lubricants

Editorial

Additives for Lubricating Oil and Grease: Mechanism, Properties and Applications

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Since the industrial revolution, science and technology, as well as industry of human society, have developed rapidly. In today's world of energy shortage, friction and wear have always received great attention. Lubricating oil and grease serve as essential components that reduce friction, wear, and prolong the life of moving mechanical parts. The effectiveness of the formulation of the lubricant and grease is easily impacted by various factors, such as temperature, pressure, and heavy loads. To enhance the performance of lubricants and grease, researchers have introduced diverse additives that enhance wear resistance, thermal stability, and the service life of mechanical components. In order to overcome friction and wear, achieve energy saving and environmental protection, and improve the performance of machinery and equipment, lubrication is one of the most effective strategies.

Additives by function are mainly antioxidants, anti-wear agents, friction modifiers (also known as oleophilic agents), extreme pressure additives, detergents, dispersants, anti-corrosion and rust inhibitors, viscosity index enhancers, and other types. The additives sold on the market are generally a combination of the above single additives; the difference is that the composition of the single additive is different, as well as the ratio of several single additives within the combination of different additives. Grease additives are basically oil-soluble additives, and lubricant additives can be partially mixed, and some additives are grease-specific additives, including antioxidant and anticorrosive agents, extreme pressure and anti-wear agents, oleophobic and friction-reducing agents, antioxidants, adhesion agents, structural stabilisers, and so on.

This Special Issue contains 11 papers dealing with different lubricants such as lubricants (Contributions 1–7), greases (Contributions 8–10), and other lubricants (Contribution 11). A part of the papers discusses lubricant additives such as the preparation of additives for extreme pressure properties (Contributions 1–4), computational simulations (Contributions 5 and 6), and nanocomposite lubricant additives research and applications (Contribution 7). Another part discusses the preparation of grease with grease nano-additives, (Contributions 8–10). In addition, (Contribution 11) graphene lubrication coatings are discussed.

Zhou et al. (Contribution 1) used layered double hydroxide (LDH) and molybdenum disulphide (MoS_2) as additives to prepare lubricants. The morphology and particle distribution of the LDH and MoS_2 were characterised using a scanning electron microscope and a laser particle size analyser, respectively. By adding LDH and MoS_2 to the lubricants, the extreme pressure and wear resistance performance and anti-seize performance at a high temperature were improved significantly. The LDH showed better anti-seize performance than the MoS_2 because of its strong and stable structure at a high temperature. The MoS_2 with a larger particle size showed better extreme pressure performance under a high load. The LDH and MoS_2 played a synergistic effect under the conditions of a high temperature and high load.

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Nasr et al. (Contribution 2) used a HFRR (High-Frequency Reciprocating Rig) tester to determine the coefficient of friction (COF) and Wear Score Diameter (WSD), and the addition of different nanoparticles allowed welding to be carried out at lower pressures when compared to pure oils. The results of the HFRR tests suggest that there may be a synergistic effect between fullerenes and SWCNT-COOH with the blended oils, which may be due to a possible interaction between the nanoparticles and different molecules of the oil blend at the molecular level.

Tsakiridis et al. (Contribution 3) focused on the tribological interaction between piston rings and cylinders using fullerenes as additives. The results showed that the use of fullerene as an additive reduced friction compared to synthetic and single grade oils. In addition, the performance of the compression piston ring system was improved by friction reduction and temperature distribution changes with the use of fullerene oil. A significant reduction in friction of 42% was observed compared to synthetic oils, which offers the prospect of improving the tribological efficiency of internal combustion engines.

Nassef et al. (Contribution 4) investigated the effect of a mixture of individual and blended nano-additives, such as graphene nanosheets, zinc oxide, and trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl)phosphonate ionic liquids (ILs) on the rheological, tribological, and physical properties of rapeseed oil. The results showed that the viscosity index (VI) values of the blends containing graphene nanoparticles were significantly increased up to 150% compared to VB 6000. In terms of tribological behaviour, the coefficient of friction of the blend containing all three nano-additives (H3) was reduced by 20% at room temperature (RT) and 26% at 60 °C, outperforming commercial fluids. In addition, H3 showed the greatest reduction in wear volume (84%) and surface roughness (60%). The wettability of H3 was attributed to the combined mechanism of the applied nano-additives; its application resulted in a 63% reduction in the contact angle, demonstrating its excellent spreading properties.

Li et al. (Contribution 5) calculated the acid-catalysed aldol condensation reaction mechanism of lubricant base oils on the basis of density functional theory (DFT). The carbonyl compounds can be converted to resonance enol structures. However, the activation energy of the process is relatively high and difficult to initiate. The presence of acid significantly reduces the activation energy of the reaction from 269.17–287.82 kJ/mol to 177.10–177.63 kJ/mol, which greatly reduces the difficulty of initiating the reaction. Carbonyl compounds and acids form carbon sites that can further react with the enol to produce intermediate reaction products that lengthen the molecular chain. This process is not difficult to initiate with an activation energy of 65.10 kJ/mol, and the larger molecular weight intermediates can be converted to carbonyl compounds containing β-hydroxyl groups by removing one of the hydrogen protons. The energy barrier for this process is 193.15 kJ/mol, and it is not easy to initiate the reaction.

Liu et al. (Contribution 6) developed two quantitative structure–property relationship (QSPR) models for hindered phenolic antioxidants in lubricating oils to help guide the molecular structure design of antioxidants. A hindered phenolic additive was designed based on the models. Its antioxidant properties were calculated to be 20.9% and 11.0% higher than those of typical commercial antioxidants, methyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate, and 2,2′-methylenebis(6-tert-butyl-4-methylphenol), respectively. The structure–performance relationships of the hindered phenolic antioxidants in lubricants obtained by computer-assisted analysis can not only predict the antioxidant performance of the existing hindered phenolic additives but also provide a theoretical basis and data support for the design or modification of lubricant additives with higher antioxidant performance.

Bukvić et al. (Contribution 7) present the results achieved in the field of nanocomposite lubricant additives research and applications. This paper also provides a partial comparative analysis of the research in this field. The main objective of this paper is to analyse the results of research on nanotubes in the field of lubricant applications and to point out the importance of their applications, such as improvements in the tribological properties of machines and a reduction in power losses. In addition, this paper illustrates the negative effects of nanoparticles on the environment and human health, as well as the cost of applying certain types of nanoparticles.

Paszkowski et al. (Contribution 8) investigated the effect of mining pollutants and wear products on the rheological and tribological properties of a lubricating grease working in the microclimate of the Polkowice-Sieroszowice mine belonging to the KGHM Polska Miedź Group (Polkowice, Poland). The material under investigation is a commercial lubricating grease thickened with complex lithium soap, based on mineral oil with a molybdenum disulfide (MoS_2) addition. A sample of the grease was taken from one of the friction junctions of a self-propelled drilling jumbo operated in the mine. Comparative tests of the fresh grease and the spent grease were carried out. Rheological experiments and tribological properties and wear after the friction process were carried out separately for both greases. Contour and topographic maps of the wear traces of the discs together with their wear profiles were compared.

Li et al. (Contribution 9) synthesised MgAl LDH by co-precipitation using a colloid mill. It was found that the environmentally friendly LDH shows higher performance compared to conventional antioxidants. By adding LDHs to the grease of a large electric shovel (GRK-A) in a surface coal mine, the grease life was extended by 20%. As the LDH addition increased, the grease sample gained greater activation energy and greater resistance to thermal oxidation and decomposition. By comparing the energy storage modulus and flow transition index at different temperatures, it can be found that the addition of an appropriate amount of LDHs has an important effect on the oxidation resistance and viscoelasticity of the system.

Zhang et al. (Contribution 10) used WS_2 nanoparticles as additives to prepare WS_2 calcium sulfonate composite polyurea grease. The tribological behaviour of WS_2 grease on the GCr15 surface was systematically investigated. The results showed that WS_2 nanoparticles could significantly improve the extreme pressure performance of calcium sulfonate composite polyurea grease. When the concentration of WS_2 nanoparticles was 2 wt.%, the coefficient of friction decreased by 14.94%, and the maximum impact-free load PB increased by 31.41%. As the temperature increases, the coefficient of friction and wear of WS_2 grease decrease and then increase. This is mainly attributed to the adsorption and friction chemical reaction between WS_2 nanoparticles and the matrix.

Li et al. (Contribution 11) obtained the optimal friction coefficient of the spherical hinge through the finite element analysis method. Four lubrication coatings and four spherical hinge sliders were prepared and tested through a self-developed rotation friction coefficient test, four-ball machine test, dynamic shear rheological test, and compression and shear performance test to evaluate the lubrication and friction properties of the spherical hinge structure. The results of the finite element analysis show that the optimum rotation friction coefficient of the spherical hinge structure is 0.031–1.131. The test results illustrate that the friction coefficient, wear scar diameter, maximum non-seize load, phase transition point, and thixotropic ring area of the graphene lubrication coating are 0.065, 0.79 mm, 426 N, 14.6%, and 64,878 Pa/s.

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List of Contributions:

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