Nanotechnology Innovations Aid the Lubricants and Grease Industry

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Introduction

This poster aims to highlight the use of nanotechnology in lubricant additives to the field of lubrication experts while providing guidance on nano-additive mechanisms in various lubricants. When added to a base oil or water, nanoparticles may enhance various tribological properties, such as anti-friction, anti-wear, and coefficient of friction (CoF). However, not all submicron particles have the same properties, and as a result, not the same benefits. It is therefore crucial to investigate the chemistry, morphology, and characteristics of different types of nanoparticles and examine the mechanisms of interaction with contact surfaces in water-based solvent and oil formulations.

Tribological Discoveries in Nanoscience

After more than 25 years of basic nanoscience research and over 15 years of focused R&D, nanotechnology applications are delivering what the scientists were hoping for: efficient, effective, and practical substance incorporation. Nano-additives are incorporated to oils by suspending or dispersing the particles using a variety of methods, such as ultrasonication. In doing so, they provide the superior friction-reducing and wear-resistant properties that make nano-additives stand out from traditional additives.

A more recent development in tribological research is the incorporation of nano-additives to water-based lubricants. A fundamental property of nanoparticles is that they are not influenced by the viscosity of the base oil, allowing for the investigation of water-based lubrication, rather than oil-based. Perhaps the most important advantage of using water as a lubricant is its environmental friendliness. Most oil-based lubricants can be toxic and detrimental to environment. Water, on the other hand, is a natural resource that acts as a cost-efficient alternative to oil. At the same time however, water as a standalone lubricant has many inherent flaws; water has poor load carrying capacity due to its low viscosity, as compared to oils. Water also has very weak film thickness and may even react with the contact metals when used as a lubricant. Many of these issues can be solved with nanoparticle incorporation.

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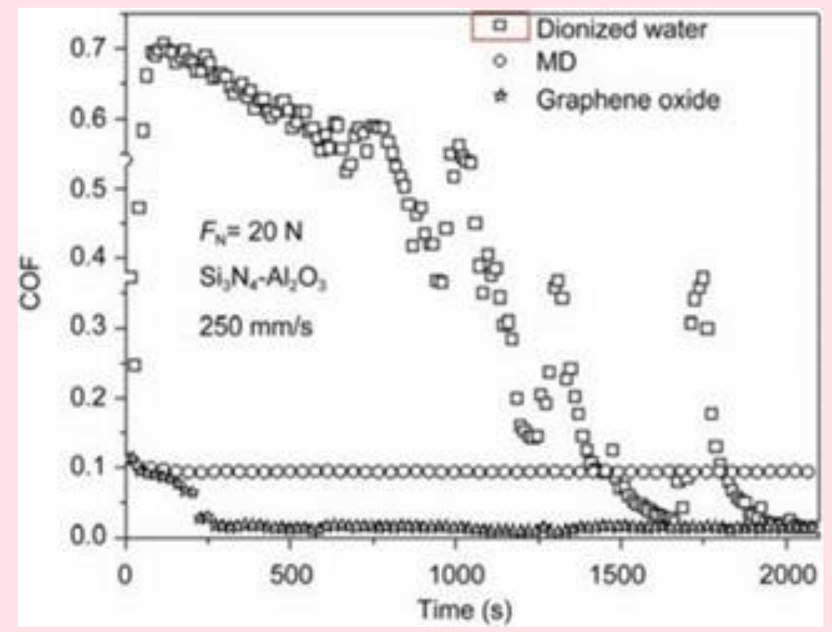
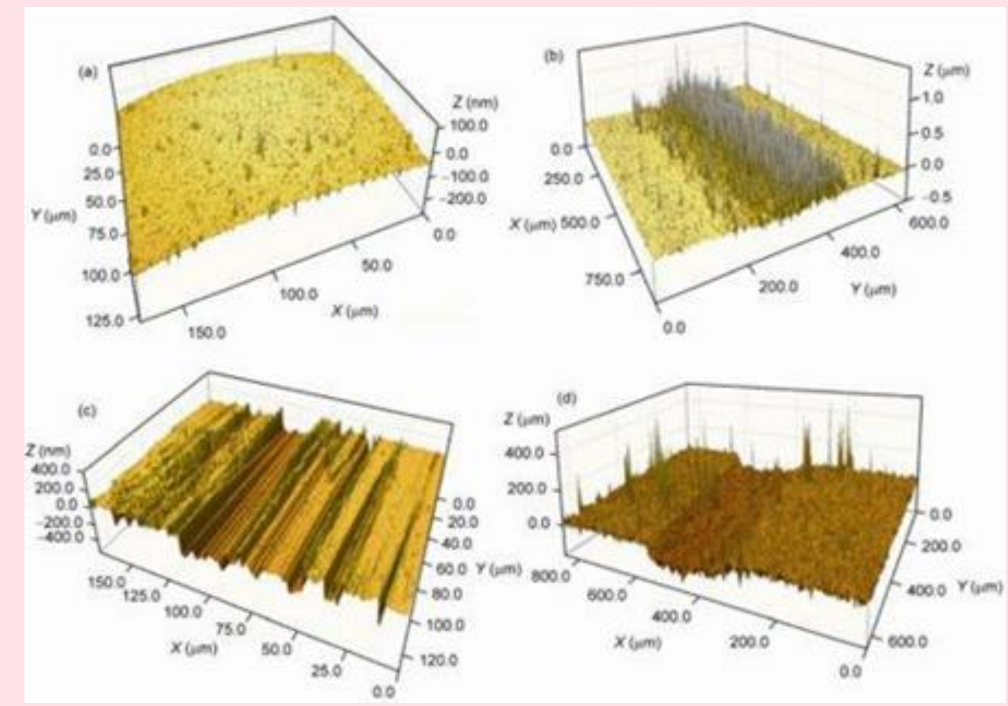
Graphene Oxide in Water

In a paper published by researchers from the Laboratory of Tribology in Tsinghua University, the authors investigated the properties of graphene oxide (GO) nanosheets and modified diamond (MD) nanoparticles as additives to water-based lubricants. The effects of friction and subsequent wear scars of a Si_3N_4 ball sliding against an Al_2O_3 plate were studied in a micro-tribotester. A plot of the CoF of these particles over time is shown below, where both the MD and GO particles significantly reduced the test system's friction. Furthermore, as shown in the second figure, three-dimensional morphology profiles of the Al_2O_3 ball and the Al_2O_3 plate were generated, used to determine the effects of wear scar. When comparing the particles, GO provides far superior wear resistance.



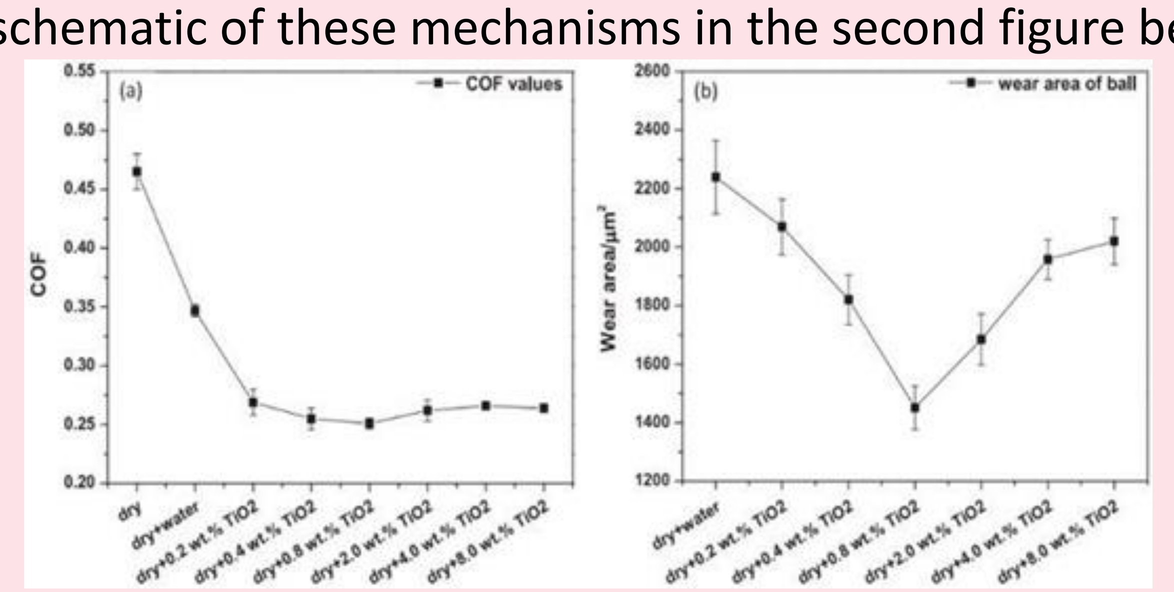
Coefficient of friction (CoF) over time



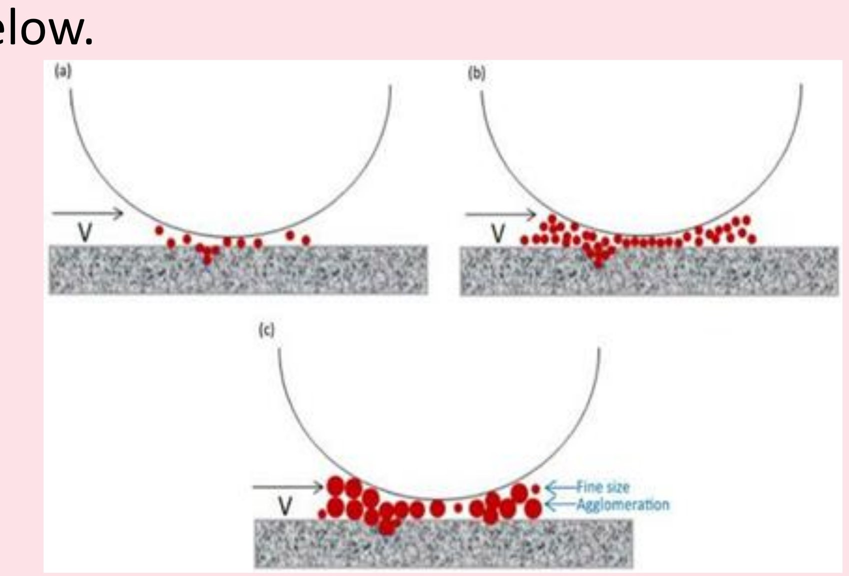
3-D profiles of wear scar on the Si_3N_4 ball (a) and the Al_2O_3 plate (b) after friction experiment lubricated by GO colloid; 3-D profiles of wear scar on the Si_3N_4 ball (c) and the Al_2O_3 plate (d) after friction experiment lubricated by MD colloid

Titanium Oxide in Water

Researchers from the University of Wollongong studied the CoF of TiO_2 nanoparticles in water using a ball-on-disk tribometer. They measured the CoF after allowing the ball to rotate dry for 5 minutes and lubricated for another 5 minutes. The lubricant solutions were tested at varying weight percentages of TiO_2. The results, as shown below, confirmed their hypothesis that the use of TiO_2 significantly improves the anti-friction properties of the water-based lubricant. After the experiment, the authors then wanted to investigate the mechanisms of TiO_2 lubrication, as well as the formation of agglomerates when increasing TiO_2 weight percentage. Using the scanning electron microscope and energy dispersive spectrometer, they were able to generate a schematic of these mechanisms in the second figure below.



CoF and wear areas of the balls



Lubricating mechanisms of TiO_2 at 0.2 %, 0.8 %, and 4.0 % (by weight)

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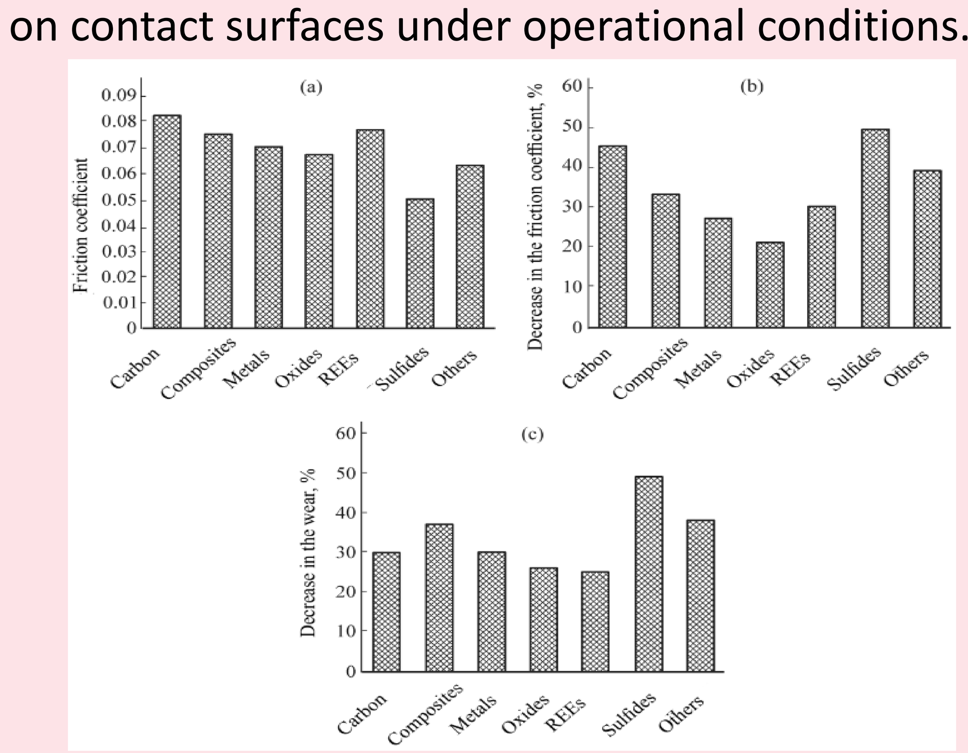
Comparing Additives

Some of the most well-performing nano-additives are molybdenum and tungsten disulfides, especially in the shape of inorganic fullerene-like structures, commonly used in greases. A significant challenge in using these sulfides as lubricants is their high insolubility in liquids, which can be overcome by surface functionalization.

Pure metal nanoparticles are often used in lubricant solutions. They can drastically reduce the friction and wear between contact surfaces by the formation of a tribo-layer. In addition, they have been found to exhibit excellent self-healing and mending properties. Examples of such metals include Fe, Cu, Co, and Ni.

Metal oxides, such as TiO_2, the most commonly used additives in lubricants. They are known to exhibit some of the best anti-friction and anti-wear properties. Common types of metal oxides consist of Fe, Cu, and Al. Some of the best performing metal oxide lubricants are composite blends, such as Al_2O_3 with TiO_2 or ZrO_2 with SiO_2.

The figure below compares various friction and wear properties of different particles. As can be seen in all three categories, metal sulfides provide superior performance. Not only do they have the least coefficient of friction, but they also reduce the most amount of wear on contact surfaces under operational conditions.



Conclusion

The capacity of nanoparticles, namely graphene oxide and TiO_2, for improving the tribological properties of water-based lubricants was shown to be excellent in the two case studies discussed. Although graphene and TiO_2 are well known solid additives, they exhibit minor enhancements to the base fluid with moderate friction reduction properties when used at high concentrations. As of now, the most potential can be found with fullerene-like molybdenum and tungsten disulfides. Spherical, submicron particles of tungsten disulfide enhance the tribological performance far better than their commercial macroscale counterparts. The main challenge for implementing these disulfides is their high liquid insolubility. Sulfur content is also highly regulated by environmental groups. A solution could be to use these sulfides as water-based lubricants. As oil standards set by agencies, such as the ILSAC or API, become more rigorous, nano-additives will play a significant role in improving oil performance and efficiency.