

Recent Advances in High-Temperature Tribology

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1. Introduction

High-temperature tribology is a multidisciplinary science that has evolved rapidly in response to the increasing performance demands of high-technology sectors, including aviation, aerospace, nuclear energy, power generation, and advanced metal forming industries. Under such extreme service conditions, critical mechanical components are required to operate reliably at high temperatures, high speeds, and/or under heavy loads. In these environments, friction, wear, lubrication, and elastic–plastic deformation—and their complex interrelationships—become dominant factors governing performance and durability.

High-temperature lubrication and anti-wear materials and technologies are therefore essential for a wide range of high-temperature tribological applications, such as rolling element bearings, air foil bearings, and gears in aerospace systems, cylinder wall–piston ring lubrication in low-heat-rejection diesel engines and small-arm action components in defense equipment, and hot rolling mills and forging tools in metal processing industries. To address the challenges of friction and wear under such extreme operating conditions, extensive research efforts over the past two decades have focused on the development of novel lubricants, including solid self-lubricating composites, glass-based lubricants, high-temperature greases, and inorganic polymers. Despite these advances, the practical application of many of these materials and lubricants remains limited, and a deeper understanding of their tribological behavior under extreme conditions is still required to meet the stringent demands of high-temperature, high-load, and high-speed applications.

The objective of this Special Issue is to bring together review articles and original research contributions that present the latest advances and fundamental insights into novel materials and composites for high-temperature tribological applications. Emphasis is placed on both experimental investigations and computational modelling of friction, wear, temperature evolution, and stress development.

2. Contributions

In this Special Issue of *Lubricants*, one review article and seven research papers of high scientific quality have been published. These contributions address key topics in high-temperature tribology, including high-temperature tool materials, novel metallic-based solid self-lubricating composites, and high-temperature glass lubricants, as well as the modelling of temperature and residual stress evolution during manufacturing processes for components or products requiring excellent friction and wear performance.



Received: 8 February 2026

Revised: 10 February 2026

Accepted: 14 February 2026

Published: 15 February 2026

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To satisfy the stringent requirements for superior wear resistance and mechanical strength over a wide temperature range during machining process, cermet materials have been extensively employed owing to their high hardness and mechanical strength, excellent resistance to thermal softening, and outstanding fracture toughness. In the Contribution 1, Elgazzar et al. presented a comprehensive review of various cermet systems, with a particular focus on high-temperature tribology and cutting performances. In this contribution, the authors summarized the most widely used commercial ceramic tool materials, including silicon nitride-based ceramics, alumina-based ceramics, SiAlON-based ceramics, and WC-Co-TiC/TiN-based cermets, together with their corresponding sintering manufacturing methods, such as spark plasma sintering, hot pressing, hot isostatic pressing, microwave sintering, and vacuum sintering. In general, these powder metallurgy-based sintering techniques represent the most important manufacturing routes for ceramic and cermet cutting tools, offering advantages in terms of both cost efficiency and dimensional precision. In addition, the authors compared the effects of incorporating different lubricants and modifying surface textures on high-temperature metal cutting and machining performance. Finally, the review highlighted the critical role of finite element (FE) analysis in machining processes for improving the understanding of frictional behavior, temperature and stress evolution, strain distribution, cutting forces, and chip morphology. Overall, this review provides a valuable reference for researchers and engineers in the machining field, supporting the development of high quality, high efficiency machining processes while reducing raw materials consumption for cutting tools.

In the Contribution 2, Zhen et al. investigated the effects of temperature (25–250 °C) and MoS₂ solid lubricant content (0–5 wt.%) on the friction and wear behavior of the polymer matrix composites PTFE/MoS₂ fabricated by hot pressing sintering. Their results showed that, compared with pure PTFE, the addition of MoS₂ effectively reduced both the friction coefficient and wear rate under a normal load of 10 N and a sliding speed of 0.33 m/s against a GCr15 steel counterpart. Among the investigated compositions, the composite containing 2 wt.% MoS₂ exhibited the best wear resistance and lubricating performance. Furthermore, the dominant wear mechanisms transitioned from mild abrasive wear at 25–100 °C to fatigue wear and severe abrasive wear at higher temperatures of 150–250 °C. In the Contribution 3, Zhen and co-authors examined the high temperature friction and wear properties of the metallic matrix composites using a nickel alloy as the matrix and silver molybdate (Ag₂MoO₄) and barium molybdate (BaMoO₄) as solid lubricants. Wear tests were performed over a wide temperature range from 25 to 800 °C under a normal load of 5 N and a sliding speed of 1 m/s against Si₃N₄ ceramic balls. The results demonstrated that the incorporation of Ag₂MoO₄ and BaMoO₄ significantly reduced the friction coefficient and wear rate only at temperatures above 400 °C, which was attributed to the synergistic effects of the molybdate lubricants and the formation of in situ oxidative lubricating layers. In contrast, relatively poor tribological performance was observed at temperatures between 25 and 400 °C due to the absence of effective lubrication mechanisms.

Over the past two decades, the incorporation of two-dimensional (2D) materials has been widely recognized as a promising strategy for developing advanced solid-lubricating composites with enhanced friction and wear performance. However, the tribological behavior of these materials is strongly influenced by environmental conditions, including temperature, pressure, and vacuum. To address these limitations and broaden the application range of 2D materials, Wang et al. conducted a systematic study on the fabrication and characterization of nano-oxide (ZnO, TiO₂, Al₂O₃, and ZrO₂)-Ag-MoS₂ composites in the Contribution 4. Among the investigated systems, the MoS₂-TiO₂-Ag composite exhibited the best tribological performance at 450 °C during sliding against Si₃N₄ ceramic balls. Compared with the MoS₂-Ag composite without nano-oxide addition, the MoS₂-TiO₂-Ag

composite showed approximately 43% and 18% reductions in specific wear rate and friction coefficient, respectively.

Braking represents a critical safety challenge in traffic systems and is typically accompanied by significant variations in the friction coefficient between contacting surfaces. Therefore, braking components which are generally fabricated from solid composite materials are required to achieve a balance between stable frictional performance and good wear resistance. In the Contribution 5, Verma and co-authors studied the carbonaceous decomposition products based on pin-on-disc wear tests that were conducted at temperatures ranging from 155 to 300 °C using a commercial low-steel friction composite brake material as the pin and cast iron as the disc. The experimental results demonstrated that the formation of carbonaceous products originated from the thermal degradation of the phenolic binder resin in the pin friction material. Furthermore, it was observed that the wear of the brake pin increased with increasing temperature from 155 to 300 °C, whereas the wear of the cast iron disc decreased as the temperature increased.

Metal forming is another critical mechanical process involving complex tribological interactions. For instance, in hot steel rolling, work rolls are subjected to severe wear due to periodic exposure to high loads and elevated temperatures. The use of suitable lubricants can therefore effectively extend the service life of work rolls by reducing friction and wear, while simultaneously improving the surface quality of rolled products. However, conventional lubricants used in the hot rolling process, such as oil-based and grease-based lubricants, perform effectively only at relatively low temperatures (<300 °C) and are prone to thermal degradation at higher temperatures. To address these limitations, Liu et al. successfully developed a novel sodium metasilicate glass lubricant for hot rolling applications in the Contribution 6. Hot rolling experiments on mild steel strips demonstrated that the use of this lubricant reduced the rolling force by more than 7.8%. Furthermore, the rolling force reduction increased to 12.7% when the sodium metasilicate glass lubricant was applied after descaling of the hot strips. This enhanced performance was attributed to the formation of a molten sodium silicate layer at the interface between the work roll and the steel strip, which provided an easily sheared lubricating layer during the hot rolling process.

In addition to experimental approaches, modelling at the nano-, micro-, and macro-scales has been widely used to investigate friction, wear, residual stress, elastic/plastic strain, texture, and temperature evolution arising from contact or deformation in mechanical and transmission system. In the Contribution 7, Cai et al. developed three-dimensional (3D) FE models to analyze the scuffing-related temperature rise in spiral bevel gears, which are critical components in helicopter aero-engine transmission systems. Their study examined the influence of gear tooth surface roughness on the temperature field under both dry friction and mixed lubrication conditions. The FE simulation results showed good agreement with experimental measurements obtained from a gear test rig, with a maximum error of less than 5%. The study revealed that contact pressure, relative sliding speed, and friction coefficient were the dominant factors governing frictional heating. By integrating heat transfer analysis, gear meshing principles, and fractal theory, the model provided a cost-effective approach for predicting the scuffing risk of spiral bevel gears and offered guidance for gear manufacturing.

For mechanical components, tailoring microstructure, mechanical properties, and residual stress states is a commonly adopted strategy to improve wear and fatigue performance. However, residual stress distributions are strongly influenced by manufacturing processes, especially laser-based techniques. In the Contribution 8, Tan and Wang investigated the effect of laser power on residual stress and temperature distributions in a laser-melted RuT300 valve seat made of cast iron. Their FE simulations revealed that

residual stress along the circumferential direction was much higher than along the axial and radial directions, and that the maximum residual stress increased from 224 to 246 MPa when the laser power was increased from 2.0 to 2.6 kW. Overall, the good agreement between FE simulations and experimental results in the Contribution 7 and Contribution 8 demonstrates that FE modelling is a powerful and cost-efficient tool for the rapid assessment and optimization of engineering design and manufacturing processes for components requiring high wear resistance and mechanical performance. Furthermore, the combined use of experimental and modelling approaches provides valuable insight into the complex relationships between manufacturing processes and mechanical and tribological behavior.

3. Conclusions and Outlook

The papers published in the Special Issue “Recent Advances in High Temperature Tribology” provide an up-to-date overview of the state of the art in the development of a broad range of materials, including cutting tool materials, solid self-lubricating composites, and novel high-temperature lubricants, as well as advanced FE models relevant to tribological behavior and manufacturing processes. The high quality and diversity of the published articles address the needs of both academic and industrial researchers seeking new insights to support future advances in these challenging and rapidly evolving fields.

Funding: J.C. acknowledges the financial support from the National Natural Science Foundation of China (No. 52175197), the Youth Innovation Promotion Association CAS (No. 2022425), Major Science and Technology Project of Gansu Province (No. 23ZDGA011).

Acknowledgments: As Guest Editors, we would like to express our sincere appreciation to all authors and reviewers for their substantial contributions and rigorous efforts in ensuring the high academic quality of this Special Issue. We also gratefully acknowledge the editorial team of Lubricants for their professional guidance and continuous support throughout the entire editorial process of this Special Issue.

Conflicts of Interest: The authors declare no known conflicts of interest.

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