coatings

MDPI

Editorial

Special Issue: Recent Trends in Wear and Erosion Resistance of Alloys

Elsayed Gamal Zaki [1,*], Mohamed S. Selim [1,2], Zhifeng Hao [2,*], S. M. ElSaeed [1] and Ashraf M. EL-Saeed [1]

[1] Petroleum Application Department, Egyptian Petroleum Research Institute, Nasr City, Cairo 11727, Egypt
[2] Guangdong Provincial Key Laboratory of Plant Resources Biorefinery, School of Chemical Engineering and Light Industry, Guangdong University of Technology, Guangzhou 510006, China
* Correspondence: chemparadise17@yahoo.com (E.G.Z.); haozf@gdut.edu.cn (Z.H.)

The development of novel alloys with enhanced wear and erosion resistance has attracted a lot of interest. The creation of materials and nanocomposites with greater resistance to surface degradation is inevitable. According to some estimates, the loss of material due to corrosion, erosive wear, and wear results in a global economic impact of billions of dollars. Many technologies have not reached their full potential because there are not enough materials to tolerate surface deterioration in crucial applications. The production of wear- and erosion-resistant materials for various application requirements has traditionally been accomplished by incorporating modest quantities of alloying elements into the base material and customizing the heat treatment, especially for alloys. A balance between mechanical characteristics and corrosion resistance is achieved through tempering treatments.

The study of wear, erosion, and surface interaction is known as tribology. Wear is a phenomenon involving material damage, loss, and deformation. It has a significant impact on the lifespan of a material from the nano- to the micro-scale [1]. Wear in a range of modern technologies is a constant concern, which encourages research into materials with high wear resistance. Material wear processes include oxidation, adhesion, abrasion, and fretting. Such wear mechanisms can occur alone or in combination [2]. Wear processes can be divided into low, mild, and severe wear states [3]. The layer-by-layer or gradual degradation of a metallic material's surface induced by electrical discharges or mechanical action is known as erosion. Metals erode due to wear, frictional rubbing, and cavitation. In order to minimize the loss or damage in a material subjected to wear, newly developed wear-resistant materials should be introduced.

Surface engineering is one of the most efficient methods to reduce wear and erosion because a material's wear and erosion conditions are focused on the surface structure. The coating preparation, surface texturing, surface hardening, and architectural layout are the four main factors that dominate surfaces with extreme wear and erosion resistance. The resistance of wear can also be accomplished through matrix strengthening and surface engineering.

In this Special Issue, matrix strengthening refers to techniques for enhancing the resistance of ceramics, metals, and polymers against wear. Microstructure design, composition management, and the use of reinforcements can provide resistance against wear conditions. This can be enhanced by customizing the deformation mechanisms [4] or adding hard in situ/ex situ nanoparticles [5]. The enhancement of the matrix's strength and hardness depends on the reinforced particles, their distribution throughout the matrix, and surface non-wettability. Thus, it was extremely important to provide this Special Issue on the most recent innovations to avoid or lessen the wear and erosion of alloys.

The surface durability is typically improved in the desired way by wear-resistant coatings. Several techniques have been used to produce wear-resistant coatings, including

check for updates

Citation: Zaki, E.G.; Selim, M.S.; Hao, Z.; ElSaeed, S.M.; EL-Saeed, A.M. Special Issue: Recent Trends in Wear and Erosion Resistance of Alloys. *Coatings* **2023**, *13*, 64. https://doi.org/10.3390/coatings13010064

Received: 5 December 2022
Revised: 13 December 2022
Accepted: 26 December 2022
Published: 30 December 2022

the application of iron treatment prior to coating deposition, strengthened coating by multiple elements doping [6], and the design of wear-resistant nanocomposite coatings [7]. The content and microstructure of coatings have a significant impact on their hardness [8]. Spinodal breakdown and precipitate formation, which take place in a number of nitrides of transition metals, can further boost coating hardness [9]. Self-lubricating coatings, including MoS_2 diamond-like carbon, used in high-speed cutting applications, are wear-resistant protective films [10].

A wear-resistant coating is achieved by adding Mo-based materials as well as additional doping for matching lubricants' rubbing surfaces to adjust stiffness and surface energy [11]. Effective surfaces can be created by surface texturing, including carefully manipulating topography [12]. Surface texturing is a vital step to improve the alloy tribology and it can be achieved by improving the load-carrying capacity and enhancing the hydrodynamic pressure on the textured surface. Also, using extra lubricants on the contact surface via the inlet suction can increase the surface texturing [13]. Reduced real contact area, reservoir effect-assisted lubricant storage, and debris trapping effect-assisted wear particle capture are the other three factors [14]. Notably, a possible technique for improving the tribology of the surface even at harsh contact circumstances is texturing both the surface and the coating. This exhibits significant wear resistance. In order to increase the endurance of hydrophobic surfaces, surface hardening has been successfully implemented.

The hierarchical and heterogeneous structure of wear-resistant materials is caused by many wear mechanisms functioning concurrently over a range of scales and hierarchy levels. Multi-scale texturing, including elliptical and circular form arrays, can enhance the tribological behavior of steel [15]. Surface engineering can design hierarchical structures with hydrophobicity and adhesion strength bio-inspired by natural self-cleaning surfaces of plants and animals [16]. Lotus leaves produce the well-known hierarchical surface with two tiers of roughness that is the result of micro- and nano-scale roughness [17]. To accomplish amazing adjustability in adhesion and tribology, several unique bioinspired hierarchical surfaces were introduced recently. They have a significant influence on metal materials' bonding strength, plasticity, fracture performance, and lattice distortion, which affect their wear resistance.

Controlling the matrix's microstructural architecture directly influences the material's wear resistance. This is based on a material's twins, dislocation, grain boundary structure, and grain size. This can also produce heterogeneous and hierarchical surface structures. Strengthening of wear-resistant materials can be achieved by dispersion hardening, as well as precipitates and second phase reinforcements. The diameters, morphology, and reinforcing content of these materials can greatly increase the wear resistance.

Fullerenes, CNTs, graphene, carbon nanotubes, and fullerenes are examples of carbon nanomaterials that have a significant potential for use as wear-resistance-inducing additives in bulk surfaces and materials [18,19]. Also, the addition of two-dimensional (2D) nanomaterials, including MXenes, graphene-related materials, transition metal dichalcogenides and hexagonal boron nitride, offers remarkable enhancing possibilities because of their significant surface area, ultrathin thickness, ultrahigh strength, and superior thermal and chemical stability [20]. The metallic material's wear resistance is enhanced by ultra-fine-grained microstructures and reinforcements by grain boundary hardening and precipitation. The wear resistance is positively affected by the materials' plasticity, strength, hardness, and stiffness. The size, morphology, and reinforcing content of these materials all have a significant impact on their wear resistance.

This Special Issue highlighted the corrosion, erosion, and wears parameters of complicated concentrated alloys. The impact of alloying components, microstructure, and processing techniques can affect the surface deterioration. A solid surface will gradually lose material due to mechanical contact between the surface and an impinging liquid that contains solid particles during erosion, a kind of material degradation. This issue also offers a thorough analysis of recent developments in wear-resistant material designs, characteristics, and applications, covering a range of cutting-edge manufacturing techniques for these materials and associated wear mechanisms.

As two main approaches to increasing material wear resistance, surface engineering and matrix strengthening were introduced. Both surface engineering by coatings and surface hardening and texturing, and matrix strengthening by composite formation, reinforcements, and microstructure formation are effective ways to improve the wear and erosion resistance of a material. A durable and wear-resistant surface layer can be achieved with careful adjustment of the composition and structure. On the contrary, structural design and composition management in the bulk materials can provide excellent wear resistance, compromising the material's mechanical capabilities.

The advancements in wear and erosion reduction can be achieved by unique surface and matrix design methodologies, and inherent material qualities for various applications. Different types of surface coatings, including amorphous/nanocrystalline, gradient multilayer, nanocomposite, and 2D-based coatings, can provide outstanding wear resistance, anticorrosion, and hydrophobicity. Wear on surfaces having hierarchical structures is significantly lower than unmodified surfaces [21]. Several methods were introduced for improving the anti-wear and anticorrosion features of a material without losing the electrical and mechanical characteristics. These methods mainly required changing the material's phase compositions and microstructures.

By extensively elaborating on the phase compositions and nanostructures, it would be possible to further increase the material wear and erosion resistance. This focuses on the formation of nano-twins, heterogeneity, cryogenic deformation, and uniformly distributed 2D nanostructures in matrices with good interfacial compatibility. Designing large-scale wear-resistant nanostructures or phase compositions critically depends on the stability and reproducibility of the designed nanostructured composites. The architectures and sizes of 2D materials attract considerable attention for extending superlubricity to trustworthy practical applications. Superlubricous contact would be possible to maintain during extended timeframe conditions by effectively using 2D material-wrapped nanoparticles. They concentrate on the creation of large-scale, low-defect materials, heterostructures, and alterations for functionalized materials' surfaces. Extreme wear damage occurs to materials exposed to high temperatures. In this case, simulations would be beneficial in revealing the relationships between wear performance and alternations in the microstructure at elevated temperatures. It is believed that the various accomplishments and the impending challenges will have substantial impacts on the development of extremely wear-resistant structures for various applications.

Author Contributions: Conceptualization, E.G.Z. and M.S.S.; methodology, S.M.E.; validation, S.M.E. and A.M.E.-S.; resources, Z.H. and A.M.E.-S.; data curation, S.M.E. and A.M.E.-S.; writing—original draft preparation, E.G.Z. and M.S.S.; writing—review and editing, E.G.Z. and M.S.S.; visualization, E.G.Z. and S.M.E.; supervision, Z.H.; S.M.E. and A.M.E.-S.; project administration, Z.H., S.M.E. and A.M.E.-S.; funding acquisition, Z.H. and M.S.S.; All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the financial support from the National Natural Science Foundation of China (Grant No: 52150410401).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhang, S.; Ma, T.; Erdemir, A.; Li, Q. Tribology of two-dimensional materials: From mechanisms to modulating strategies. *Mater. Today* **2019**, *26*, 67–86. [CrossRef]
2. Baydoun, S.; Arnaud, P.; Fouvry, S. Modelling adhesive wear extension in fretting interfaces: An advection-dispersion-reaction contact oxygenation approach. *Tribol. Int.* **2020**, *151*, 106490. [CrossRef]
3. Aghababaei, R.; Brink, T.; Molinari, J.-F. Asperity-level origins of transition from mild to severe Wear. *Phys. Rev. Lett.* **2018**, *120*, 186105. [CrossRef]
4. Zhai, W.; Bai, L.; Zhou, R.; Fan, X.; Kang, G.; Liu, Y.; Zhou, K. Recent progress on wear-resistant materials: Designs, properties, and applications: A review. *Adv. Sci.* **2021**, *8*, 2003739. [CrossRef]

5. Hofmann, D.C.; Andersen, L.M.; Kolodziejska, J.; Roberts, S.N.; Borgonia, J.P.; Johnson, W.L.; Vecchio, K.S.; Kennett, A. Optimizing Bulk Metallic Glasses for Robust, Highly Wear-Resistant Gears. *Adv. Eng. Mater.* **2017**, *19*, 1600541. [CrossRef]
6. Dai, W.; Kwon, S.H.; Wang, Q.; Liu, J. Influence of frequency and C_2H_2 flow on growth properties of diamond-like carbon coatings with AlCrSi co-doping deposited using a reactive high power impulse magnetron sputtering. *Thin Solid Film.* **2018**, *647*, 26. [CrossRef]
7. Yuan, S.; Lin, N.; Zou, J.; Lin, X.; Liu, Z.; Yu, Y.; Wang, Z.; Zeng, Q.; Chen, W.; Tian, L.; et al. In-situ fabrication of gradient titanium oxide ceramic coating on laser surface textured Ti_6Al_4V alloy with improved mechanical property and wear performance. *Vacuum* **2020**, *176*, 109327. [CrossRef]
8. Bai, H.; Zhong, L.; Kang, L.; Liu, J.; Zhuang, W.; Lv, Z.; Xu, Y. A review on wear-resistant coating with high hardness and high toughness on the surface of titanium alloy. *J. Alloys Compd.* **2021**, *882*, 160645. [CrossRef]
9. Chen, W.; Fang, B.; Zhang, D.; Meng, X.; Zhang, S. Thermal stability and mechanical properties of HVOF/PVD duplex ceramic coatings produced by HVOF and cathodic vacuum arc. *Ceram. Int.* **2017**, *43*, 7415. [CrossRef]
10. Scharf, T.W.; Kotula, P.G.; Prasad, S.V. Friction and wear mechanisms in $MoS_2/Sb_2O_3/Au$ nanocomposite coatings. *Acta Mater.* **2010**, *58*, 4100–4109. [CrossRef]
11. Vazirisereshk, M.R.; Martini, A.; Strubbe, D.; Baykara, M. Solid Lubrication with MoS_2: A Review. *Lubricants* **2019**, *7*, 57. [CrossRef]
12. Rosenkranz, A.; Costa, H.L.M.; Baykara, M.Z.; Martini, A. Synergetic effects of surface texturing and solid lubricants to tailor friction and wear—A review. *Tribol. Int.* **2021**, *155*, 106792. [CrossRef]
13. Qiang, L.; Wang, Y.; Zhang, S.; Xu, W.W.; Wang, Z.B. Preparation and Sensing Properties of Photocurable Composite Electrophoretic Coating. *Surf. Technol.* **2019**, *48*, 180–188.
14. Boidi, G.; Grützmacher, P.; Kadiric, A.; Profito, F.; Machado, I.; Gachot, C.; Dini, D. Fast laser surface texturing of spherical samples to improve the frictional performance of elasto-hydrodynamic lubricated contacts. *Friction* **2021**, *9*, 1227–1241. [CrossRef]
15. Dwivedi, S.; Dixit, A.R.; Das, A.K.; Adamczuk, K. Additive texturing of metallic implant surfaces for improved wetting and biotribological performance. *J. Mater. Res. Technol.* **2022**, *20*, 2650–2667. [CrossRef]
16. Malshe, A.P.; Bapat, S.; Rajurkar, K.P.; Haitjema, H. Bio-inspired textures for functional applications. *CIRP Ann.* **2018**, *67*, 627. [CrossRef]
17. Selim, M.S.; El-Safty, S.A.; Shenashen, M.A.; Higazy, S.A.; Elmarakbi, A. Progress in biomimetic leverages for marine antifouling using nanocomposite coatings. *J. Mater. Chem. B* **2020**, *8*, 3701–3732. [CrossRef]
18. Zhai, W.; Lu, W.; Chen, Y.; Liu, X.; Zhou, L.; Lin, D. Gas-atomized copper-based particles encapsulated in graphene oxide for high wear-resistant composites. *Compos. Part B* **2019**, *157*, 131. [CrossRef]
19. Selim, M.S.; El-Safty, S.A.; Abbas, M.A.; Shenashen, M.A. Facile design of graphene oxide-ZnO nanorod-based ternary nanocomposite as a superhydrophobic and corrosion-barrier coating. *Colloid. Surf. A Physicochem. Engin. Asp.* **2021**, *611*, 125793. [CrossRef]
20. Liu, B.; Zhou, K. Recent progress on graphene-analogous 2D nanomaterials: Properties, modeling and applications. *Prog. Mater. Sci.* **2019**, *100*, 99. [CrossRef]
21. Wu, Y.; Zhao, W.; Wang, W.; Zhang, Y.; Xue, Q. Novel structured anodic oxide films containing surface layers and porous sublayers showing excellent wear resistance performance. *RSC Adv.* **2016**, *6*, 94074. [CrossRef]