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EDITORIAL

Guest editorial: Special Issue on Artificial Intelligence and Emerging Computational Approaches for Tribology

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Tribo-behavior is a complex system-based time-dependent process, and it is difficult to accurately model a tribo-system and predict its behavior. Hence, tribology research, in most cases, has relied on extensive experimentation. Driven by the artificial intelligence (AI)-for-science revolution, AI and other emerging computational approaches provide opportunities to explore the complex processes in tribo-systems and the physical mechanisms of tribo-behavior in an efficient way, significantly pushing the boundaries of tribology research.

This special issue of *Friction* aims to gather the latest developments of AI and machine learning (ML), as well as computational approaches and solutions for tribology-related problems and real-world applications. Hence, 15 papers by tribologists and scientists have been compiled to cover the theory, methodologies, tools, and computational aspects of tribology, and guide readers into the emerging fields of AI and computational approaches for tribology.

Among these publications, one review article entitled "AI for tribology: Present and future" comprehensively examines the extensive application of AI in tribology, as this diverse and complex field is characterized by its multidisciplinary, multilevel, and multiscale nature. It delves into AI's role in various tribological subfields, highlighting the emergence of "tribo-informatics", a novel discipline integrating tribology and informatics. The review further categorizes tribo-system information, introduces an integration methodology combining this information with AI techniques for monitoring, prediction, and optimization in tribology, and aims to present a comprehensive understanding of tribo-informatics, ultimately improving problem-solving efficiency in tribology.

Cutting-edge ML algorithms, including neural networks, have enabled rapid advancements in tribology research. They have been introduced in a broad suite of tribology applications, such as wear monitoring and useful life prediction. The paper entitled "Comparison-embedded evidence-CNN model for fuzzy assessment of wear severity using multi-dimensional surface images" proposes an intelligent *in-situ* wear assessment method for machine health inspection, using 3D topography reconstruction via photometric stereo vision and a contrastive learning-based network (worn surface feature extraction network, WSFE-Net) for feature identification. It assesses wear severity through a network (WSA-Net), integrating 2D and 3D surface data with Dempster–Shafer evidence to minimize uncertainty. In this way, it achieves high fidelity in continuous wear experiment evaluations with very low uncertainty.

Atomic-scale friction and wear are important in various tribo-systems, including in precision manufacturing and energy transmission. The paper entitled "Atomistic understanding of rough surface on the interfacial friction behavior during the chemical mechanical polishing process of diamond" utilizes molecular dynamics (MD) simulation to understand chemical mechanical polishing (CMP) at the atomic level. This work exemplifies a successful case-study of using computational approaches to predict wear in real-world surface machining processes.

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Lubricants are important to achieve low friction and wear. The paper entitled "Low-viscosity oligoether esters (OEEs) as high-efficiency lubricating oils: Insight on their structure–lubricity relationship" explores the lubrication performance of OEEs in reducing synthetic oil viscosity. It uses a quantitative structure–property relationship (QSPR) model combining experimental and statistical approaches. Findings reveal that glycol chains enhance lubrication, and straight-chain OEEs outperform branched ones due to a thicker adsorption film. The study confirms OEEs' oxidation in friction and demonstrates robust and accurate predictive models for viscosity, thermal stability, friction coefficient, and wear volume.

Similarly, the paper entitled "Classification and spectrum optimization method of grease based on infrared spectrum" utilizes the Kohonen neural network algorithm to evaluate over 60 different lubricating greases, based on their infrared properties. This work illustrates that ML algorithms provide capability beyond the traditional experimentation capacity to characterize lubricants.

Excitingly, more fundamental mathematical and physics understanding has been enabled by tribology-related AI and ML. The paper entitled "A new method to solve the Reynolds equation including mass-conserving cavitation by physics informed neural networks (PINNs) with both soft and hard constraints" introduces a method to solve the Reynolds equation with mass-conserving cavitation, employing PINNs. It manages the void fraction inequality with a hard constraint method and stabilizes boundary value problems. Additionally, it prevents trivial solutions. The method shows strong agreement across domains and boundaries.

Similarly, the paper entitled "A new 3D elastoplastic hydrodynamic lubrication model for rough surfaces" proposed a new contact calculation model of elastoplastic hydrodynamic lubrication (PEHL) with a 3D rough surface. The model integrated numerical calculations to solve the EHL problem with the finite element method. It reduces errors caused by the assumption of semi-infinite space in contact calculation. The contradiction between smooth surface assumption and rough surface is mitigated in the R-PEHL model. This serves as a reference for the R-PEHL model solution, and the application of fluid-structure coupling mechanics and interface lubrication mechanics.

AI and ML have also enabled more effective tribological sensing capacity and can help monitor critical tribology processes and predict performance. For sensing tribology processes, the paper entitled "Optimized Mask-RCNN model for particle chain segmentation based on improved online ferrograph sensor" describes the development of an integrated optimization method for online ferrograph-based wear debris analysis (WDA), which enhances real-time wear state monitoring. It redesigns the online ferrograph sensor and improves particle chain segmentation accuracy. Key innovations include magnetic pole optimization for clearer wear particle imaging and a light source simulation model for uniform illumination. A Mask-RCNN-based segmentation model addresses irregular particle morphology, significantly boosting particle feature extraction accuracy and imaging clarity, even in highly degraded oils.

When it comes to the monitoring of failure due to tribology phenomena, the paper entitled "Scuffing failure analysis based on a multiphysics coupling model and experimental verification" proposes a multiphysics coupling model that captures the breakdown of both lubricant film and tribofilm during scuffing progress. Experiments under a step-load sequence and various temperatures are conducted to validate this model and to further understand the origin and mechanism of scuffing failure.

To predict and interpret the tribological experiments, the paper entitled "Prediction of ball-on-plate friction and wear by ANN with data-driven optimization" investigates the feasibility and performance of AI application to interpret contact and hydrodynamic pressure in a ball-on-plate setup. The data-driven optimization, assisted with a specific deep learning algorithm, is adopted to achieve the goal, predicting macroscopic ball-on-plate tribological behavior accurately.

Electrical contact wear is a critical problem in energy generation and power transmission. The paper entitled "Prediction of contact resistance of electrical contact wear using different machine learning algorithms" combines multiple ML algorithms to attempt to predict the contact resistance of H62-brass electrical contacts as a function of wear. Contact resistance monitoring and microscopic observation of worn surface morphology provide a solid basis for these ML models' validation.

Bearing service life is heavily influenced by friction and wear, and a lack of accurate life prediction models is needed in the context of preventive maintenance. The paper entitled "Bayesian inference-based wear prediction method for plain bearings under stationary mixed-friction conditions" proposes a method to predict the remaining useful life (RUL) of plain bearings under wear-critical conditions using transient wear data from a mixed-EHL and wear simulation. It utilizes a statistical, linear degradation model updated via Bayesian inference to account for wear progression during operation. The method effectively predicts RUL across various wear behaviors including hydrodynamic, stationary, and progressive wear scenarios, demonstrating its applicability to real-world situations.

As additive manufacturing (AM) becomes a hot topic for the tribology society, the paper entitled "Generating synthetic as-built additive manufacturing surface topography using progressive growing generative adversarial networks" measures surface topography of as-built AM parts and generates synthetic surface topography maps that are statistically similar, using progressively growing generative adversarial networks.

Combing multiple tribology metrics is useful to monitor and predict tribo-behavior of complex systems. Therefore, the paper entitled "Predicting the coefficient of friction in a sliding contact by applying machine learning to acoustic emission data" combines ML algorithms with acoustic emission techniques to predict the coefficient of friction. The measured and predicted acoustic emission data during friction contacts are in good agreement.

Finally, composite materials have been widely used to enhance tribology performance. The paper entitled "Modeling and prediction of tribological properties of copper/aluminum–graphite self-lubricating composites using machine learning algorithms" demonstrates this potential by investigating self-lubricating tribological properties in copper/aluminum–graphite composite materials. Five algorithms were used and compared, in terms of coefficient of friction and wear rate, and the beneficial factors for self-lubricating are quantitatively ranked. This exciting application of ML proves successful in complex tribological materials design.

In summary, the articles contributed to this issue collectively underscore the transformative impact of AI-driven approaches in tribology, paving the way for future innovations. Through a combination of theoretical insights and practical breakthroughs, this issue not only provides a comprehensive overview of the current state and future prospects of AI and machine learning in revolutionizing tribology research, but also involves insightful up-to-date AI and computational research articles in tribology fields from several scholars.

We express our sincere appreciation to all the authors for their insightful and constructive contributions to this special issue. We hope that the readers will appreciate the various viewpoints presented in the different papers, and that these perspectives will serve as a source of inspiration for their own research endeavors, thereby contributing to the progression of the field.