP membrane; the pH of the dextran sulfate sodium salt solution has an effect on the grafting effect of sodium heparin, in which the grafting effect is better when the solution used is pH=7 than when the solution is pH=8.5; The effects of Aluminium isopropoxide (AIP) as well as Sodium Triacetoxyborohydride (STAB) as a reducing agent in treating such heparin-coated PMP membranes were compared, and it was found that STAB-treated heparin-coated PMP membranes had better antithrombotic properties and were effective for a longer period of time than those of the control group and the AIP group.

Conclusions: A better implementation of three of the steps in the buildup process of LBL heparin coatings was revealed, and the built coatings had better antithrombotic properties than the control.

C-07

Rolling resistance moment: the factor that affects the motion of liquid marbles

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Liquid marbles (LMs) are non-wetting liquid drops manufactured by encapsulating the droplets with micro- or nano-scale particles. It could produce high marble displacement velocities and leak-free transport, making the marble become an attractive platform for digital microfluidics. However, the rolling friction of marbles is an issue that affects their accurate transportation and manipulation. Therefore, this paper describes a method to measure rolling friction and explains the source of rolling friction: the rolling resistance moment of particles. Two different sizes of particles (SiO_2 and Lycopodium) were prepared to form the marbles and these marbles were in turn placed on an inclined substrate to initiate the rolling on a horizontal substrate. The rolling displacement was recorded with a high-speed camera and the velocity, acceleration, and rolling friction were calculated using Newton's second law. These rolling friction ratios of the two types of liquid marbles in the range of 5 to 25 μL are consistent with our theoretical estimation (0.02 to 11.09) of the rolling resistance moment model. Thus, the rolling resistance moment of the particles is the main factor affecting the rolling friction. The rolling friction mechanism of liquid marbles in this article can promote the transport as well as manipulation of micro-droplets and contribute to the self-cleaning of the surfaces in industrial applications, such as solar panels.

C-08

The development of B/Cr co-doped DLC coating by FCVA deposition system and its tribological properties at 300°C

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The hard diamond-like carbon (DLC) coating prepared by filtered cathodic arc deposition (FCVA) lost its promising wear resistance while subjected to high temperature extreme environments. Element-doped DLC Coating was proposed to

suppress carbon oxidation reaction and subsequently enhance the wear resistance under high-temperature atmosphere. Our previous research clarified the excellent tribological properties of boron-doped DLC (B-DLC) but identified challenge such as arc discharge extinguishment and coating declamation (under high-temperature friction test), significantly lowering the deposition efficiency and limiting practical utilization. In this study, we introduced Argon gas during the deposition process and optimized its flow rate to 10 sccm, maintaining the stable arc discharge with infrequent extinguishment and achieving high hardness and deposition rate of doped-DLC. Moreover, we applied a chromium interlayer and added the chromium dopant (Cr-dopant, 0.5, 1.0, and 3.0, at. % for each) into B-DLC, aiming to develop a high-temperature stable co-doped DLC with superior low friction and high wear resistance. The Raman spectroscopy and nano-indentation respectively demonstrated the incorporation of Cr dopant increased the disordered carbon structure and consequently lowered the hardness of carbonaceous hard coating. The tribological properties of B/Cr co-doped DLC versus Si_3N_4 ball were evaluated using a macroscopic ball-on-disk friction tester, with 1% Cr-doped B-DLC (a-C:B:Cr_1) coating exhibiting super low friction with an average friction coefficient of 0.02 and a low specific wear rate of less than 5.0×10^{-6} mm^3/Nm. Raman spectroscopy revealed that the graphite-like tribo-film transferred onto the surface of Si_3N_4 counterparts contributed to stable low friction. Additionally, XPS (X-ray Photoelectron Spectroscopy) analysis on the wear track of DLC coating speculated the rich B-B bond might be the cause of high wear resistance.

C-09

Microstructure and corrosion erosion resistance of NiTiAlCrCoN films with different Co contents

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Abstract: In order to investigate the effect of Co content on the structure and properties of NiTiAlCrCoN films, magnetron sputtering technology was used to prepare NiTiAlCrCoN films with different Co content on 304 stainless steel and single crystal Si sheets.X-ray diffractometer, scanning electron microscope and energy spectrum were used to characterize the structure and morphology of coating materials. Cavitation erosion experiments were carried out by ultrasonic vibration cavitation machine to explore the cavitation failure mechanism of NiTiAlCrCoN

film.The results show that the coatings with different Co content have a simple face-centered cubic structure, and there is a preferred orientation on the (200) crystal surface. The diffraction Angle of the (200) crystal surface decreases and the crystal surface spacing increases with the increase of Co content.The surface of the coating is smooth and flat, without granular impurities, and there is no porosity and automatic shedding phenomenon. With the increase of the molar ratio of Co, the hardness monotonously increases, the mass loss by cavitation erosion gradually increases, and the elastic modulus gradually decreases. When the Co molar ratio is 1.4, the coating quality loss is the least, and the cavitation corrosion resistance is the best within 12h, which is because the addition of Co element enhances the solid solution strengthening effect inside the film, strengthens the strength of the inner wall of the cavitation pit, and prevents the further expansion of the cavitation pit.

C-10

Microstructure and properties of FeCrNiMoSix high-entropy alloy coatings prepared by laser cladding

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Abstract

Ocean engineering equipment often experiences friction and corrosion during service, and their interaction accelerates the degradation of marine materials. To this end, an effective strategy is proposed for protecting ocean engineering equipment by using high-entropy alloy coatings. A new FeCrNiMoSix (x=0.25, 0.5, 0.75) high-entropy alloy coating has been developed and applied to Q235 steel through laser melting technology. The aim is to enhance both wear resistance and corrosion resistance simultaneously. The impact of Si element content on the microstructure and properties of FeCrNiMoSi high-entropy alloy coating was systematically examined through optical microscopy, scanning electron microscopy, microhardness tests, wear tests, and electrochemical corrosion tests. The results show that the FeCrNiMoSix coatings consist mainly of BCC and FCC phases, with a small amount of intermetallic compounds. With the increase in Si content leading to greater lattice distortion, while promoting the transformation between FCC and BCC, as well as the formation of the FeMoSi phase. Consequently, the abrasion and corrosion resistance of the coatings were significantly improved. Among them, the $FeCrNiMoSi_{0.5}$ coating exhibits

optimal tribological properties (specific wear rate of 2.32x10^{-5} mm3·N^{-1}·m^{-1}) and corrosion resistance (self-corrosion current density of 1.69x10^{-7} A/cm^2). These findings suggest that the $FeCrNiMoSi_{0.5}$ coating shows promise as a surface protection material for ocean engineering equipment.

C-11

Tribological behavior of duplex-treated 42CrMoAl steels by plasma nitriding and (CrWAlTiSi)N nona-multilayer coating

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Due to their high corrosion resistance, non-transformation, and non-magnetism, austenitic stainless steels can meet the service requirements. However, their low hardness and poor wear resistance impose serious drawbacks. A combination of plasma nitriding and coating as a surface treatment has been shown to improve the wear esistance without affecting the corrosion performance. his study investigates the enhancement of friction and wear resistance of a 42CrMoAl substrate through the combination of plasma nitriding and (CrWAlTiSi)N ceramic coating. The rapid plasma nitriding was conducted on the substrate using a hollow cathode discharge-assisted plasma nitriding apparatus. The (CrWAlTiSi)N ceramic coating, consisting of a CrN bottom layer, a CrTiAlSiN interlayer, and a WCrTiAlN top-multilayer, was successfully deposited using cathodic multi-arc evaporation. The samples were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM) with energy-dispersive X-ray (EDX) analysis, and transmission electron microscopy (TEM). Mechanical properties were evaluated using nano-indentation and Vickers micro-hardness tests, while dry sliding-wear characteristics were investigated through ball-on-disk wear tests. The results showed that the combination of plasma nitriding and ceramic coating resulted in excellent anti-friction and highly wear-resistant surfaces. The modified layer formed through the diffusion of nitrogen/carbon during nitrocarburizing significantly improved the surface hardness of the substrate. Additionally, compared with single-coated samples, duplex treatment significantly improved the adhesive strength of coated samples. The duplex treatment improved the bearing capacity, fatigue resistance, and adhesion of the coating, which was very effective in improving the friction and wear performance of the substrate. Tribology measurements revealed that an optimized multilayered coating followed by pre-nitriding results in excellent anti-friction and highly wear-resistant surfaces.

C-12

Friction and wear characteristics of hard coating combination and its application in standing wave linear ultrasonic motor

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Standing wave linear ultrasonic motor is a new type of motor driven by friction. It is very popular because of its simple structure and high driving efficiency. Due to the intermittent and impact contact between the vibrator and the slider of the ultrasonic motor, there is a serious wear problem on the friction interface.It has been shown that the application of hard coating material with good wear resistance to the standing wave linear ultrasonic motor can effectively reduce the wear of the friction interface and improve the performance of the motor.Therefore, In this paper, the tribological characteristics of the sixteen friction pairs composed by AlTiN, TiN, TiCN and DLC, as well as their application in the standing wave linear ultrasonic motor were studied. Firstly, The tribological characteristics of the 16 kinds of combinations were investigated by using HIT-II ball-on-disc tester. The wear mechanisms of the coating combinations were analyzed by scanning electron microscopy, Energy-dispersive spectroscopy and Raman spectroscopy. The results show that the seven combinations of AlTiN balls/different coated discs and DLC discs/different coated balls have smaller wear and friction coefficient. the wear mechanism of the friction pairs composed of AlTiN balls and four kinds of coated discs is extremely slight abrasive wear. The wear mechanism of the combinations of DLC discs and the coated balls (except for the AlTiN ball) is mainly adhesive wear, accompanied by slight abrasive wear. Subsequently, The test-bed of V-vibrator standing wave linear ultrasonic motor was built. The driving force, average velocity, stability and friction wear characteristics of 7 kinds of coating friction pairs selected from the ball-on-disc tests were tested. The results show that the AlTiN vibrator/TiCN slider has better motor performance and less wear, and can be used as the coating friction pair of the standing wave linear ultrasonic motor.

C-13

Analysis of Interface Damage and Failure Behavior of Solid Lubrication Film Under Rolling Contact State

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Lubricating oil interrupt is one of the harsh conditions of aviation bearing. After the lubrication oil is interrupted, the heat generated in the bearing work cannot be taken away, so the temperature is significantly higher. Coupled with the high shear effect of the friction interface, the material is very prone to sticky wear. The solid film is used in the transmission parts to reduce the friction factor, enhance the abrasion resistance, and improve the carrying capacity. Therefore, the use of solid film to improve the bearing anti-oil-breaking capacity has become an important research direction. In this paper, based on the Cohesion Model (CZM), a finite element analysis model of the thin film matrix bearing system was established. Bilinear constitutive relationships were used to describe the bearing and damage failure behavior of the thin film matrix interface. By analyzing the bearing state of the interface under normal and tangential loads, the effects of friction coefficient, elastic modulus, and film thickness on the interface stress, separation displacement, and energy release rate of the thin film matrix bearing system were studied, The results indicate that an increase in friction coefficient can lead to a deterioration of the interface load-bearing state at the contact front, thereby increasing the risk of interface damage and detachment failure; An increase in the elastic modulus of the film can reduce the damage area and degree of the interface at the contact front. When the elastic modulus of the film is less than the elastic modulus of the matrix, the interface load-bearing performance deteriorates sharply; As the film thickness increases, the tangential damage area and degree of the interface first decrease and then increase. When the film thickness is 0.2b, it is beneficial to improve the load-bearing performance of the film substrate interface.

C-15

Design and study on the new friction interface of ultrasonic motor based on lubricating coating

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The mechanical output performance of ultrasonic motors is significantly affected by the coupling of force and heat, especially in vacuum environments where thermal accumulation at the friction interface is prone to occur, leading to increased wear and affecting operational precision, stability, and lifespan. This study starts by enhancing the performance of stator materials. Through molecular dynamics simulation, it establishes a contact model of the friction interface of ultrasonic motors, and deeply analyzes the interaction mechanisms and dynamic evolution processes between the friction interfaces at the nanoscale. A design method for wear-resistant coatings on the stator surface, matched with the rotor, is proposed. Based on experimental preparation using two-dimensional nanomaterials, a super wear-resistant coating is fabricated, optimizing the friction interface of ultrasonic motors and enhancing the service life of the friction interface. Upon installation verification, the energy conversion efficiency is increased by 62.1% compared to similar motor, contributing significantly to improving the mechanical output characteristics of the motor. Furthermore, to further optimize the friction interface, machine learning algorithms are employed to study the accuracy and robustness of different machine learning models in predicting the performance of the friction interface. This provides technical support for the optimization design of the friction interface of ultrasonic motors.

C-16

Efficient one-step preparation for high-quality Inconel 625-xAl2O3 composite coating via plasma enhanced high-velocity arc spraying

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High-efficiency and low-cost preparation of high-quality composite deck coating is one of the research hotspots in the surface manufacturing field of large vessels and offshore platforms. In the current study, a novel plasma enhanced high-velocity arc spraying (PE-HAS) was developed. Inconel 625-xAl2O3 composite coatings were successfully deposited via varying the feeding ratio of alloy wire and ceramic powder. Furthermore, the microstructure, phase transformation, mechanical, corrosion resistance, surface non-skid and wear resistance properties of the coatings were comprehensive investigated. Results indicate that the coatings exhibited high densification, low defects (porosity≤ 3.65%), and strong bonding (≥45 MPa).

Especially in-situ double-layer structure of the coating further provided a good corrosion resistance. What's more, coatings with excellent non-skid surfaces could slide for long times at a high friction coefficient (~1.054). The different morphologies of Al_2O_3 phases formed many local enhanced areas. Accordingly, the microhardness and wear resistance of the coatings were significantly improved. In conclusion, this work achieved an efficient one-step preparation for Inconel 625-xAl_2O_3 deck coating with double-layer structure using plasma enhanced high-velocity arc spraying, which provided an important reference to breaking through the technological confine of the traditional spraying.

C-17

Study on the effect of magnetorheological fluids(MRFs) on the sealing performance

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The magnetorheological fluids(MRFs) seal has the advantages of suitability for significant sealing gaps, high sealing pressure resistance, long service life, and simple processing and manufacturing. It is essential to note that magnetorheological fluids have a substantial and undeniable effect on both the magnetic field distribution pattern within the seal gap and the pressure resistance of the seal, as highlighted by the study.This paper intends to investigate the effects of different types of MRFs on sealing performance through a combined approach of numerical simulation and experimental validation. The results show that the presence of MRFs can significantly reduce the occurrence of magnetic leakage in the seal structure. From the distribution of magnetic lines in the seal gap, the distribution of magnetic flux lines in the seal gap formed by the pole shoe and the magnetic conductivity axis along the axis direction is the densest, i.e., themagnetic flux density is the strongest. In contrast, a lower magnetic flux density is present at the tooth groove. The pressure resistance of the MRFs seal exhibits a gradual increase with an increasing volume fraction of magnetic particles in the MRFs.

C-18

Efficient Water Energy Harvesting Using a Hybrid Nanogenerator Integrating Water Wave and Evaporation-Driven Mechanisms

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Water, as a vital natural resource, plays a crucial role in the development of diverse energy systems. In this paper, we propose an innovative hybrid nanogenerator that integrates a water wave triboelectric nanogenerator (TENG) and an evaporation-driven generator to harness water energy more efficiently and comprehensively. This hybrid system not only effectively addresses the low power output of water wave TENGs in calm water conditions but also enables continuous energy harvesting from water evaporation through the evaporation-driven generator. Under a simulated wave frequency of 2.5 Hz, the optimized water wave TENG achieves a peak power of 0.62 mW. In real-world water surface tests, a 0.33 μF capacitor can be charged to 15 V within 80 seconds. Furthermore, the wood-based evaporation-driven generator can continuously generate direct current electricity during the spontaneous evaporation of water. With a matched load of 10 kΩ (23 °C, 30% RH), the evaporation-driven generator demonstrates a solar-to-steam conversion efficiency of 84.2%, a maximum current density of 3.2 $\mu A/cm^2$, and a maximum output power density of 1.4 mW/m^2. To enhance the practicality of the evaporation-driven generator, we designed a multi-stage voltage-multiplying circuit and incorporated pulse charging technology, successfully achieving increased voltage output and reduced charging time. In summary, the proposed water wave-evaporation hybrid nanogenerator offers a novel solution for efficient water energy harvesting, expanding the application scope of TENG technology in the field of water energy collection and laying a solid foundation for the development of multifunctional water-based energy systems.

C-19

A coupling model for tribodynamic behavior of hydro-viscous flexible drive with consideration of saucer-warping deformation

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An improved coupling model, including the dynamic transmission characteristics and thermal deformation behavior of the disks, is developed for predicting the tribodynamic behavior of hydro-viscous flexible drive under realistic driving conditions. The present work overcomes previous limitations by incorporating transient saucer-warping deformation due to friction heat. Dynamic parameters because of the saucer-warping angle effects, including the film thickness and total torque, are analyzed based on an iterative method. And axial deformation, radial deformation and saucer-warping angle are simultaneously obtained by the finite element analysis. Based on the comparison with the experimental data, the performance of the coupling model is found satisfactory. The results show that the increase of saucer-warping angle is favorable for the improvement of flexible transmission characteristics. As a result of the saucer-warping angle effects, significant reduction of the inlet flow rate will lead to the reduction of maximum total torque. Neither radial displacements nor axial displacements are good enough to predict the evolution rule about friction heat during the engagement process. Based on the combined effects of equivalent film thickness and real frictional area, the torque results for the deformed disks are larger than that when the disks are parallel. Saucer-warping angle effect begins to dominate the total torque especially when the film thickness reaches its minimum. The present model developed in this research may become an efficient alternative model for the prediction of flexible transmission behavior of the real driving system.

C-20

Research on the Friction and Wear Characteristics of PEEK/Stainless Steel under Oil-Seawater Emulsion Medium

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Seal failure occurred in oil-hydraulic systems working in deep-sea environments can cause seawater to seep into the hydraulic oil. The emulsification of the oil may affect its friction characteristics in extreme deep-sea environments thus affect the service performance of hydraulic systems. For the paired sub-material polyetheretherketone (PEEK)/stainless steel commonly used in deep sea oil hydraulic system, the effect of seawater on the lubrication performance of hydraulic oil was analyzed by friction

experiments under hydraulic oil-seawater lubrication, laying the foundation for the design of deep-sea hydraulic systems. The research results indicated that the friction coefficient of PEEK/stainless steel decreases after seawater infiltration into hydraulic oil, which is due to the decrease in viscosity and internal friction force of hydraulic oil after seawater addition. The amount of wear decreased first and then increased with the infiltration of seawater. The decrease in wear was attributed to the improvement in lubricity. The increase in wear after adding 15% seawater was attributed to the transition of lubrication status from fluid dynamic lubrication to mixed lubrication. The transfer film generated during the wear process plays a lubricating role. Oxidative wear and abrasive wear are the main forms of wear.

Group D

Track 4: Tribo-chemistry and Lubricants

Track 7: Tribology in New Energy System

D-01

Tribological mechanism of eco-friendly amino acids ionic liquids as water lubrication additives

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Exploring eco-friendly lubrication media has gradually become one of the hot research directions in the field of tribology. The exceptional biocompatibility and biodegradability of amino acid ionic liquids (AAILs) render them highly promising for addressing environmental compatibility concerns. However, AAILs are still being less studied in the field of lubrication. Therefore, the development of green

multifunctional water-based lubricant additives, in which both anions and cations are amino acids and their derivatives, is of great significance in realizing green lubrication.

With the aim to further explore the potential of AAILs as water-based lubricant additives, herein, two AAILs water-based lubricant additives, Lys-LS and Arg-LS, were synthesized using sodium lauroyl sarcosinate (a biodegradable food additive approved by the FDA) and cationic amino acids. Compared with pure water lubrication, the utilization of 0.5% mass fraction aqueous solutions of the two AAILs as lubricants exhibits a remarkable enhancement in the tribological performance of water-based lubricants, with a reduction in friction coefficient and wear volume by approximately 70% and 85%, respectively.

The results of mechanism studies indicate that the tribochemical reaction films and physical/chemical adsorption films formed by the ionic liquids at the interface worked synergistically to effectively prevent direct contact between the sliding pairs, endowing the water-based lubricant with excellent tribological properties. The two AAILs additives were characterized by simple preparation, non-toxicity and greenness, and were promising to be employed as critical additives for metalworking fluids and flame-retardant hydraulic fluids.

D-02

The Detergency and Tribological Properties of Oil-Miscible Quaternary Ammonium-based Ionic Liquids: A Novel Potential Multifunctional Lubricant Additives

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Recently, the ionic liquids (ILs) have attracted much attention duo to their unique physicochemical properties, including non-flammability, low volatility, low melting point, excellent thermal stability and have been widely used as neat lubricants or lubricant additives[1–6]. When ILs were employed as lubricant additives, they were primary investigated as anti-friction and wear-resistance additives. There are few examples that disclosed their high temperature detergency, especially as oil miscible additives[7].

With the aim to further exposed their potential as multifunctional lubricant additives of ILs, herein, two quaternary ammonium-based ionic liquids were prepared, characterized and tested as ashless detergents, dispersants, and anti-friction, anti-wear additives of PAO2 and 150SN. As a result, compared with commercial detergents (T109 and Hitec614), [$N_{8,8,8,1}$][SDBS] and [$N_{8,8,8,16}$][SDBS] as additive not only improved the cleanliness and dispersion performance of the base oil , also enhanced their friction reduction and wear protection properties. Specifically, adding 2 wt% [$N_{8,8,8,16}$][SDBS] to PAO2 could improved the cleanliness performance of the base oil by 89.6%, exceled the commercial detergent T109 by 218.1%. The anti-friction and anti-wear capabilities of the four additives were in the following descending order: [$N_{8,8,8,16}$][SDBS] ≥ T109 > [$N_{8,8,8,1}$][SDBS] > Hitec614.

The mechanism studies indicated that part of the ILs improved the tribological performance of the base oil via adsorption and complex tribochemical reactions to form triboflim. Another portion of the ILs adsorbed on the oxidative deposits and wear particles produced during the friction procedure to forms an anion-cation bilayer micelle structure through self-assembly, which not only enhances colloidal stability, improves cleanliness of the base oil, but also enhanced tribological performance of the blends by alleviating the wear of produced wear particles.

In summary, the prepared oil miscible ILs not only showed excellent cleanliness, but also exhibited unique anti-friction, anti-wear properties, which providing a new strategy to prepare multifunctional lubricant additives.

D-03

Enabling ultra-low wear and long-lived lubrication by DLC–supramolecular gel composite lubrication system under extreme contact stress

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The limited life of diamond-like carbon (DLC) solid lubricants is determined by the depletion and irreparability of the films. Although DLC–liquid composite lubrication effectively reduces friction and extends the life of the lubrication system, most of the available composite lubrication strategies focus on mild experimental conditions. Besides, the sealing of DLC–liquid composite lubrication becomes challenging due to the creep of liquid lubricant. Here, we developed a DLC–supramolecular gel (HTG) composite lubrication system to achieve long-life outstanding lubrication under extreme contact stress while avoiding sealing challenges relying on the unique thixotropic properties of the gel. DLC–HTG composite lubricant system exhibited excellent friction reduction performance and ultra-low wear in tribological tests with a maximum contact stress of 2.24 GPa. DLC films containing designed double transition layers and Si doping possess high interfacial bond strength and mechanical properties, providing the basis for high wear resistance. The establishment of a robust tribofilm and the confining effect of HTG on wear debris dominate the achievement of ultra-low wear. Moreover, creep and leakage of the lubricant is avoided by the reversible capture of the base oil by HTG. This ultra-low wear sliding extends the service life of the lubrication system with the broad implications for mechanical engineering, transportation, and wind power generation.

D-04

Thermal stability and failure mechanisms of organic-inorganic hybrid nanoparticles in various polar media

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Inorganic nanoparticles need to be modified by organic modifiers to ensure their long-term stable dispersion when used as lubricant additives. Therefore, the decomposition temperature of organic modifiers is considered the maximum operating temperature for nano-additives. In this study, we found that the decomposition temperature of copper nanoparticles (CuDDP) modified by alkyl phosphorothioate (HDDP) dispersed in different polar lubricating oils was much lower than that of the modifier and varied with the molecular structure of the lubricating oil. Furthermore, the thermal decomposition mechanism of CuDDP was analyzed by NMR and FT-IR spectroscopy, which showed that CuDDP had a similar decomposition process with HDDP, and the inorganic nanoparticles did not promote the decomposition of the organic modifier. However, the various polar media will produce different contents of

reactive oxygen radicals after being heated, and these radicals as well as the polar groups in the lubricating media are involved in the decomposition process of the organic modifiers. This leads to the rapid decomposition of HDDP at low temperatures, as a result of which the content of the modifiers on the surface of the inorganic nanoparticles decreases, affecting the dispersion stability and then producing precipitation. This study is an important guide for the development and synthesis of high-temperature-resistant surface modifiers and is generalizable to organic-inorganic hybrid nanoparticles.

D-05

Analysis of Organic Fluorine Compounds Using Molecular Dynamics Simulations

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Organic fluorine compounds have been used as materials that exhibit a variety of excellent physical properties such as water and oil repellency, lubricity, and heat resistance, whereas the physicochemical basis for these properties is unclear. In recent years the Stratified Dipole-Arrays (SDA) theory has been developed to explain the fundamental physical properties of organic fluorides. According to this theory, by separating the physical properties of organic fluorides into single molecules and molecular assemblies, we can explain contradictory features such as water repellency and oil repellency. Since SDA theory is based on analytical theory of the set of dipole momentum on the molecules, limitation of application to real molecules may exist.

In this paper, we attempted a detailed verification using molecular dynamics (MD) simulations with the aim of clarifying the molecular assembly structure of organic fluorides which is important for their low-friction properties. MD simulation is applied for systems of MA-R_f*n* molecules on water. Molecular structures of MA-R_f3, MA-R_f5, MA-R_f7 and MA-R_f9, which are called MA-R_f*n* depending on the number of CF_2, in which some of the hydrogen groups of myristic acid are replaced with fluorine are discussed. After the structure relaxation simulation of single MA-R_f*n* molecule dropped on water molecules, they fluctuate on the water/vacuum interface regardless of n = 3, 5, 7, or 9, which is predicted as single molecular behavior by the SDA theory. Then, the relaxation structure of 300 MA-$R_f n$ molecules on water are obtained. Molecular packaging structure are not formed for MA-R_f3 and MA-R_f5. On the other hand, clearly packaged structure is formed for MA-R_f7 and MA-R_f9 which is suggested by the SDA theory. More detailed analysis revealed that the molecular assembly structure of MA-R_f7 and MA-R_f9 forms a cubic and hexagonal packing, respectively, which exactly agree with the predictions by the SDA theory.

D-06

Frictional Properties Analysis of Graphene Oxide in Solvent by Molecular Dynamics Method

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Graphene oxide (GO) is a sheet-like nanomaterial that can be synthesized by exfoliating and oxidizing natural graphite, and has a two-dimensional structure similar to graphene. It has electrical insulation properties and high mechanical strength, so it is used in electronic devices. Additionally, more hydrophilic nature compare with graphene make it easier to disperse in polar solvents and is used in a variety of applications. Because of these properties, it is known that GO can be modified with alkyl groups to exhibit low friction properties not only in water lubrication but also in oil environment. Furthermore, although in the analysis of GO using Molecular Dynamics (MD) simulation show the mechanical properties and frictional wear properties of a single GO sheet, the frictional properties within a layer or in a solvent is not examined.In this study, we made a hierarchical GO model using MD simulation and compared with experiments. Reactive force field is used to understand polar nature of materials. The analysis revealed that GO is stable in water, whereas in oil, the sheets in contact with the oil move from side to side which implies the instability. In addition, the alkyl-modified GO becomes integrated with the oil and appears to exhibit the low friction properties of the alkyl group. Moreover, the friction coefficient calculated from the base metal are in qualitative agreement with the experimentally obtained results. Therefore the molecular dynamics analysis using a reaction force field of a multilayer GO sheet and clarified some of the differences in the frictional properties between water lubrication and oil lubrication.

D-07

Initial aggregation of lithium soap in oil: Molecular dynamics simulation

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Metal soaps have various industrial applications, such as lubricants and preservatives, and lithium and calcium soaps are used as thickeners for greases. Grease is a semi-solid lubricant consisting of oil and thickener, and is used in machine elements where the liquid lubricants are difficult to apply. Thickeners are important substances that determine the heat resistance and shear stability of the grease itself, and they hold and solidify the oil by forming a three-dimensional network structure. This fiber structure is on the nm to μm scale, and was already observed with an electron microscope in the 1950s, but it has been pointed out that the deoiling process for observation may affect the fiber structure, and many details of the structure are still unknown. Capturing the fiber formation process at the nanoscale will lead to the molecular design of greases with excellent performance. In this study, we used all-atom molecular dynamics to analyze the initial aggregation process of the thickeners lithium stearate (LiS) and lithium 12-hydroxystearate (Li12HS) in oil. As a result, LiS formed plate-like reverse micelles, while Li12HS formed spherical reverse micelles. The plate-like micelles of LiS resembled double-layered liquid crystals, a structure similar to the crystal structure proposed in experiments. Li12HS had a complex structure in which the head and side chains bridged the two micelles, forming a single large aggregate. Since the detailed structure of Li12HS has not been clarified experimentally, additional analysis is required in the future. From the above, it was found that the initial aggregation process of lithium soap differs significantly depending on the presence or absence of hydroxyl groups in the side chains.

D-08

Rapid selection of environmentally friendly layered alkaline-earth metal phosphates as solid lubricants using crystallographic data

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Lubricating technology is essential for saving energy. Identifying effective, environmentally friendly layered materials that meet the demands of solid lubricants is an important direction. Herein, we probed the relationships between the load-carrying capacity and crystal structure. It can be seen that increasing the sliding resistance of interlayers using corrugated layers could increase the load-carrying capacity of layered solid lubricants. This finding expands on the traditional lubrication mechanism of layered materials. Following the rules, rapid selection of layered potassium magnesium and calcium phosphates as effective solid lubricants was achieved using crystallographic data and strict filtering criteria. In order to prepare materials suitable for lubrication, the synthesis of layered potassium magnesium and calcium phosphates were optimised. They would be utilised in the food, textile or marine machinery industries in the future. The mentioned method can successfully guide the synthesis of application-oriented materials.

D-09

Application of artificial intelligence in predicting the lubrication performance of MoS2-Al2O3 nanofluid

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In recent years, artificial intelligence (AI) techniques such as artificial neural network (ANN) and machine learning (ML) are currently used as an efficient selection and prediction tool for the design of many complex engineering systems, including tribology and lubrication systems. In the present study, artificial intelligence algorithms including two artificial neural network (multilayer perceptron (MLP), back propagation (BP)) and two machine learning algorithms (random forest (RF), k-nearest neighbors (KNN)) were employed to predict the four-ball tribology behavior of MoS2-Al2O3 nanofluid. MoS2-Al2O3 composite nanoparticles were synthesized using solvothermal method and then dispersed in water-based fluids. 27 groups of tribology tests were conducted according to Box-Behnken experimental design were

set as the training groups. The input variables (velocity of friction pairs, test force, test temperature, nanoparticle concentration) and output parameters (friction coefficient, wear scar diameter, wear surface roughness) were selected as the main variables. It was found that the RF algorithm had better predict accuracy and stability for the four-ball tribology behavior of MoS2-Al2O3 nanofluid than MLP algorithm, BP algorithm and k-nearest KNN algorithm. Besides, Pearson correlation analysis was carried out to reveal the relationship between input and output as well as different output variables. Through in-depth characterization of worn surface, a protective tribofilm in the thickness of 15~20 nm composed of amorphous phases, fine nanoparticles, iron oxides, FeSO4, and Fe2(SO4)3 was found on the worn surface. The formation of tribofilm improved the wear-resistance and self-lubrication performance of metal surface. The present study proposed an approach to introduce artificial intelligence technique into the design and performance prediction of lubricants in material processing and industrial manufacturing.

D-10

A HIGH OUTPUT HYDROVOLTAIC POWER GENERATION DEVICE BASED ON THE IONIC RECTIFICATION EFFECT

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Hydrovoltaic power generation, as an emerging technology, can harness energy from the environment through strong interactions between water and porous nanomaterials, making it highly attractive for developing portable power sources. However, current hydrovoltaic devices still suffer from issues like low current density (< 10 μA·cm^{-2}) and short continuous operational times (< 1 h). Here, we developed a high-performance sandwich-structured hydrovoltaic device via the ion rectification effect. This device consists of aluminum-based double-sided carbon conductive tape (top electrode), a metal oxide nanocomposite material (active layer), and a hydroxylated carbon nanotube/conductive polymer composite electrode (bottom electrode). The ion diode-type hydrovoltaic device exhibited an open-circuit voltage of 0.55 V and a short-circuit current density of 82.5 μA·cm^{-2} at room temperature. Due to the presence of ion rectification, the reverse current caused by differences in ion concentration during long-term operation can be effectively suppressed, ensuring the long-term operation and superior current density of the device. In addition, through the series-parallel integration of multiple units, electronic devices such as hygrometers and

mobile phones can be successfully powered. This work can provide an idea for enhancing the performance of hydrovoltaic power generation through the ion rectification effect.

D-11

TiO2 nanoparticles as an oleic acid additive to improve the electrical output performance of tribology nanogenerator

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Over the past decade, triboelectric nanogenerators (TENGs) have attracted significant attention across various fields due to their compact size, light weight, high output voltage, versatile shapes, and strong compatibility. A multitude of researchers have dedicated their efforts to enhancing the structure and efficacy of TENGs. However, substantial wear at solid-solid contact interfaces presents a major obstacle to the electrical output stability of TENGs. The objective of this study was to investigate the impact of TiO_2 nanoparticles as an additive in oleic acid lubricant on the tribological characteristics and electrical output performance of TENGs. The findings suggest that the increase in load and frequency conditions has a significant positive impact on the electrical output performance of the TENG, with different materials demonstrating varying levels of electrical output performance. Additionally, it has been observed that the addition of oleic acid has been shown to significantly reduce wear on PI film in TENG. Particularly, when 0.1wt% TiO_2 is added to oleic acid, the electrical output performance of TENG in the experiments of this study is improved. The incorporation of TiO_2 nanoparticles in oleic acid alters the surface characteristics of the friction pair during the friction process, thereby impacting the electrical output performance of the TENG. This study may provides a reference for the design and application of TENG.

D-13

A piezo-tribovoltaic nanogenerator with ultrahigh output power density and dynamic sensory functions

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Tribovoltaic nanogenerator (TVNG) mainly collects energy from sliding motions of two semiconducting materials, but it cannot effectively react to the pressure change in the vertical direction. Here, we propose a piezo-tribovoltaic nanogenerator (P-TVNG) by integrating piezoelectric and tribovoltaic effects to collect energy from both the sliding motion and the variation of applied pressure. Hence, this P-TVNG can gain extra performance improvement on the top of the original output limit of TVNG. The maximum output power density of P-TVNG is up to 3.61 W m-2, which is 28.9 % higher than the highest record of the TVNG using similar materials. Additionally, the piezo-module can work as a separated sensory component by switching the circuit, which can monitor and analyze various working parameters of TVNG. A series of dynamic characteristics of TVNG during its operation have been identified, including the hysteresis between output current and applied pressure, the influence and incompatibility of interface stress to output performance and so on. As a multifunction of devices, this P-TVNG system is possible to be applied in semiconductor industry, smart manufacturing and many other fields. This work improves the performance of the TVNGs while extending its functionality, which broadens the application field of TVNG devices.

D-14

Edge friction volt effect of MOS2

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As a way to collect natural mechanical energy, contact electrification can efficiently convert low-frequency natural mechanical energy into electrical energy, which is a new green energy collection method. Semiconductor is the basic hardware of microelectronics in the new century, but it needs external energy supply to realize its basic function. The friction volt effect is the phenomenon of DC voltage and current generated by mechanical friction at the semiconductor interface. This paper focuses on the study of the friction volt effect from a microscopic perspective. The conductive probe of an atomic force microscope is used to conduct friction research on some two-dimensional semiconductors. It is found that MOS_2 generates higher direct current signals at its edge under the friction of the atomic force conductive probe, which is related to the defects at the edge of the two-dimensional material. This study is of great significance for the selective modification of functional groups at the edges of two-dimensional materials.

D-15

Omnidirectional Water Wave Energy Harvesting by Spherical Triboelectric Nanogenerator with Sliced Pizza-shaped Electrodes

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Ocean waves contain abundant renewable kinetic energy, but harnessing their power is difficult due to the low frequency and erratic nature. Here, we report a spherical triboelectric nanogenerator featuring multilayer “sliced pizza-shaped” electrodes (SP-TENG) to efficiently harness omnidirectional wave energy. Unlike conventional TENGs that either convert kinetic motion from a single direction or compromise energy harvesting efficiency to capture multi-directional wave energy, our SP-TENG not only effectively harnesses multi-directional wave energy but also maximizes electric output by fully utilizing the device's internal space. Moreover, using PP fur as a tribo-material further increases the charge output by enhancing inter-material contact efficiency. The SP-TENG effectively captures kinetic energy from all directions, achieving a peak power density of 13 W/m3 and charge density of 2.4 mC/m3 at 0.6 Hz frequency. This study presents a practical and efficient approach for harvesting high-entropy blue energy on a large scale.

D-16

Influence of edge effect on the output of sliding freestanding triboelectric nanogenerator

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The sliding freestanding layer triboelectric nanogenerator (SF-TENG) is widely used in many areas of life, and the staggered chain teeth TENG can convert linear or rotating mechanical energy into electrical energy. In this paper, single-layer staggered electrode TENG, double-layer staggered electrode TENG and double-layer staggered

chain teeth TENG are designed, focusing on the influence of electrode edge effect on SF-TENG output performance. Some output performance of three kinds of SF-TENG under the same external conditions and contact area were explored through finite element simulation and experiment, and the mechanism of electrode edge effect affecting the output performance of SF-TENG was revealed. The finite element calculation and experimental results show that the open-circuit voltages of the three kinds of TENG decrease sequentially, and the range is 57.5V-55.1V. The double-layer staggered chain teeth TENG has the largest edge area and the smallest open circuit voltage, which can provide valuable reference for the development of double-layer or multi-layer TENG technology.

D-17

Recent Development in TENGs to Collect Acoustic Energy

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As a sustainable and environmentally friendly energy, sound has permeated into our daily lives. Yet, the effective collection of acoustic energy remains limited. The emergence of triboelectric nanogenerators has brought significant breakthroughs in collecting low-frequency sound energy and ultrasonic energy. This review delves into the theoretical basis behind the collection of acoustic energy by TENGs and introduces common structures and materials of acoustic TENGs. Additionally, we systematically summarize the latest developments in triboelectric acoustic transducers (TATs) and triboelectric ultrasonic transducers (TUTs) in various fields such as biotherapy, localization, and charging. These innovative developments lay the foundation for advancements in areas like medical health, flexible wearable sensors and ocean monitoring. Finally, we thoroughly discuss the challenges and prospects of this field, aiming to promote the large-scale collection and utilization of acoustic energy.

D-18

Fabrication of triboelectric polymer films via repeated rheological forging for ultrahigh surface charge density

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Triboelectric polymer with high charge density is the foundation to promote the wide range of applications of triboelectric nanogenerators (TENG). This work has developed a method to produce triboelectric polymer based on repeated rheological forging. The Fluorinated Ethylene Propylene (FEP) film fabricated by repeated forging method not only has excellent mechanical properties and good transmittance, but also can maintain an ultrahigh tribo-charge density. Based on the FEP film with a thickness of 30 μm, the output charge density from contact-separation TENG reaches 352 μC·m-2, which is 1.46 times of the highest record before. Then, the same film is applied for the TENG with air-breakdown mode and a charge density of 510 μC·m-2 is further achieved. The repeated forging method can effectively regulate the composition of surface functional groups, the crystallinity and the dielectric constants of the FEP, leading to the superior capability of triboelectrification. Finally, we have summarized the key parameters for elevating the electrification performance on the basis of molecular structure and related fabrication crafts, which can guide the further development of triboelectric polymers.

D-19

Mass transfer system of a large number of small objects based on conjunction of triboelectric nanogenerators and photo-responsive interface

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Mass transfer technology for large quantities of tiny substances, such as electronic chips and drug particles, plays a crucial role in many industries. This study proposes a transferring system for large quantities of small objects based on the synergism of triboelectric nanogenerators (TENGs) and photo-responsive dielectric materials. TENG device can provide an output voltage of over 8 kV within a rotation time of 40 ms and the titanium oxide phthalocyanine (TiOPc) photoconductive films is fabricated as the photo-responsive interface, in order to match the output impedance of TENG. The transfer system enables a maximum adsorption load of 98 mg/mm^2,

which is enough for handling all common electronics chips/wafers. Under the stimulation of laser light, the conductivity of the TiOPc interface can be increased by two orders of magnitude within 1ms, which leads to the vanish of the surface potential on the laser spot and the release of patterned or pointed object. This photo-responsive strategy can achieve both large quantity transfer of tiny objects and highly selective release of the element at designed position. This collaborative mechanism of electrostatic force and photoconductivity provides a different approach for realizing efficient and precise Mass transfer system of semiconductor and chip industry.

D-20

Acid-Doped Pyridine-Based Polybenzimidazole as a Positive Triboelectric Material with Superior Charge Retention Capability

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The energy conversion efficiency of a triboelectric nanogenerator (TENG) is severely limited by the charge density of triboelectric materials, while drastic and unavoidable charge decay happens during contact due to the insufficient charge retention capacity of positive triboelectric materials. Here, elaborately synthesized acid-iondoped pyridine-based polybenzimidazole processing with strong charge retention capability is demonstrated to couple with negatively corona-polarized electrets. As illustrated by thermal stimulation and an ion mass spectrometer, the formation of acid-ion chimerism processes high activation energy for stored charges, and the selective anion migration can compensate the escape of polarized charge. Accordingly, the charge density can reach up to 596 μC m^{-2} and the charge retention rate reaches 49.7%, which is so far the highest intrinsic charge density obtained in the open air. Thus, the ionic chimerism strategy provides an effective way to suppress the charge escaping in the open air and gives a great expandable avenue for the material challenges of TENG's practical deployment.

D-21

Contact Electrifcation at Diversifed Interfaces and Related Applications on Triboelectric Nanogenerator

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The triboelectric nanogenerator (TENG) can efectively col_x0002_lect energy based on contact electrifcation (CE) at diverse interfaces, includ_x0002_ing solid–solid, liquid–solid, liquid–liquid, gas–solid, and gas–liquid. This enables energy harvesting from sources such as water, wind, and sound. In this review, we provide an overview of the coexistence of electron and ion transfer in the CE process. We elucidate the diverse dominant mechanisms observed at diferent interfaces and emphasize the interconnectedness and complementary nature of interface studies. The review also ofers a compre_x0002_hensive summary of the factors infuencing charge transfer and the advance_x0002_ments in interfacial modifcation techniques. Additionally, we highlight the wide range of applications stemming from the distinctive characteristics of charge transfer at various interfaces. Finally, this review elucidates the future opportunities and challenges that interface CE may encounter. We anticipate that this review can ofer valuable insights for future research on interface CE and facilitate the continued development and industrialization of TENG

D-23

Effect of temperature on tribological properties and electrification performance of a sliding-mode triboelectric nanogenerator with a patterned surface

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The existing studies showed that the ambient temperature could affect the electrical performance of the contact-separation-mode triboelectric nanogenerator (CS-TENG). However, for sliding-mode TENG (S-TENG), the triboelectrification is accompanied by material wear, and the influence of temperature on the electrical output as well as durability is ambiguous. Little research has been devoted to investigating the relationship between the tribological properties and electrification performance of S-TENG with a patterned surface. In this paper, a test platform with a temperature control system was constructed and the patterned polyimide (PI) films with different pitches were produced to investigate the effect of applied temperature on the tribological properties and electrification performance of S-TENG with the different pitches. The results show that the effect of applied temperature on the electrical output of S-TENG is different from that of CS-TENG. For a certain surface, the open-circuit

voltage, short-circuit current and short-circuit charge initially increase with the increase of applied temperature at first and decrease afterward, which could be attributed to the combined effect of the transfer charge caused by contact electrification and material wear. The coefficient of friction, temperature rise due to frictional heating, and mass loss of PI film increase with the enhancement of applied temperature. Moreover, the open-circuit voltage of the patterned surface with a pitch of 2μm increases by up to 65.9%, and mass loss reduces by up to 57.1% compared to a smooth one, which improves the electrical output and durability of S-TENG under different applied temperatures.

D-24

Transistor-like and Bionic Energy Harvester for Wireless Coded Transmission

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Converting vibration energy into electricity for achieving self-powered sensing systems is of essential importance for the advancement of the Internet of Things (IoT). However, achieving high power output and energy density remains challenging due to the devices' high output impedance and limited charge density. Herein, a high-power vibration energy harvester inspiration from biology and transistors by leveraging the triboelectric nanogenerator technology was developed, achieving a record-breaking high output power and energy density. By designing charge channels inspired by plant vascular bundles, the charge density output was enhanced to 17 mC/m^3. Additionally, a gate switch design akin to the field-effect transistor has effectively reduced the internal resistance in the device from over megaohm to about kiloohm. With the combined effects of the biomimetic vascular bundle and transistor-like switch structure, the volume power density of the device exceeds 10 MW/m^3 at 0.5 Hz, beyond all previous reports. With such high-power output, we achieved a battery-free wireless code transmission system, advancing the vision of building a distributed battery-free IoT system.

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