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Review of Tribological Properties of Lubricating Oils with Nanoparticle Additives

Nishant Mohan *, Mayank Sharma, R. C. Singh
Department of Mechanical Engineering, Delhi Technological University, New Delhi, India

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Abstract

With the advent of nanotechnology, research into lubricants and lubricant additives has experienced a paradigm shift. Instead of traditional materials, new nanomaterials and nanoparticles have been recently under investigation as lubricants or lubricant additives because of their unusual properties. Now, there are numerous different types of nanomaterials with potentially interesting friction and wear properties described the literature. This study assays the tribological properties liquid paraffin, with surface modified Ag, Y_2O_3, and TiO_2 nanoparticles used as additives. The friction and wear experiments were performed using a four ball tribotester. The experimental results show that nanoparticles promise reduced friction and wear among the mating surfaces in machines.

1. Introduction

For any machine to operate smoothly, some energy must be provided for the sole purpose of overcoming friction. Minimizing energy lost through friction increases the efficiency of machines. Recent studies have indicated that advancesin tribology could lead to savings of approximately 11% of total annual energy loss in three major areas: power generation, transportation, and industrial processes[1]. Therefore, in the context of energy efficiency, the significance of reducing friction cannot be overemphasized. This is especially true as oil reserves continue to dwindle and energy costs are rising relentlessly.

In addition, friction and wear are two major reasons vital engineering components in various systems fail, such as gears, pin-joints, pistons, bearings, camshafts, pumps, compressors, and turbines. The cost of equipment, installation, and repair related to frictional deficiencies, wear, and damage places an enormous burden on any national economy.

Furthermore, lubricant technologies have not kept up with advances in the manufacturing, energy, and defense industries. In fact, tribological and mechanical limitations have been shown to be the critical factors hindering the transition from prototype to product in many high-tech applications.

Therefore, as existing lubricants reach their performance limits, one of the major scientific challenges for the 21st century is to develop new lubricants that fulfill the emerging requirements in diverse strategic fields, from energy to transportation or manufacturing, for use under increasingly more stringent conditions.

Corresponding Author,
E-mail address: dtu.nishant@gmail.com

In recent years, nanoparticles have been widely exploited for use in catalysis [2,3], magnetic recording media [4,5], biological labeling [6], and formulation of magnetic ferro fluids [7]. Many methods have been developed to produce metal nanoparticles. Examples include vapor deposition [8], electrochemical reduction [9], radiolytic reduction [10], chemical reduction [11–13], and thermal decomposition [14], etc.

Ag nanoparticles have been applied in many scientific fields such as photonics [15], surface-enhanced Raman scattering [16]. But as a traditional solid lubricant, Ag has seldom been used as oil additive due to its poor oil solubility. L. Sun et al. [17] resolved this problem by adding dispersing agent or using surface modification preparation technique. Up to now, the di-n-octodecyldithiophosphate (DDP) coated nanoparticles such as MoS_2 [18], $Ni(OH)_2$ [19], Cu [20], and ZnS [21], used as oil additives have been investigated, results showed these coated nanoparticles exhibited good tribological properties. On similar lines, Q. Xue et al. [22] synthesized 2-ethyl hexoic acid (EHA) surface-modified TiO_2 nanoparticles using a surface-modified method in organic solvent, and their tribological behaviour was investigated using a four-ball wear tester. Among the various inorganic nanoparticles, rare earth (RE) nanoparticles have also attracted particular interest as additives in lubricating oils due to their special physical and chemical properties [23,24]. It is found that the excellent tribological performance of RE nanoparticles can be attributed to the formation of a boundary lubricating film mainly composed of organic acid, oxide of rare earth and complex of rare earth metals on the rubbed surface [25, 26]. Nano-Y_2O_3 was prepared by L. Yu et al. [27] by a precipitation method with polyvinyl alcohol as the dispersant as described by [28]. Currently, the dispersion of inorganic nanoparticles in lubricating oils is still a challenge for application of nano-additives [29].

2. Lubricants

The lubricant must protect the automotive component that it lubricates. In some cases this protection is in the form of a fluid film that keeps opposing surfaces separated. In other cases, the lubricant provides wear protection by forming a chemical film on a surface, to generate boundary lubrication protection. Automotive lubricants protect against corrosion by virtue of alkaline agents to neutralize acids that form in hot spots. The lubricant transports protective chemicals to the sites where they are needed and transports waste products away from the sites where they are generated. This diversity of function strongly influences the choice of chemical composition and physical properties for a given type of lubricant and dictates that a variety of lubricants are required to perform the various lubrication functions in a vehicle. That is, different engine components require substantially different kinds of protection [30].

A large number of additives are used to impart performance characteristics to the lubricants. The main families of additives are: Antioxidants, detergents, anti-wear, Metal deactivators, Corrosion inhibitors, Rust inhibitors, Friction modifiers, Extreme Pressure, Anti-foaming agents, Viscosity index improvers, Demulsifying and Emulsifying agents, Stickiness improver, provide adhesive property towards tool surface (in metalworking), complexing agent (in case of greases). Note that many of the basic chemical compounds used as detergents (example: calcium sulfonate) serve the purpose of many items in the list as well. Usually it is not economically or technically feasible to use a single do-it-all additive compound. Oils for hypoid gear lubrication will contain high content of EP additives. Grease lubricants may contain large amount of solid particle friction modifiers, such as graphite, molybdenum sulfide.

3. Friction And Wear Tests

The tests were carried out by dispersing the NPs in liquid paraffin, having a distillation range of 200-280°C and, density of 0.835–0.855 g/cm^3, with a four ball tester, in which a steel ball is rotated against three stationary balls, according to ASTM D2783. Friction and wear tests were conducted at 1450 rpm under room temperature for 30 min. After testing, the mean wear scar diameter was measured using a microscope.

Figure 1 gives the anti-wear properties of pure LP and LP with DDP coated Ag NPs versus applied loads. It can be seen that at the same applied load, the wear scar diameter (WSD) of LP containing nanoparticles is smaller than that of pure LP, which indicates that the DDP coated Ag nanoparticles have good anti-wear ability. On the other hand, it also can be seen from Fig. 1 that the DDP coated Ag nanoparticles can improve the load-bearing capacity of LP remarkably (from 300 to 800 N).

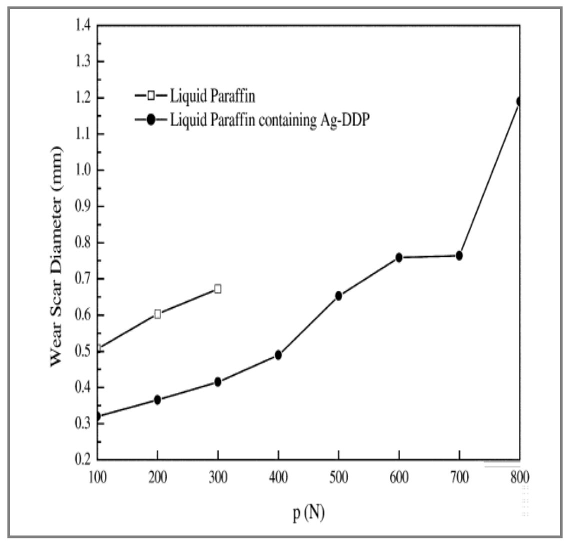

Fig: 1. Wear scar diameter curves of liquid paraffin and liquid paraffin containing DDP coated Ag nanoparticles with applied load [17]

Results indicates that as little as 0.1 % EHA-TiO_2 nanoparticle in base oil possesses excellent anti wear ability, and it can significantly reduce the wear scar diameter of a steel ball. A larger amount of EHA-TiO_2 nanoparticle in liquid paraffin could not further decrease wear. Results also illustrated that, with the addition of EHA-TiO_2 nanoparticle to the base oil, the friction coefficient reduced remarkably. With the lubrication of liquid paraffin only, a relative bigger wear scar diameter was observed, and the friction system scuffing at a load of 400 N. However, with the lubrication of liquid paraffin containing 0.5% EHA-TiO_2 nanoparticles, a smaller wear scar diameter was generated, and the friction system could be lubricated effectively even at a load of 600 N.

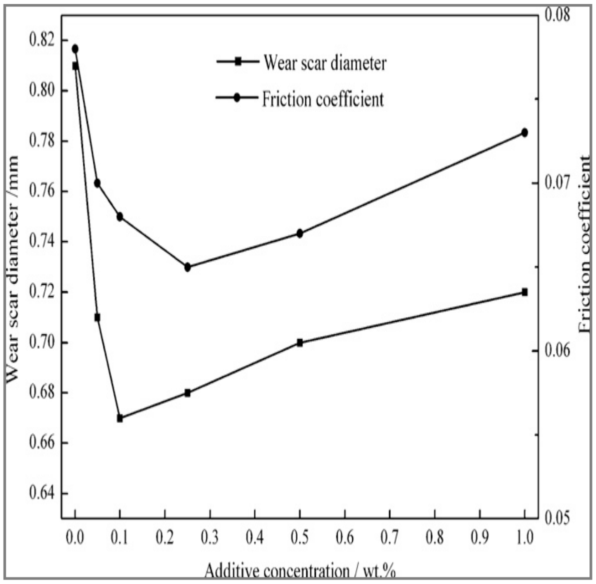

Fig: 2. Wear scar diameter and friction coefficient as a function of surface-modified nano-Y_2O_3 concentration [27]

It can be seen from Figure 2 that the wear scar diameter and friction coefficient decrease gradually with increasing concentration of surface-modified nano-Y_2O_3, but higher concentrations of surface-modified nano-Y_2O_3 in liquid paraffin lead to increase in scar diameter as well as friction coefficient. For instance, when 0.10% of surface-modified nano-Y_2O_3 is added into liquid paraffin, the best antiwear performance is obtained, namely, the wear scar diameter decreases by 21% to 0.67mm with respect to that of liquid paraffin (0.88 mm). Meanwhile, the lowest friction coefficient is achieved with liquid paraffin containing 0.25% surface-modified nano-Y_2O_3.

Figure 3 presents the SEM images of the wear scar of steel balls lubricated by liquid paraffin and liquid paraffin containing 0.10% surface-modified nano-Y_2O_3. It is clear from Figure 3 that the rubbing surface lubricated only by liquid paraffin is quite rough with obviously wide and deep furrows and grooves in sliding direction (Fig. 3a and b). On the contrary, the rubbing surfaces shown in Fig. 3c and d are smoother than those in Fig. 3a and b, and the furrows and grooves on the surface lubricated by liquid paraffin containing 0.10% surface-modified nano-Y_2O_3 are highly inhibited, which is indicative of good anti-wear properties for surface modified nano-Y_2O_3.

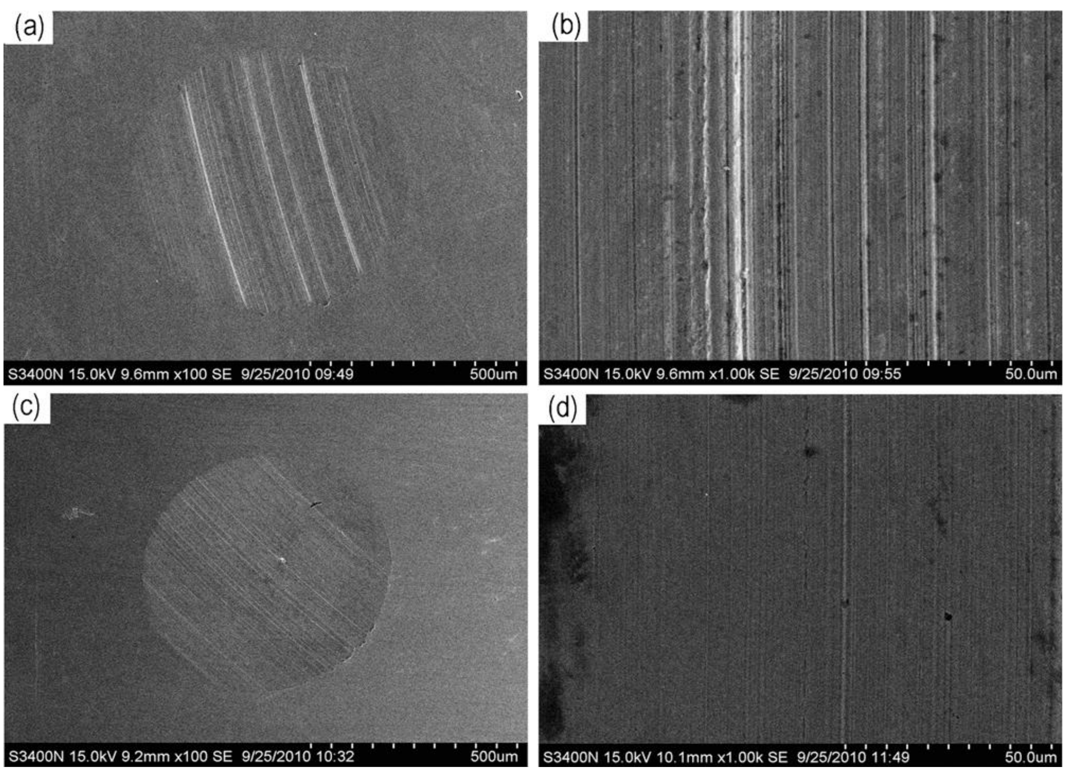

Fig: 3. SEM images of wear scar of the steel balls lubricated by liquid paraffin (a, b) and liquid paraffin containing surface-modified nano-Y_2O_3 (c, d). [27]

4. Conclusion

1. Because of the existence of DDP coating on the surface of the Ag nanoparticles, water adsorption and oxidation were prevented. The DDP coated Ag nanoparticles used as additives in LP exhibited good anti-wear ability and improved the latter's load-carrying capacity remarkably.
2. Under boundary lubrication conditions, 2-ethyl hexoic acid (EHA) surface-modified TiO_2 nanoparticles possess excellent load-carrying capacity and good anti wear and friction-reduction properties. 2-ethyl hexoic acid modified TiO_2 nanoparticles as an oil additive could form a boundary film, mainly composed of TiO_2, to provide an anti wear function and load-carrying capacity.
3. Liquid paraffin containing surface-modified nano-Y_2O_3 exhibits good load carrying capacity, extreme pressure properties and antiware performance.

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