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Preparation of Silver Nanoball@GNSs Lubricant and its Antifriction under Current Carrying

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ABSTRACT

In this experiment, silver nanoball@ graphene nanosheets (SG) composite additive using under a current-carrying was prepared via in-situ reduction method, which has both good electrical conductivity and tribological properties. The conductivity test results showed a 12-fold increase in the conductivity of the novel composite compared to the pure ionic liquid LP108. Without the current carrying, the values of COF were decreased to 0.070 and the wear volume of the disk was reduced by 88.4% at an additive concentration of 0.10 wt%. when a 1A current was applied to both ends of the friction pair,the average COF of the lubricant material was as low as 0.06892 with a 78.6% reduction in wear. This is because the movement of anions and cations in the ionic liquid can be accelerated by the electric current, and Ag and C elements in the additive can be adsorbed on the surface of the friction pair to form a protective film. This research result opens up a new way to improve the tribological properties of sliding electrical contacts from micro and nano scale technology and to develop a new generation of highly conductive lubricant materials.

KEYWORDS

Graphene; Silver Nanoball; Current-carrying; Tribological Properties; Lubricants.

1. INTRODUCTION

Accompanied by the rapid development in the fields of power electronics, aerospace, and automatic control, the current-carrying friction phenomenon has been widely appeared in various electromechanical devices [1-4]. Because of the force-electric-thermal coupling effect of current, the frictional interface could be influence by a complex condition[5-8], which make the friction damage of current-carrying friction substituents more serious. Its friction and wear behavior not only affects the service life and reliability of electrical equipment [9], but also causes energy waste, material destruction and other problems [10]. Therefore, it is particularly necessary to urgently seek a simple and efficient friction reduction method. The use of current-carrying lubricants is the most rapid, intuitively effective and universally adaptable means of friction reduction, favored by the modern industrial market. Therefore, it is urgent to seek a current-carrying lubricant lubricating medium with excellent lubricating properties and good electrical conductivity.

Ionic liquids (ILs), as a kind of molten salts consisting of weakly coordinating anions and organic cations with desirable characteristics such as high thermal stability, negligible vapor pressure, and superior electrochemical properties [11,12], have been introduced into the field of current-carrying friction as high-performance fluid lubricants [13-15]. Although a number of scholars have carried out extensive and fruitful research work [16], most of them have focused on low loading and low electrical charge conditions, which is because the lubricating film of ionic liquid has a lower load carrying capacity[17,18], especially for the tribological process under the condition with current-carrying, and nano-particles may enhance the frictional properties of ionic liquids[19,20]. Graphene-silver composites combine the advantages of excellent mechanical properties, lubrication, high electrical and thermal conductivity of the self-lubricating phase graphene [21-23] with the high electrical and thermal conductivity and good ductility of silver nanoparticles [24,25]. While retaining the graphene layered structure, silver nanoparticles can well solve the agglomeration phenomenon between the graphene nanolayers due to van der Waals forces, and realize the simultaneous enhancement of friction performance and electrical conductivity of current-carrying lubricants. Thus, it becomes an ideal service material for current-carrying lubricant additives.

Based on the above analysis and combined with the previous research of our group, graphene-silver nanoballs (SG) nanocomposites additive were successfully prepared by in-situ reduction method and modified and dispersed in LP108 ionic liquid in this paper. The lubricant material was investigated in terms of ratio, concentration, morphology and tribological performance and wear mechanism under non-current-carrying/current-carrying working conditions, and the synergistic lubrication mechanism between the two nanoparticles was analyzed and discussed. The results show that the GNSs-SNB nanocomposite GNSs-SNB has excellent lubrication and self-healing properties under non-current-carrying/current-carrying conditions.

2. EXPERIMENTAL METHODS

2.1. Experimental Material

Silver nitrate (99.0 wt%), polyvinylpyrrolidone (K30), 1-octyl-3-methylimidazolium hexafluorophosphate ($C_{12}H_2H_2F_6N_2P$, 95 wt%), dopamine hydrochloride (99.8 wt%), sodium hydroxide (NaOH, 96 wt%), and dimethylformamide (DMF,99.5 wt%) were supplied by Aladdin Bio-Tech Co. Graphene were supplied by beike 2D materials Co., Ltd.

2.2. Preparation of Lubricant Materials

The lubricant additive were synthetized via the method of in-situ reduction. This process yielded graphene coated with silver nanoball (SG) particles composite additives. The additives were then modified and dispersed in ionic liquid LP108 at different mass ratios to create LP108/SG nanolubricant materials. Graphene nanosheets were dispersed in DMF via ultrasonic dispersion. A specific amount of $AgNO_3$ was weighed and dissolved in 10 mL of DMF until completely dissolved. This solution was added to the reaction mixture at a rate of 0.368 mL/min using a dispensing funnel over one hour, followed by transfer to a reactor for reaction. Finally, the products were separated, washed, and dried repeatedly with anhydrous ethanol to obtain the SG lubricant additive.

2.3. Characterization and Testing

The morphology and microstructure of the composite additives were analyzed using scanning electron microscopy (SEM) at 15 kV. The shear stress, strain and viscosity of the lubricant materials were tested using an Anton Paar MCR302 rotational rheometer (Austria) and a RheoPlus rheometer. The conductivity of the lubricant material and the pure ionic liquid were examined using a conductivity meter (LEI-CI, China). The frictional performance of the lubricant material was tested using a friction tester, respectively. The friction sub-material was made of GCr15 bearing steel, and the experimental load was 50 N. Reciprocating motions were carried out, and the friction pair were connected to a DC power supply for regulation. Scanning electron microscope and three-dimensional surface profiler were used to characterize the surface abrasion morphology of the specimen.

3. RESULTS AND DISCUSSION

3.1. Microscopic Morphology of Lubricant Additives

Figure. 1(a-d) shows the SEM test results of SG lubricant additives fabricated with GNSs and $AgNO_3$ at different mass ratios (1:60, 1:40, 1:20). It can be observed from Fig. 1(a-d) that the coverage of the SG lubricant additives fabricated with different mass ratios is significantly different, and the spherical silver nanoparticles are generally distributed on the surface of the lamellae. SEM imagines were shown that there were many nanoparticles loaded on the layers of GNSs. The number of silver nanoparticle spheres decreases with the decrease of silver nitrate content. The aggregation degree of silver nanospheres is further reduced due to the addition of graphene layers. Graphene layers and nano silver spheres were successfully combined for forming the nanolubricant material additives.

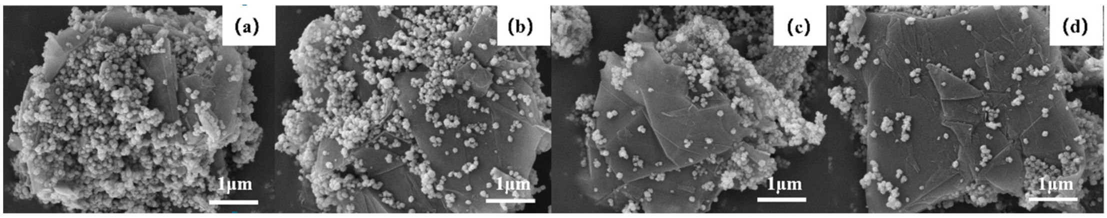

Figure 1. (a-d) SEM imagines of SG lubricant additives: (a) 1:60; (b) 1:40; (c) 1:20; (d) 1:5.

3.2. Rheological Properties and Electrical Conductivity of Lubricant materials

Figure 2(a) and (b) were shown that the of viscosity curve according to the shear stress of LP108/SG lubricant materials. The influence of SG additives on the viscosity of LP108 is not obvious as the shear rate increased, the highest value of viscosity is not more than 0.1 Pa·s. Figure 2(c) is indicated that the electrical conductivity of LP108/SG lubricant material. The electrical conductivity of LP108 was significantly improved by the addition of SG additives. The values of electrical conductivity of LP108/SG-40 lubricant material was increased to 603 μs/cm, which is more than that of pure LP108 (49.7 μs/cm), and it is about 12 times higher than that of pure LP108. As highly conductive nanoparticles will form a conductive network structure in the lubricant, additive concentration once too high will be aggregated or agglomerated will reduce the number of the conductive path, and the high contact resistance between the frictional pair will hinder the flow of interface current, which will lead to a reduction in the overall conductivity.

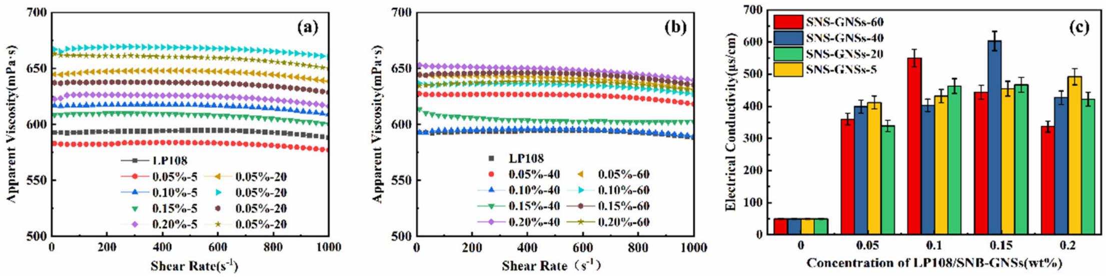

Figure 2. Viscosity curve according to shear stress of LP108/SG lubricant materials: (a) LP108/SG-5 and LP108/SG-20, (b) LP108/SG-40 and LP108/SG-60, (c) Conductivity of LP108/SG lubricant materials

3.3. Tribological Properties

3.3.1. Tribological Performance of LP108 Lubricant Materials without Current-carrying

The COF curves of different LP108 lubricant materials without current-carrying were tested using a frictional tester as shown in Figure 3. It was indicated that the frictional properties of pure LP108 was obviously enhanced by the different content of composite additives. Firstly, the lubricating film of

LP108 absorbed on the interface was broken by the external load in the run-in period of frictional process, leading to a increased values of COF. Secondly, the COF curve is beginning to stabilize when the composite additives was come into the contact interface. The lubricant materials with 0.05wt% nanocomposite additive with the mass ratios of $AgNO_3$ to GNSs of 40:1(0.05 wt% SG-40), the average COF was reduced to 0.0724 (0.0753 of pure LP108) (Figure 3(a)), and the wear volume was decreased to 26218.5 μm^3 (Figure 3(c)).The wear volume was not reduced as compared to that of the pure LP108 (25365.1 μm^3 of pure LP108). For the three-dimensional topography of wear surface in Figure 4, it was shown that the width of the furrow on the wear surface of the steel disc was shallow, and no obvious corrosion was observed (Figure 4(a)). This content is not the optimum content for this SG-40 lubricant materials. With the increase of additive concentration, the average COF and wear volume was gradually increased, resulting in some degree of failure. This is due to the fact that the agglomerates of excessive additives could be formed on the surface of the friction interface, leading to a entanglement of abrasive debris and more severe abrasive wear and a large number of plough grooves. In the end, COF and wear volume of frictional disk were increased by the abrasive wear.

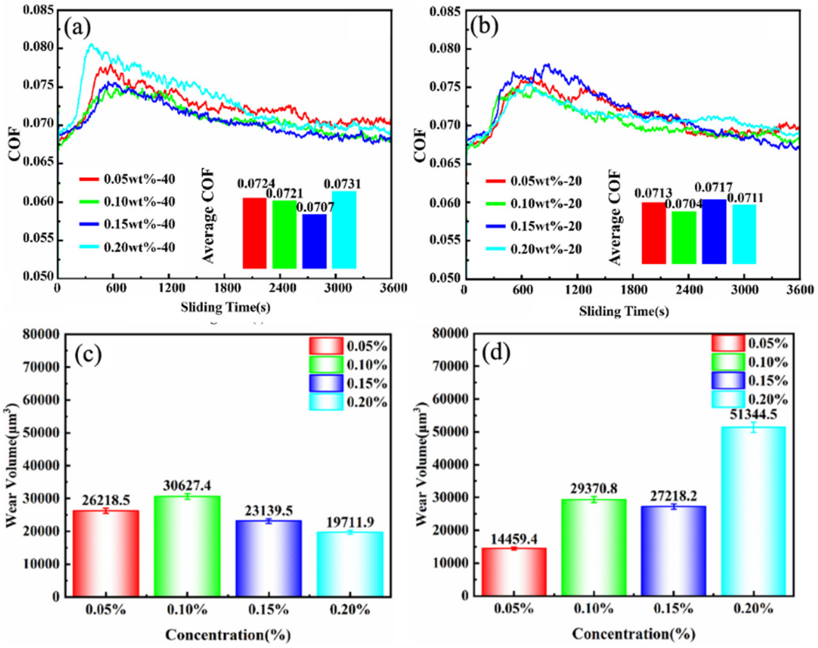

Figure 3. COF curves and average COF: (a) LP108/SG-40; (b) LP108/SG-20 and Wear volume changes: (c) LP108/SG-40 and (d) LP108/SG-20

The COF of the LP108 lubricant materials with different content of SG-40 composite additives, which was shown that the trend of increase first and reduction later in the COF curves. This is because that the low content of the composite additives is not enough to bear the external load and repair the worn area. Therefore, a small amount of composite additives cannot have good friction and wear performance in friction process. As the content of SG-40 composite additives was increased to the value of 0.15 wt%, the average COF of this lubricant material was decreased to 0.0707 (0.0753 of pure LP108) (Figure 3(a)), and the wear volume was reduced to 23139.5 μm^3 (Figure 3(c)). The three-dimensional surface topography of the wear surface of friction disk was revealed that the wear scar are more obvious and there was no obvious corrosion as shown in Figure 4(c1). So, 0.15wt.% SG-40 composite additives was the optimal content for SG-40. As the content of SG-40 increased to 0.2 wt%, the average COF and wear volume were slightly increased, which was shown that there was a little lubricating failure produced in the friction process. For LP108 with 0.10wt%SG-20 sample, the COF was decreased to 0.07041(Figure 3(b)), and the wear volume decreased to 29,370.8 μm^3 (Figure 3(d)), which was 88.4% lower as compared to that of the pure LP108. As the SG-20 composite additives increased to 0.2 wt%, the COF of this lubricant was rised to 0.0711(Figure 3(b)), but the wear volume was obviously raised to 29,370.8 μm^3 (Figure 3(b)). Adhesive wear phenomenon can be observed on the friction surface in Figure 4(d2). In the end, LP108 with SG-40 and LP108 with SG-20 lubricant materials were used for the next current-carrying test.

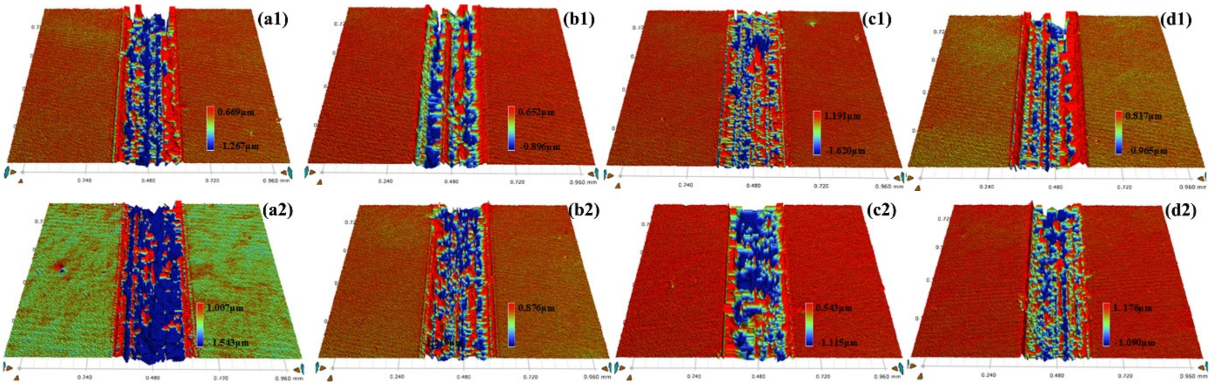

Figure 4. The three-dimensional topography of wear surface of (a1-d1) LP108 with different content of SG-40 and (a2-d2) LP108 with different content of SG-20.

3.3.2. Tribological Performance of LP108 Lubricant Materials under Current-carrying

The influence of the current on composite lubricant materials has been studied in this section. The current of 1A was applied in this frictional process. As shown in Figure 5(a1), the composite additive SG-40 own a better lubricating performance at the content of 0.05 wt%, and its average values of COF was only 0.0696, which was lower than that of pure LP108 (0.0722). Further more, the wear volume of LP108 with 0.05wt% SG-40 composites lubricant was largely dropped to 11163.5 μm^3 , and the wear volume is decreased by 79.7% as compared to that of LP108 (55122 μm^3). As for LP108 with 0.1wt% SG-20 composites lubricant in Figure 5(b1), it has a lowest average values of COF, which was 0.0689. And its wear volume of LP108 with 0.1wt% SG-20 composites was little decreased to 11777.7 μm^3. That is because nanoparticles in the SG-20composite additive entered into the interface were rolling friction had the function of rolling friction, resulting in a lower COF and wear volume.

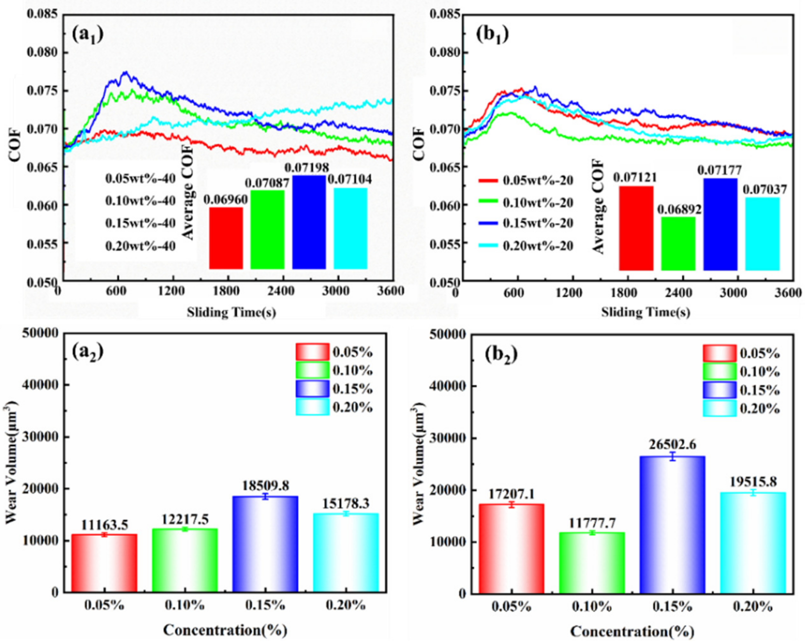

Figure 5. COF curves and average COF: (a1) LP108/SG-40; (b1) LP108/SG-20 and Wear volume changes: (a2) LP108/SG-40 and (b2) LP108/SG-20

The worn face of frictional disk should be investigated in order to research on lubrication mechanism. The three-dimensional topography of wear surface were shown in Figure 6. Adhesive wear phenomenon was discovered on the wear surface of the disk, but there was no obvious corrosion phenomenon on the interface. The 0.15wt% SG-40 is the optimal content for reducing the friction under the current-carrying content. There has been an increase in COF in subsequent frictional process with the increase of content, which was declared that the fluidity and stability of the lubrication film may be broken by the SG composite additives under current-carrying conditions. The agglomeration of SG composite additives could accelerate the wear and significantly increase the interface resistance and frictional resistance. As shown in Figure 6(b2), tribological performance of LP108 with less than 0.10wt.% of SG-20 were not obviously improved. The reason was that the content of the composites additive is too low to bear the load and repair the worn area, leading to some obvious furrow phenomenon. The best lubrication effect was achieved at the content of 0.10 wt% SG-20, where its average COF was as low as 0.06892 (0.07225 of pure LP108), and the wear volume was reduced to 11777.7 μm^3 (55122 μm^3 of pure LP108), whose wear volume was reduced by 78.6% as compared to that of the pure LP108. The three-dimensional topography of its friction sub-surface can be seen (Figure 6(c2)), the surface of steel disk was presented adhesive wear phenomenon, and the obvious corrosion was not produced. This content of additive was the optimal content used under the current-carrying condition. For the current-carrying friction condition, the addition of composite additives could enhance the lubrication and self-repair of lubricant, and improve the anti-wear and anti-corrosion properties of the lubricant.

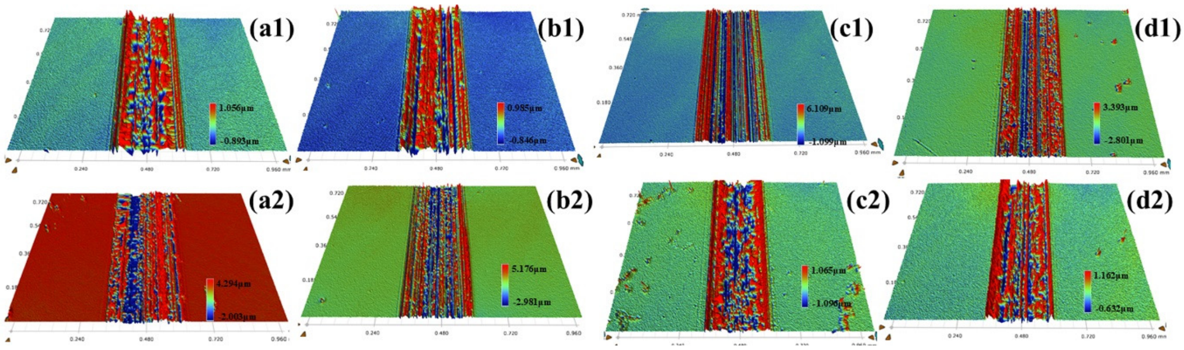

Figure 6. The three-dimensional topography of wear surface of (a1-d1) LP108 with different content of SG-40 under current-carrying and (a2-d2) LP108 with different content of SG-20 under current-carrying.

4. CONCLUSION

In this paper, SG composite lubricant additive was successfully prepared via the in-situ reduction method, and the tribological performance of this composite additive were investigated under non-current-carrying or current-carrying conditions. The results were shown that the electrical conductivity of LP108/0.15 wt% SG-40 lubricant material was significantly increased by 12 times as compared to that of the pure LP108. For the friction conditions without current-carrying, the average COF of LP108/0.10wt% SG-20 lubricant material was reduced to 0.07041 (0.07534 of the pure LP108), and the wear volume was also reduced by 88.4%. Under the friction conditions with current-carrying, the average COF of LP108/0.10wt%-SG-20 was decreased as low as the values of 0.0689, and the wear volume was reduced by 78.6% as compared to that of pure LP108. The addition of electric current may cause the anions and cations and the Ag and C elements in the additives to adsorb on the surface of the friction interface to form a protective film. The results were shown that the new SG composite lubricant additive could provide a new idea for the application in the field of current-carrying friction.

REFERENCES

[1] Ren W, Chen G. Experimental study on the wear mechanism of the contact line in rigid pantograph-catenary systems[J]. Tribology International, 2023, 187: 108739.

[2] Xue P, Chen C, Fan X, et al. Current-carrying friction in carbon coated ball bearing[J]. Friction, 2023: 1-13.

[3] Wang X, Yao P, Zhou H, et al. Research Progress on Surface Damage and Protection Strategies of Armature–Rail Friction Pair Materials for Electromagnetic Rail Launch[J]. Materials, 2024, 17(2): 277.

[4] Li J X, Wu B N, Ding H H, et al. Wear and damage behaviours of wheel and rail materials: Effects of friction modifier and environmental temperature[J]. Wear, 2023, 523: 204796.

[5] Cao Y, Wu G, Wang Y, et al. Influence of Interfacial Tribo-Chemical and Mechanical Effect on Tribological Behaviors of TiN Film in Different Environments[J]. Processes, 2024, 12(5): 923.

[6] Fu Y, Qin H, Xu X, et al. What are the progresses and challenges, from the electrical properties of current-carrying friction system to tribological performance, for a stable current-carrying interface?[J]. Journal of Bio-and Tribo-Corrosion, 2022, 8: 1-28.

[7] Spikes H A. Triboelectrochemistry: Influence of applied electrical potentials on friction and wear of lubricated contacts[J]. Tribology Letters, 2020, 68: 1-27.

[8] Han Q, Wen J, Zhong Z, et al. Numerical simulation of frictional heating effects of sliding friction bearings for isolated bridges[J]. International Journal of Structural Stability and Dynamics, 2018, 18(08): 1840008.

[9] Zhang Z, Ouyang W, Liang X, et al. Review of the evolution and prevention of friction, wear, and noise for water-lubricated bearings used in ships[J]. Friction, 2024, 12(1): 1-38.

[10] Holmberg K, Erdemir A. The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars[J]. Tribology International, 2019, 135: 389-396.

[11] Li C, Wang G, Han Q, et al. Effects of current-carrying conditions on lubrication and tribological performance of ionic liquid[J]. Journal of Molecular Liquids, 2022, 367: 120471.

[12] Kondrat S, Feng G, Bresme F, et al. Theory and Simulations of Ionic Liquids in Nanoconfinement[J]. Chemical Reviews, 2023.

[13] Liu M, Ni J, Zhang C, et al. The application of ionic liquids in the lubrication field: Their design, mechanisms, and behaviors[J]. Lubricants, 2024, 12(1): 24.

[14] Pivnic K, Fajardo O Y, Bresme F, et al. Mechanisms of electrotunable friction in friction force microscopy experiments with ionic liquids[J]. The Journal of Physical Chemistry C, 2018, 122(9): 5004-5012.

[15] Chen W, Feng Y, Wan Y, et al. Investigation on anti-wear and corrosion-resistance behavior of steel-steel friction pair enhanced by ionic liquid additives under conductive conditions[J]. Tribology International, 2023, 177: 108002.

[16] Huang W, Kong L, Wang X. Electrical sliding friction lubricated with ionic liquids[J]. Tribology letters, 2017, 65: 1-6.

[17] Bresme F, Kornyshev A A, Perkin S, et al. Electrotunable friction with ionic liquid lubricants[J]. Nature Materials, 2022, 21(8): 848-858.

[18] Li C, Wang G, Han Q, et al. Effects of current-carrying conditions on lubrication and tribological performance of ionic liquid[J]. Journal of Molecular Liquids, 2022, 367: 120471.

[19] Cheng G, Li X, Zhang D, et al. Mechanism of Multilayer Graphene/Ionic Liquid Synergistic Regulation of Interface State under Current-Carrying Friction[J]. Advanced Engineering Materials, 2024, 26(3): 2301629.

[20] Maurya U, VASU V, Saini V. Nano-innovations in lubrication: Unveiling the synergistic boundary lubrication potential of zinc titanate with phosphonium ionic liquid[J]. Tribology International, 2024, 199: 109987.

[21] Ying P, Hod O, Urbakh M. Superlubric Graphullerene[J]. Nano Letters, 2024.

[22] Wang L, Tang Q, Liang T, et al. Lubrication performance of graphene in the sliding electrical contact interface[J]. Friction, 2024: 1-14.

[23] Fan S, Chen Y, Wu J, et al. Structure, superlubricity, applications, and chemical vapor deposition methods of graphene solid lubricants[J]. Tribology International, 2024, 198: 109896.

[24] Venkatesh R, Sakthivel P, Vivekanandan M, et al. Synthesis and Thermal Adsorption Characteristics of Silver-Based Hybrid Nanocomposites for Automotive Friction Material Application[J]. Adsorption Science & Technology, 2023, 2023

[25] Zheng C, Zhang C, Sun W, et al. Experiments and molecular dynamic simulations on the cryogenic tribological behaviors of pure silver in liquid nitrogen[J]. Tribology International, 2023, 188: 108836.