International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

A Brief Overview of Composite Materials as Lubricant Additive in Tribology Experiments

Sajad Ahmad Dar[1], Dr. Fayaz Ahmad Sheikh[2]

[1]Department of Chemistry, National Institute of Technology, Hazratbal, Srinagar-190006, India
Corresponding author Email: *imetsajad1545[at]gmail.com*

[2]Department of Chemistry, Government Degree College, Ganderbal, India
Email: *fayazsheikh037[at]gmail.com*

Abstract: ***Energy wastage due to frictional loses is one of the great concerns in present day life. To prevent such losses and to meet energy demands of common people, tribology has an important role to play. Here, in this review paper we have provided an insight about the various tribological parameters and the ways to improve the performance of materials for better tribological function. Surface modification of nanomaterials and the role of capping in improving the tribological properties, has been discussed with some real-time examples. Further, importance of metal and metal oxide based nanomaterials and their composites with organic moieties in tribology, have been thoroughly discussed in this review paper.***

Keywords: Tribology; Lubrication, Bio-tribology, Friction

1. Introduction

Currently, tribology is an important field to minimize the energy losses due to friction and has become a challenging issue in the present scenario. Worldwide research is going on to combat energy wastage due to friction so as to meet the energy demands of the people. The advancement of tribology has attracted a surge of attention from both the academic and business worlds, which is important for the growth of the global economy and human civilization. Addition of suitable materials to the lubricants has been proven a useful way to reduce friction between the two sliding surfaces. Among different lubricant additives, nano-materials like Fe, Cu, Co etc. have been proven potent candidates in this field due to their small particle size [1-2]. Modification of surface of nanoparticle by suitable capping agents is another way to improve the tribological properties of the lubricant additives which have reduced friction to large extent [3]. Jingfang et al. has reported a significant enhancement in the tribological properties of Cu nanoparticle when the surface was modified with dialkyldithiophosphate [4]. The enhancement in the antiwear ability of modified copper nanoparticles as lubricant additive in liquid paraffin is attributed to the surface modification that has resulted in different interactions with the surface of the friction pairs during the friction.

Here in this review paper, we have briefly explained the various tribological parameters like wear, friction, etc. and the various ways to improve the performance of materials for better tribological function. Surface modification of nanomaterials and the role of capping agents in improving the tribological properties, has been discussed with some real-time examples. Effect of surface modification on the tribological properties of materials along with some real-time examples of composite materials having phenomenal properties towards the development of tribology, is mainly highlighted in this review paper. Further, importance of metal and metal oxide based nanomaterials and their composites with organic moieties in tribology, have been thoroughly discussed in this literature review.

Lubrication

The lubricating properties of materials are of great scientific interest. Lubrication has to play great role in the systems involving moving surfaces to reduce the wear and frictional losses. The materials, in which molecular structures are allowing the particles to slide, are potent candidates in the field of lubrication. The main purpose of lubrication is:

- To form lubrication film between the two sliding surfaces to reduce wear and tear.
- To reduce noise or friction.
- To prevent overheating of bearings
- To prevent foreign material penetration, rust, and corrosion

There are a vast number of materials like graphene, carbon nitride, molybdenum disulphide, tungsten disulphide, zinc oxide etc. [5-6], which have phenomenal lubrication properties but layered materials like graphene, carbon nitride etc. are of particular importance due to the presence of loosely bound graphite layers that can slide easily over each other like a pack of cards during their lubrication action [7]. Tribology plays an important role in the industries where specific oils are used to control wear and friction of the surfaces in mutual contact like bearings, seals, and gears. Worldwide research is going on to improve the tribological properties of the systems and in this field nanoparticles as lubricant additives have been found quite efficient to improve the performance of the lubricants properties like load carrying capacity, coefficient of friction (COF), wear scar diameter (WSD), etc. [8]. The efficient tribological properties of nanoparticles are attributed to the small size of nanoparticles which allows them to fill the extremely small surface roughness.

Metal and metal oxide based nanoparticle as lubricating additives have been found to possess excellent tribological properties. Among different metal nanoparticles,

nanoparticles of aluminum, silver, and copper nanoparticles are widely used in tribological applications [9-11].

Four different possible mechanisms have been provided by different researchers to explain the friction reducing properties of nanoparticles during the process of lubrication [12-15]. Some researchers believe that the nanoparticles possess micro-bearing effect where nanoparticles provide rolling friction when they enter the contact area of sliding components. Another possible mechanism involves formation of a protective film in between the two sliding surfaces. Nanoparticles as lubricant additives can also be considered as polishing agents to reduce the roughness between the surfaces sliding over each other while as some researchers believe that the nanoparticles with a small size and low melting points fill or melt to repair cracks to reduce the friction. Nanoparticles of metals, metal oxides, and the composites involving nanoparticles not only improve the tribological properties of lubricating oil, but at the same time, are environmental benign in nature and can be used without deteriorating effects on the living systems.

Role of surface modification in lubrication

Surface medication is a simple and easy method to improve the lubrication properties of lubricant additives. Surface modifications promote tribological properties by changing the overall friction behavior of the surfaces, preventing agglomeration and enhancing stability of the sample particles [16]. Some important examples where capping of materials by suitable surface modifying agent has resulted in the enhancement of tribological properties of the lubricant additive have been discussed in this section.

- Many metal oxide particles are widely employed as lubricant additives, especially for zinc oxide (ZnO) with high surface energy, strong adsorption and diffusivity. ZnONPs modified by oleic acid show a better anti-friction and wear resistance performance under lubricating conditions subject to different loads [17].
- Surface modification of MoS2 nanosheets by n-octadecyl mercaptan was not only effective for friction-reducing and antiwear additives but at the same time stability of suspension was enhanced to a greater extent after surface modification. A surface modified MoS2 was found to display dramatic reductions in the coefficient of friction and wear which is attributed to the formation of a boundary protection film during tribochemical reactions [18].
- Surface of Cu nanoparticles was modified by dioctylamine dithiocarbamate and the tribological properties of the modified Cu nanoparticles as lubricant additive were explored with a four–ball machine. Tribological results revealed that modified Cu nanoparticles having small particle size, possess excellent antiwear ability which is due to the deposition of nano-Cu on worn steel surface [19].
- In a similar study surface of palladium nanoparticles was modified with tetrabutylammonium chains by Abad et al. using a ball-on-disk tribometer [20]. A significant improvement in the tribological properties was witnessed due to tetrabutylammonium acetate which is supposed to form a protective transfer film comprised of metallic Pd.
- Synthesis of cerium borate nanoparticles was carried out via sol-gel method and the surface of the particles was modified by oleic acid [21]. The results obtained from the tribology experiments revealed that there is a significant improvement in anti-wear properties as well as in the coefficient of friction after surface modification of the nanoparticles. Some important surface modified materials used in the field of tribology to reduce friction between the surfaces are presented in the table 1.

Table 1: List of surface modified materials used in the field of tribology

Material	Capping agent	Role	Reference
Zinc borate	Hexadecyltrimethoxysilane and oleic acid	Caping plays an important role in the outstanding anti-wear property of the composite.	22
zinc borate	sorbitol monostearate	50% reduction of friction coefficient and a 10% drop of wear scar diameter were observed	23
SiO_2 nanoparticles	Silane	Results show that the interactions between nano-SiO_2 and modifier are purely covalent Surface modification has improved dispersivity, stability and tribological properties.	24
TiO2 nanoparticle	Oleic acid	Oleic acid surface-modified TiO_2 nanoparticles possess excellent load-carrying capacity, antiwear and friction reduction properties	25
SiO2 nanoparticles	Oleic acid	Surface-modified nanoparticles as lubricant additives have better antiwear and antifriction properties than the pure paraffin oil besides, having exhibiting good dispersivity and stability in liquid paraffin.	26
CuO nanoparticles	Oleic acid	Significant improvement in the wear properties (wear scar diameter and co-efficient of friction) was obtained after coating CuO nanoparticles with oleic acid.	27

Brief overview of lubricant materials

A vast number of materials especially nano-composites of metal oxides have been used in the field of tribology. Some of the important materials possessing phenomenal tribological properties have been discussed in this section.

- Prasad et al. investigated tribological characteristics of tungsten disulfide (WS_2)–zinc oxide (ZnO) composite from ambient to 500 °C using a ball-on-flat tribometer. Friction tests were conducted on nanocomposite films containing 50% by weight of the oxide and comparison measurements were made on pure WS_2 films under identical conditions. A significant reduction in the coefficient of friction for WS_2 was obtained both at 300°C as well as at room temperature. However, when temperature was increased to 500°C, the friction coefficient of pure WS_2 films increased to 0.50 [28]. Further, it was reported by Haltner and Oliver [29] that significant improvements in maximum load carrying capacity of molybdenum disulfide can be improved with the use of selected sulfide additions by facilitating the formation of smoother films on the counter-face.

- Qiang et al synthesized monodispersed and hydrophobic ZnO/Al_2O_3 composite nanoparticles via sol–gel method and the tribological properties of the ZnO/Al_2O_3 composite nanoparticles were studied. The tribology results revealed that the coefficient of friction and the wear scar diameter are decreased by about 37.5% and 26.2%, respectively compared to pure lubricating oil. ZnO/Al_2O_3 composite nanoparticles were found to have excellent antifriction and antiwear properties. It is assumed that the excellent lubricating properties of ZnO/Al_2O_3 composite are not only due to turning the sliding friction into rolling friction, but also due to the formation of a hard Al_2O_3 protective film onto the thrust-ring surface containing ZnO/Al_2O_3 nanoparticles. [31].
- Surya et al. investigated tribological performance of Graphene in Phenolic based composite and the results revealed that the Graphene filled Phenolic composite possesses high friction stability, besides, exhibiting excellent friction-fade performance and friction-recovery performance. They also reported that the wear resistance of the graphene composite is much higher (about three times) than the graphite based composite which is attributed to the stabilization of the tribo-film formation on the surface by graphene [32].
- In another study, Abdullah carried out surface modification of WO_3, TiO_2 and ZnO nanoparticles by different capping agents like Tween-20, Tween-60, Span-20 etc. The tribological properties of capped nanoparticles were studied using pin-on-disc tribometer. The results show that the capped nanoparticles can be used as an efficient additive biodiesel and can be used to overcome the problem of wear and friction in the normal diesel engines [33].
- Qiang et al. used ultrasonic dispersion method to introduce ZnO and Si_3N_4 nanoparticles into the grease matrix and after characterization by various techniques, tribological properties of the composite grease were studied. Tribological results revealed that the best lubrication performance was achieved 1 wt% ZnO and 0.5 wt % Si_3N_4. Under these conditions a significant decrease in the friction coefficient (0.0701) and wear scar diameter (0.727) was observed which is 34.3% and 8.3% lower than that of the base greases, respectively. Surface morphology of composite is supposed to play an important role for enhancement in the antifriction property. Excellent lubrication and antifriction properties of the composite signifies its prominent role in noise and temperature rise for high speed bearings. [34].
- Harshit et al. synthesized graphene nano-platelets (GNP) using a liquid phase exfoliation method to produce well dispersed silica–GNP composites. Tribological properties of the silica–GNP composites were explored with different volume percentages of GNP. From the tribological results it was found that an optimum concentration of GNP provides a significant lubricating effect to the silica matrix which plays a prominent role in improving the tribological properties of the nano-composites. [35].
- Kang et al. synthesized TiAl-based materials via spark plasma sintering method and the mechanical and tribological properties of the composite were investigated using a ball-on-disk tribometer and the nano-mechanical tester. Effect of the weight percentages on the tribological properties was studied and a comparative analysis was carried out. When graphene nanosheets were combined with TiAl-based material an excellent mechanical properties were obtained which is mainly attributed to the formation of lubrication film. [36].
- Nan et al. prepared 3D graphene using calcium ions as the cross-linker and melamine foam as template and explored the enhanced tribological properties of graphene/epoxy composites. The results revealed that there is about 1015.52% increase in the thermal conductivity of the composite as compared to the silica-filled epoxy. Further, the coefficient of friction and wear rate of the composites was reduced to 0.29 and 0.19×10^{-5} $mm^3/N{\cdot}m$ respectively. This dual-network model provides a new strategy to develop new solid lubricating materials with excellent thermal and tribology properties [37].
- Yazdani et al. investigated tribological performance of the hot-pressed pure Al_2O_3 and composites of Al_2O_3 with graphene nano-platelets (GNP) and carbon nano-tubes (CNTs) under different loading conditions using the ball-on-disc method. Compared to pure Al_2O_3, the composite containing 0.5 wt % GNP shows a remarkable reduction (23%) in the coefficient of friction and a significant reduction (70%) in the wear rate. The excellent wear resistance property of the composite is attributed to the coordination between GNPs and CNTs where GNPs is supposed to play an important role in the formation of a tribofilm on the worn surface by exfoliation and CNTs is expected to improve the fracture toughness and prevent the grains from being pulled out during the tribological tests. [38]
- Shuai et al. synthesized reduced graphene oxide/ZnS (RGO/ZnS) composites using a facile and effective hydrothermal method in order to improve the tribological properties of epoxy coatings through surface modification. ZnS nanoparticles were uniformly dispersed on RGO nanosheets with the diameters of several decade nanometers. The tribological behavior of RGO/ZnS composite had better lubricating properties than those of ZnS or RGO. Moreover, the test results indicated that composite had good stability at higher applied load. The excellent tribological properties of RGO/ZnS hybrids were attributed to the excellent synergistic effects between ZnS nanoparticles and RGO [39].
- Lu A et al. evaluated layered compound $ZnS(NH_2CH_2CH_2NH_2)_{0.5}$ as an additive in grease using four ball tester. The results revealed that $ZnS(NH_2CH_2CH_2NH_2)_{0.5}$ grease has good load bearing ability and excellent anti-wear properties. The worn surfaces were analyzed with SEM, EDS, 3D, and XPS. The improvement in anti-wear property may be attributed to two-dimensional structure of $ZnS(NH_2CH_2CH_2NH_2)_{0.5}$, where easier sliding is on account of larger interspaces. Owing to simple synthetic method and superior tribological properties,

$ZnS(NH_2CH_2CH_2NH_2)_{0.5}$ holds great potential for use in demanding industrial applications in the future as a grease-based additive [40].

2. Conclusion

This study of technological developments has revealed that tribology research has grown quickly in recent years and that its use is becoming more widespread in other domains of research. This review aims to conceptualize various parameters of tribology like friction; lubricants, wear etc. and their importance to conserve energy and improve the environment and quality of life. Effect of surface modification on the tribological properties of materials along with some real-time examples of composite materials having phenomenal properties towards the development of tribology, is mainly highlighted in this review paper. Further, importance of metal and metal oxide based nanomaterials and their composites with organic moieties in tribology, have been thoroughly discussed in this literature review. A brief overview about the various composite materials used by different researchers in the field of tribology has been provided at the end of the review paper.

References

[1] Sheida Shahnazar, Samira Bagheri, Sharifah Bee Abd Hamid, Enhancing lubricant properties by nanoparticle additives, International Journal of Hydrogen Energy, Volume 41, Issue 4,2016, Pages 3153-3170
[2] Juozas Padgurskas, Raimundas Rukuiza, Igoris Prosyčevas, Raimondas Kreivaitis, Tribological properties of lubricant additives of Fe, Cu and Co nanoparticles, Tribology International, Volume 60, 2013, Pages 224-232
[3] Huabing Yin, Xuecheng Zhang, Zhiwei Guo, Yicong Xu, Xiang Rao, Chengqing Yuan, Synergetic effects of surface textures with modified copper nanoparticles lubricant additives on the tribological properties of cylinder liner-piston ring, Tribology International, Volume 178, Part A, 2023, 108085
[4] Jingfang Zhou, Jianjun Yang, Zhijun Zhang, Weimin Liu, Qunji Xue, Study on the structure and tribological properties of surface-modified Cu nanoparticles, Materials Research Bulletin, Volume 34, Issue 9, 1999, Pages 1361-1367
[5] S.K. Khatkar, N.M. Suri, S. Kant and Pankaj, A review on mechanical and tribologicalproperties of graphite reinforced selflubricating hybrid metal matrix composites, Rev. Adv. Mater. Sci. 56 (2018) 1-20;
[6] Ligang Zhang, Yuexia Guo, Huanfei Xu, Guitao Li, Fu yan Zhao, Ga Zhang, A novel eco-friendly water lubricant based on *in situ* synthesized water-soluble graphitic carbon nitride, Chemical Engineering Journal Volume 420, Part 1, 15 September 2021;,
[7] BOLLMANN, W., SPREADBOROUGH, J. Action of Graphite as a Lubricant. *Nature* **186**, 29–30 (1960). https://doi.org/10.1038/186029a0
[8] Anurag Singh, Prashant Chauhan, Mamatha T.G, A review on tribological performance of lubricants with nanoparticles additives, Materialstoday: Proceedings, Volume 25, Part 4, 2020, Pages 586-591
[9] Le, V.N.A.; Lin, J.W. Influence of aluminum nanoparticles additives on tribological properties of base oil. *Key Eng. Mater.* **2017**, *737*, 184–191.
[10] Kumara, C.; Luo, H.M.; Leonard, D.N.; Meyer, H.M.; Qu, J. Organic-modified silver nanoparticles as lubricant additives. *ACS Appl. Mater. Inter.* **2017**, *9*, 37227–37237.
[11] Battez, A.H.; Gonzalez, R.; Viesca, J.L.; Fernandez, J.E.; Fernandez, J.M.D.; Machado, A.; Chou, R.; Riba, J. CuO, ZrO2 and ZnO nanoparticles as antiwear additive in oil lubricants. *Wear* **2008**, *265*, 422–428.
[12] Fei, J.; Zhao, B.; Li, C.Y.; Liu, T.; Zhou, M. Carbon spheres wrapped with 2D covalent organic polymer as lubricant additives for enhancing tribological properties. *Colloids Surf. A* **2022**, *633*, 127862.
[13] Alazemi, A.A. Experimental study of the lubrication mechanism of micro-spherical solid particles between flat surfaces. *Lubricants* **2021**, *9*, 81.
[14] Shen, Y.D.; Lei, W.W.; Tang, W.T.; Ouyang, T.C.; Liang, L.Z.; Tian, Z.Q.; Shen, P.K. Synergistic friction-reduction and wear-resistance mechanism of 3D graphene and SiO_2 nanoblend at harsh friction interface. *Wear* **2022**, *488–489*, 204175.
[15] Gu, Y.F.; Fei, J.; Huang, J.F.; Zhang, L.J.; Qu, M.; Zheng, X.H. Carbon microspheres coated with graphene oxide nanosheets as oil-based additives for tribological applications. *Mater. Today. Commun.* **2022**, *25*, 101271.
[16] *Ceramics* **2023**, *6*(2), 980-993, Surface Modification of Silica Nanoparticles with Ethyl Oleate for the Purpose of Stabilizing Nanolubricants Used for Tribological Tests
[17] Tribological properties and anti-wear mechanism of ZnO@graphene core-shell nanoparticles as lubricant additives,
Baijing Ren, Liang Gao, BotaoXie, Mengjun Li, Shang da Zhang, guoqing Zu, Xu Ran, Tribology International Volume 144, April 2020
[18] Surface Modification of MoS2 Nanosheets as Effective Lubricant Additives for Reducing Friction and Wear in Poly-α-*olefin, Ind. Eng. Chem.* Res. 2018, 57, 23, 8105–8114
[19] Guang-bin YANG, Shan-tao CHAI, Xiu-juan XIONG, Sheng-mao ZHANG, Lai-gui YU, Ping-yu ZHANG,Preparation and tribological properties of surface modified Cu nanoparticles,Transactions of Nonferrous Metals Society of China,Volume 22, Issue 2,2012,Pages 366-372
[20] Tribological properties of surface-modified Pd nanoparticles for electrical contacts, M.D. Abad, J.C. Sánchez-López, Wear, Volume 297, Issues 1–2, 15 January 2013, Pages 943-951
[21] Lingtong KONG [a], Hua HU [b], Tianyou WANG [b], Ding hai HUANG [a], Jianjian FU , Synthesis and surface modification of the nanoscale cerium borate as lubricant additive, Journal of Rare Earths, Volume 29, Issue 11, November 2011, Pages 1095-1099
[22] C. Zhao [a], Y.K. Chen [a b], Y. Jiao [a], A. Loya [a], G.G. Ren , The preparation and tribological properties of surface modified zinc borate ultrafine powder as a lubricant additive in liquid paraffin, Tribology International, Volume 70, February 2014, Pages 155-164

[23] Tian Y, Guo Y, Jiang M, Sheng Y, Hari B, Zhang G, et al. Synthesis of hydrophobic zinc borate nanodiscs for lubrication. Materials letters. 2006;60:2511-5.

[24] Xiaohong Li [a b c], Zhi Cao [b], Zhijun Zhang [b], Hongxin Dang, Surface-modification in situ of nano-SiO_2 and its structure and tribological properties, Applied Surface Science, Volume 252, Issue 22, 15 September 2006, Pages 7856-7861

[25] Yongjian Gao [a b], Guoxu Chen [a], Ya Oli [b], Zhijun Zhang [b], Qunji Xue, Study on tribological properties of oleic acid-modified TiO_2 nanoparticle in water, Wear, Volume 252, Issues 5–6, March 2002, Pages 454-458

[26] D.X. Peng [a b], Y. Kang [b], R.M. Hwang [c], S.S. Shyr [c], Y .P. Chang, Tribological properties of diamond and SiO_2 nanoparticles added in paraffin, Tribology International, Volume 42, Issue 6, June 2009, Pages 911-917

[27] M. Asrul, N.W.M. Zulkifli, H.H. Masjuki, M.A. Kalam, Tribological Properties and Lubricant Mechanism of Nanoparticle in Engine Oil, Procedia Engineering Volume 68, 2013, Pages 320-325

[28] S.V Prasad, N.T McDevitt , J.S Zabinski, Tribology of tungsten disulfide–nanocrystalline zinc oxide adaptive lubricant films from ambient to 500°C, Wear Volume 237, Issue 2, February 2000, Pages 186-196

[29] Haltner, A.J.; Oliver, C.S. Effect of Water Vapor on Friction of Molybdenum Disulfide. *Ind. Eng. Chem. Fundam.* **1966**, *5*, 348–355.

[30] Qiang Chen, Shaohua Zheng, Shikuan Yang, Wei Li, Xiaoyun Song & Bingqiang Cao, Enhanced tribology properties of ZnO/Al_2O_3 composite nanoparticles as liquid lubricating additives, Journal of Sol-Gel Science and Technology volume 61, pages501–508 (2012)

[31] Surya Rajan B, Sai Balaji M A, Mohamed Aslam Noorani A B, Tribological performance of graphene/graphite filled phenolic composites - A comparative study, Composites Communications, Volume 15, 2019, Pages 34-39

[32] Abdullah, S. 2012. Structural and Tribology Properties of WO3, TiO2 and ZnO Composite Nanoparticles as Lubricant Additives. *Journal of Energy and Environment*. 4, 1 (Dec. 2012)

[33] Qiang He, Anling Li, Zhigang Wang, Yong Zhang, Linghao Kong & Kang Yang (2018) Tribological behavior of ZnO-Si_3N_4 nanoparticles-based lubricating grease, Journal of Experimental Nanoscience, 13:1, 231-244, DOI: 10.1080/17458080.2018.1511923

[34] Harshit Porwal, Peter Tatarko, Richa Saggar, Salvatore Grasso, Mahesh Kumar Mani, Ivo Dlouhý, Jan Dusza, Mike J. Reece,Tribological properties of silica–graphene nano-platelet composites, Ceramics International, Volume 40, Issue 8, Part A, 2014, Pages 12067-12074

[35] Harshit Porwal, Peter Tatarko, Richa Saggar, Salvatore Grasso, Mahesh Kumar Mani, Ivo Dlouhý, Jan Dusza, Mike J. Reece,Tribological properties of silica–graphene nano-platelet composites, Ceramics International, Volume 40, Issue 8, Part A, 2014, Pages 12067-12074

[36] Kang Yang, Hongru Ma, , Qiang HeThe Analysis in In Situ Preparation, Mechanics, and Tribology of TiAl–SnAgCu/Graphene Composites *Advanced Engineering Materials*Volume 20, Issue12 December 2018

[37] Nan Zhang, Chunhui Qu, Song Li, Chengkun Wang, Mingkun Xu, Zenghui Yang, Xinrui Zhang, Tingmei Wang, Qihua Wang,Significantly enhanced tribology and thermal management by dual-network graphene/epoxy composites,Tribology International,Volume 164,2021,107239

[38] Yazdani, B., Xu, F., Ahmad, I. *et al.* Tribological performance of Graphene/Carbon nanotube hybrid reinforced Al_2O_3 composites. *Sci Rep* **5**, 11579 (2015). https://doi.org/10.1038/srep11579

[39] Shuai Zhang, Jin Yang, Beibei Chen, Shun Guo, Jianfeng Li, Changsheng Li, One-step hydrothermal synthesis of reduced graphene oxide/zinc sulfide hybrids for enhanced tribological properties of epoxy coatings, Surface and Coatings Technology, Volume 326, Part A, 2017,Pages 87-95

[40] Lu A, Niu W, Dai Y, Xu H, Dong J. Tribological Properties of $ZnS(NH_2CH_2CH_2NH_2)_{0.5}$ and ZnS as Additives in Lithium Grease. *Lubricants*. 2019; 7(3):26. https://doi.org/10.3390/lubricants7030026