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Influence of Nano-particle on the Wear behaviour of Thin Film Coatings A Review

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Abstract

The current study deals with the friction and wear behaviour of thin film coating used for automotive applications like piston rings, under the influence of nanoparticle like alumina-oxide, copper and many more. The study reports the influence of factors like load and speed under the presence of third body i.e. nano-particle and it has been found that the friction and wear of coatings are determined by adhesion at small load and dominated by adhesion and ploughing at higher load. The shape of particle also affects the wear properties during the test at Pin on disc tribometer. It is found that a small-sized particle can increase the wear of the coating by reducing the friction. These unique tribological mechanisms of the film can help to promote its wide applications in a sand-dust and presence of tiny particle environment.

Keywords: Nano particle; coating; wear; friction;

INTRODUCTION

Nanotechnology is a vibrant and developing area of science, engineering, and technology accomplished at the nanoscale level. In recent years, researchers have pointed out the numerous advantages of adding nanoparticles to lubricant oil. With its miniscule size, nanoparticles can easily mix with the lubricant oil to enhance its lubricating properties. The nanoparticles added to the lubricant oil help in preventing corrosion, reducing friction, and modifying the viscosity of the oil. Numerous articles have shown the effectiveness of adding nanoparticles to lubricants.

Influence of two kinds of nanoparticles as additives on GL-4 fully-formulated oil and poly-alpha olefin 8 base oil has been studied. Their experimental results showed that CuO additives had better effects on tribological behavior than Al_2O_3 nanoparticles in two types of synthetic oils. With 2 wt % CuO concentration dispersed in PAO8, the wear scar diameter reduced by 14% and the coefficient of friction reduced by 18%. Research studies [1-4] tested the tribological behavior of ZnO/ Al_2O_3 composite nanoparticles as additives to the lubricant. Their results showed that when added to lubricant the composite nanoparticles reduced friction and wear better than pure ZnO and Al_2O_3. Researcher synthesized and modified the surface of TiO2 nanoparticles with a double-coated agent. The concentration of nanoparticles ranged from 0.1 wt % to 1.6 wt % in a water-based medium. Their experimental results showed that the TiO_2-modified nanoparticles could increase the applicable load, reduce the friction force, and increase the anti-wear capacity of pure water. These excellent tribo-mechanical properties increase the research in nanoparticles that is also quite different relative to micro- particles and bulk materials. It also provides an effective way for surface modification of many devices that requires mechanical strength by improving the quality of nonmanufacturing/nanofabrication, etc. on the other hand nanoparticles with the lubricants also affect the tribological properties of mating parts in automobiles. In lubricated condition, the comparison in the hardness between nanoparticles and the mating parts determines whether particles are deformed into the surface when the contact pressure is sufficient [5-7].

This investigation aim is to review the important and recent trends in the tribo-mechanical properties of nanoparticles. The summarize work gives us a clear understanding to the Influence of nanoparticles on some of the mechanical properties of nanoparticles, such as wear, friction, hardness, elastic modulus and adhesion. and wide range of applications of nano-particles, include a lubricant with nano-particles as additives, nano-particles in nano manufacturing and nano-particle reinforced composite coating.

MATERIALS AND METHODS:

Table1give us a general classification and table 2 also clears the picture of the nanoparticles (NPs) application accordingly their weight, medium and effects in tribology. Some additive solutions contain the appropriate percentage of NPs have been used in the standard oil. Various mixing percentage and their effects are also shown in table2.

Table 1. General Classification of Nanomaterials

Engineered Nanomaterials	Carbon based	Fullerenes, C60 or C70 , Carbon nanotubes
	Metal based	Silver, nanometal oxide
	Dendrimers	Polymer with branched units
	Composites	Bioorganic complex

Table 2. Different materials (NPs) and their effects

S.No.	Name of NPs	Weight% and medium	Effects	Reference
1	Titanium oxide (TiO2)	0.1 to 1.6 wt % in a water-based medium	TiO_2-modified nanoparticles reduce the friction force, and increase the anti-wear capacity of pure water.	Gu et al. [7]
2	Titanium oxide (TiO2)	Added 25 nm TiO2 nanoparticles into a base oil with 0.01 wt %.	Significant reduction in coefficient of friction (COF) and wear rate has been observed in comparison to using a pure base oil lubricant with 0.01 wt %	Chang et al. [8]
3	Copper (Cu)	Tribology behavior of Pegasus 1005 oil with Cu additives as NPs.	Cu nanoparticles of 130 nm and engine oil was more effective than the engine oil itself containing 50 nm nanoparticles for the reduction in friction.	Zin et al. [9]
4	Copper (Cu)	Synthesized Cu NPs added into paraffin oil.	Their results showed that Cu nanoparticles of size 2–5 nm, reduced the COF of steel pair and displayed excellent thermal stability	Zhang et al. [10]
5	Alumina oxide (Al_2O_3)	Al_2O_3 NPs with different concentrations in engine oil has been used to evaluate their tribology. .	The analysis results showed that the minimum coefficient of friction was obtained with 0.8 wt % of medium nanoparticles size 60 nm.	Thakre et al. [11]

Synthesis of Nanoparticles

Nanomaterials attracts tremendous attention of the researchers due to its inherent properties in the preparation of nanoparticles. Some of the common methods are reported below.

Mechanical Attrition

Mechanical attrition produces its nanostructures by the structures decompositions of coarser gained structures as a result of plastic deformation. Some mechanical alloying process like rod milling and ball milling techniques received much attention as an advanced tool for the fabrication of several nanomaterials. These processes can be performed on both centrifugal type and high energy vibratory mills performed the experiments at room temperature. High energy ball mill includes [12,13]:

(a) Attrition Ball Mill (b) Planetary Ball Mill
(c) Vibrating Ball Mill (d) High energy Ball Mill
(e) Low energy Tumbling Mill

Chemical Precipitation

The basic method has been to synthesis and studies the nanomaterial in situ i.e. in the same liquid medium avoiding the physical changes and aggregation of tiny crystallites. The synthesis involved reaction between constituent material in suitable solvent. The dopent is added to the parent solution before precipitation reaction. Surfactant is used to maintain separation between the particles formed. Thermal coagulation and Oswald ripening were controlled by double layer repulsion of crystallites using non-aqueous solvents at lower temperatures for synthesis [12,13].

Gas Condensation

Gas condensation was the first technique used to synthesize Nano-crystalline metals and alloys. In this technique, a metallic or inorganic material is vaporized using thermal evaporation sources such as a Joule heated refractory crucibles, electron beam evaporation devices, in an atmosphere of 1-50 m bar. In gas evaporation, a high residual gas pressure causes the formation of ultra-fine particles (100 nm) by gas phase collision. The ultra-fine particles are formed by collision of evaporated atoms with residual gas molecules. Gas pressures greater than 3 mPa (10 torr) are required [14,15].

Vacuum Deposition and Vaporization

In vacuum deposition process, elements, alloys or compounds are vaporized and deposited in a vacuum. The vaporization source is the one that vaporizes materials by thermal processes. The process is carried out at pressure of less than 0.1 Pa (1 m Torr) and in vacuum levels of 10 to 0.1 MPa. The substrate temperature ranges from ambient to 500°C. The saturation or equilibrium vapor pressure of a material is defined as the vapor pressure of the material in equilibrium with the solid or liquid surface. For vacuum deposition, a reasonable deposition rate can be obtained if the vaporization rate is fairly high. A useful deposition rate is obtained at a vapor pressure of 1.3 Pa (0.01 Torr) [16,17].

Electrodeposition

Nanostructured materials can also be produced by electrodeposition. These films are mechanically strong, uniform and strong. Substantial progress has been made in nanostructured coatings applied either by DVD or CVD. Many other non-conventional processes such as hypersonic plasma particle deposition (HPPD) have been used to synthesize and deposit nanoparticles. The significant potential of nanomaterial synthesis and their applications is virtually unexplored. They offer numerous challenges to overcome. Understanding more of synthesis would help in designing better materials. It has been shown that certain properties of nanostructured deposits such as hardness, wear resistance and electrical resistivity are strongly affected by grain size. A combination of increased hardness and wear resistance results in a superior coating performance [18,19].

EFFECT OF NANO-PARTICLES ON THE TRIBO-MECHANICAL PROPERTIES

Nanoparticles in lubrication

Nanoparticles play a major role in advance manufacturing due to its considerable impact at the mechanical properties. It may also influence the tribological properties of lubricated systems with nanoparticles. Various research reports about the wear behaviour of piston rings and liner with the lubricants. The effects of the mechanical properties of nanoparticles as lubricant additives on the tribological properties differ in various materials. From a general point of view, the combined effects of rolling, sliding and the formation of a third body layer and tribofilms are the main reasons for the increased lubricating behaviour after adding nanoparticles [20], as briefly described in the following parts. The lubricating properties of typical nanoparticle materials are summarized in table 3.

Spherical shaped nanoparticles which are mechanically stable without significant cluster are favourable for their rolling action contact area between tribopairs like piston rings and cylinder liner arrangement. This nature of nanoparticles with the lubricant (engine oil) provide a very low friction and wear. This reduction in coefficient of friction strongly reliant on the size, shape and concentration of nanoparticles in the lubricants. The sliding nature of nanoparticles also results in significant reduction in friction and wear. This behaviour came into existence due to particle non-spherical shape results low adhesion to the tribopairs. Besides, particle accumulation in the contact area is another factor that could lead to sliding friction during the shearing of tribopairs. Metal transfer and direct contact can be minimize by the nanoparticles play a role as a medium between the tribopairs. Another important aspect of the nanoparticle in the lubricant under a low applied pressure is that the viscosity of the lubricant could be enhanced and thereby the oil film formation properties in the lubricated contact could be improved. It is also pointed that nanoparticles as lubricant additives do not always give favourable tribological properties. Increases in friction and wear, as well as lubricant starvation, were also observed due to the abrasive effect of rigid nanoparticles under large pressures and heavy collections of oils with high particle concentrations in the inlet of the contact area [21-30].

Table-3 Different NPs and their favourable aspects with the lubrication mechanism

Material Category	**Example**	**Favourable aspects**	**Lubrication mechanism and regime**	**Unfavourable aspects**
Carbon-based nanoparticle	Graphite nanoparticle [29,30]	Friction reduction, anti-scuffing, surface polishing	(1) Ball-bearing effect (2) Viscosity-increasing effect (3) Increase in the surface hardness of tribopair	
	Diamond nanoparticle [31,32]	High temperature resistance, extreme pressure and self-lubrication ability	Ball-bearing spacers, reduce metal contact and increase the wettability of lubricant on surface	Water insoluble due to hydrophobicity
Silicon nanoparticle	SiO2 [33] Al2O3/SiO2 composite nanoparticles [34,35]	Cheap and easily available	Bear load, separate tribopair, prevent direct contact, and promote rolling, inhibit the expansion of the microcracks on the tribopair surface due to particle embedment	
Metal nanoparticles	Au [36], Ag [36, 37] Cu, Ni [38]	Friction and wear reduction, anti-contact fatigue, good extreme pressure	Friction and wear reduction, anti-contact fatigue, good extreme pressure.	Low dispersibility in organic solvent
	CuO, ZnO and ZrO_2 [39-40], TiO_2 Al_2O_3 [41,42]		Formation of the third body layer due to mechanical compaction	

NANOPARTICLES APPLICATION IN COATINGS

Incorporating diverse range of nanoparticles within a metal or polymer matrix to produce nanocomposites. Such nanocomposites can enhance the mechanical properties, wear resistance and self-lubricating properties [43].

Due to some of the integral assets of the matrix, for instance the high wear resistance, strength, modulus and high thermal and electrical conductivity, metal or metal alloy matrix composite coatings show distinct advantages over polymeric composites. In these coatings, ceramic (Al_2O_3, TiO_2, SiC and carbon-based graphite and CNTs nanoparticles are usually added. There are three reasons why ceramic particles are used as reinforcement to enhance the hardness and the wear resistance of composites. High strength and hardness of particles, migration and dislocation motion of grain boundaries can be prevented by the particles in the matrix. heterogeneous nucleation effect of particles in meta or metal alloys. The addition of graphite nanoparticles or CNTs in a metal matrix could, on the one hand, reduce the porosity of a pure metal coating, then the coating would be much denser and compact with fewer cracks. On the other hand, the crystalline size in the coating could be refined due to the presence of nanoparticles. In addition, the structural and chemical stability of CNTs, which have a higher stiffness and strength compared with the metal matrix are another important factor contributing to the strengthening effect. Some modification of the can be achieved by adding inorganic or organic nanoparticles, causing some new characteristics of polymers to be obtained in the physical properties [44-48].

CONCLUSIONS

Increasing demand of the tribological properties of many mechanical systems, new designs and improvements of surface modifications and manufacturing technologies. Nanoparticles exhibiting many unique mechanical properties have become one of the most attractive choices for meeting these needs in the past couple of years. The foregoing parts review basic physics and recent important results of nanoparticles from the perspectives of their mechanical properties and interfacial interactions, as well as related applications. Available fundamental research data regarding the mechanical properties of nanoparticles provide valuable guidance for their effective implementation in surface engineering, micro/Nano manufacturing and nanofabrication etc. Many of these applications with nanoparticles have already made impressive progress in practice and exhibited significant advantages in many fields. Despite these, further works are still needed to acquire information on the mechanical properties of more kinds of nanoparticles with the advances of convenient characterization techniques and mature nanoparticle production technologies. Quantitative descriptions of the mechanical properties of nanoparticles in relation to the size dependent and material effects etc. should be also made. Additionally, how to achieve a much clearer picture about the roles of nanoparticles in their specific applications is of great significance. Hence, direct visualizations of the interfacial behaviour of nanoparticles in applications on the micro-/nano- and even atomic scales would be very helpful.

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