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Tribological Effect of Size, Shape and Structure of Nanoparticle in Lubricant Oil – A Review

Maharaja K[1], Vijayan S N[2], Karthik S[3]
Assistant Professor, [1,2,3] Department of Mechanical Engineering, Karpagam Institute of Technology, Coimbatore, Tamilnadu, India.

Abstract - *Many researchers have tried to improve the tribological characteristics of lubricants to decrease friction coefficients and wear rates. Recently, nanoparticles have emerged as a new kind of additive because of their size, shape and other properties. A nano lubricant is a new kind of engineering lubricant made of nanoparticles, dispersant, and base lubricant. Investigations related to the tribological characteristics of oil lubricants with addition of nanoparticles are reviewed here.*

Keywords: *Tribology, Nano Particle, Lubricant, oil*

I. INTRODUCTION

The addition of nanoparticles into lubricating oil significantly reduces the friction coefficient and increases the load-bearing capacity of the friction parts in mechanical systems. A variety of mechanisms have been proposed to explain the lubrication enhancement of the nanoparticle suspended lubricating oil (i.e., nano-oil), including the ball bearing effect, protective film, mending effect and polishing effect. These mechanisms can be mainly classified into two groups, as shown in Fig. 1. The first is the direct effect of the nanoparticles on lubrication enhancement. The nanoparticles suspended in lubricating oil play the role of ball bearings between the friction surfaces. In addition, they also make a protective film to some extent on the rough friction surfaces. The other is the secondary effect of the presence of nanoparticles on surface enhancement. The nanoparticles deposit on the friction surface and compensate for the loss of mass, which is known as mending effect. And also the roughness of the lubricating surface is reduced by nanoparticle-assisted abrasion, which is known as a polishing effect.

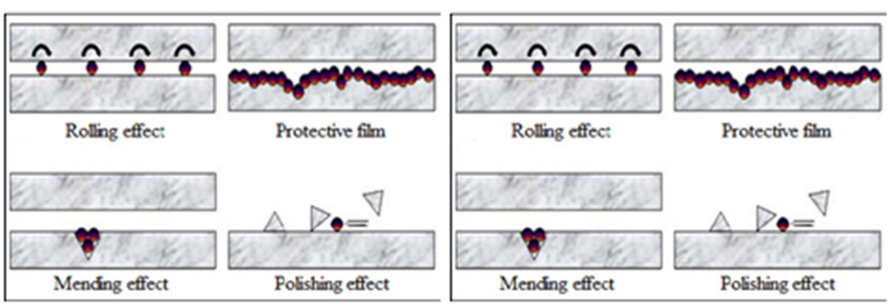

Fig. 1 Possible lubrication mechanisms by the application of nano oil between the frictional surfaces

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II. Tribological Behavior

A. Effect of Size and Shape of Nanoparticle

Chang-Gun Lee [1] indicated that the addition of graphite nanoparticles to the lubricant enhanced the lubrication characteristics. The presence of nanoparticles between the friction surfaces reduced contact between the plates by acting as ball-bearing spacers. The friction coefficients of the lubricated surfaces were evaluated by varying the applied normal force is shown in Fig. 2. The morphology analysis indicated that the addition of nanoparticles decreased wear and resulted in a relatively smooth surface with fewer scars, thus indicating that the presence of the graphite nanoparticles significantly reduced metal contact.

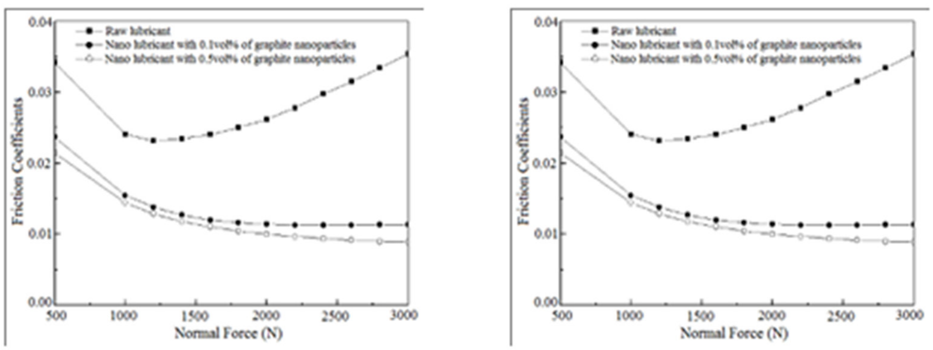

Fig. 2 Friction coefficients of nano lubricants as a function of normal force

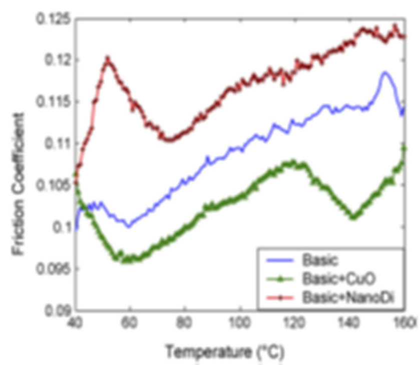

Fig. 3 Friction coefficient of the Base oil with and without nanoparticles

Y.Y. Wu [2] suggested that nanoparticles including CuO, TiO2, and Nano-Diamond used as additives in lubricating oils exhibit good friction reduction and anti-wear behavior, especially for CuO. For the friction-reduction test, when CuO was added to the engine oil and the base oil, the friction coefficients were reduced by 18.4 and 5.8%, respectively, as compared to the oils without nanoparticles are displayed in Fig. 3. This might be attributed to the viscosity effect at low temperature and the rolling effect at high temperature. The sphere-like nanoparticles may result in rolling effect between the rubbing surfaces, and the situation of friction is changed from sliding to rolling. Therefore, the friction coefficient can be reduced.

For the anti-wear test, when CuO was added to the engine oil and the base oil, the worn scar depths were decreased by 16.7 and 78.8%, respectively, as compared to the oils without nanoparticles. The anti-wear mechanism is attributed to the deposition of CuO nanoparticles on the worn surface, which may decrease the shearing stress, thus improving the tribological properties.

WANG Xiao-li [3] invesigated that the dispersion stability of nano-copper as lubrication oil additive is one of the key problem to realize good lubrication effect because nano-copper easily agglomerate in liquid medium. So nano-copper needs surface treatment for improving dispersion stability. The prepared copper additive is about 20 nm elliptical shape particle, and the grain size is uniform and dispersive. Nano-copper additive has stable tribological property, and nano-copper additive has excellent dispersion stability in lubrication oil can obtained by KBH4 reduction in liquid phase and ball milling method.

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R. Chou [4] studied that the nanoparticles have been dragged into contact and have interacted with the surface, causing an improvement in the tribological behavior of the base oil. The most likely antiwear mechanism of nanoparticulate additive is the formation of a protective layer due to welding (without melting) of the nanoparticles on the wear surface (tribosinterisation). Also, nanoparticles may be inlaid into the surface of the test material, forming a boundary lubrication film to prevent the rubbing faces from coming into direct contact. Besides the above mentioned mechanisms, nanoparticles can also act as nano-bearing, increasing the carrying load capacity of the lubricant.

Bon-Cheol Ku [5] suggested that the added fullerene molecules accelerate self-restoration of the polymeric tribofilm damaged in the course of mechanochemical degradation, and also the fullerene particles with a spherical structure play a role of ball bearing in the friction surfaces. The improvement of lubrication characteristics of oil with the addition of fullerene nanoparticle is dominantly caused by the enhancement of the load carrying capacity of oil as shown in Fig. 4.

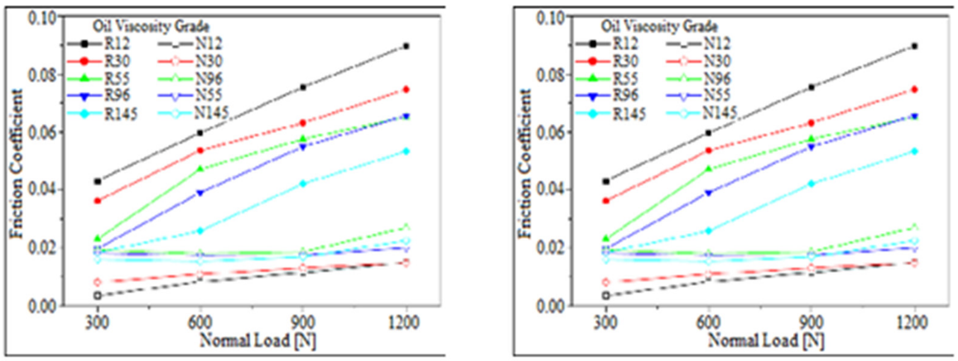

Fig. 4 Lubrication test results for friction coefficient as a function of oil viscosity grade and normal load with raw oil (R) and nano-oil (N)

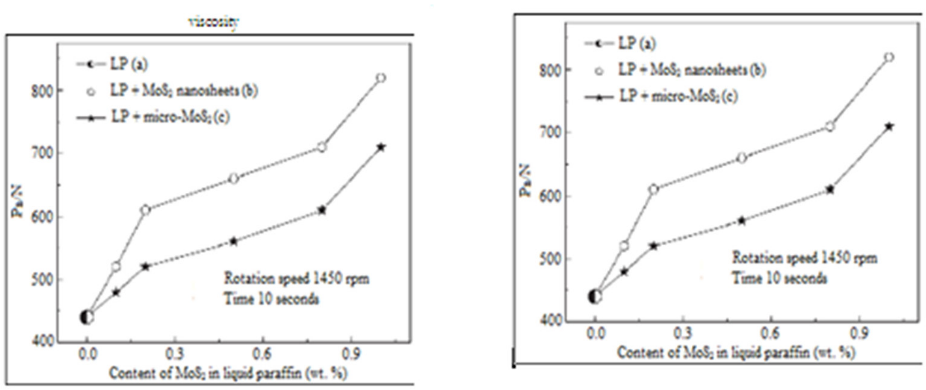

Fig. 5 Variations of PB of liquid paraffin (LP) with increasing MoS2 content at 1450 rpm for 10s.(a)Pure LP,(b)LP+MoS2 nanosheets, (c)LP+micro-MoS2

K.H. Hu [6] found out the lubrication mechanism of MoS2 nanosheets as an additive in liquid paraffin. Due to the higher surface energy of MoS2 nanosheets, they were adsorbed on the rubbing surfaces forming a physical tribo-film, which can adhere on the metal substrates and slid between the two rubbing surfaces. The film not only bore the load of the steel ball but also separated the rubbing faces and prevented them from direct contact. When the adsorbed MoS2 nanosheets were worn out and oxidized into MoO3 and FeSO4, the good diffusion ability derived from small thickness of nanosheets enabled them to easily enter the contact area again. The oxidation of MoS2 led to a complex lubrication film comprising MoO3 and FeSO4, which was of better wear resistance during rubbing is shown in Fig. 5. The oxidation rate of MoS2 nanosheets is affected by friction temperature, sliding time, load, sliding speed and soon, which is very complicated.

B. Effect of Structure of Nanoparticle

L. Joly-Pottuz [7] proposed that Carbon nano-onions were synthesized by annealing diamond nanoparticles at 1,700 °C for 10 min. Graphite has already been used as lubricant, and its lubrication mechanism is based on the shear between its large graphitic lamellae.

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But the large size of the lamellae could avoid them to enter easily the contact area. Furthermore, they have to be aligned inside the contact area. Tiny carbon onions may enter easily the contact area and their round shape could be an advantage. Carbon nano-onions are composed of a ten of nested graphitic carbon shells in a giant fullerene-like structure and most of particles do not contain any visible residual diamond core but possibly a C60 molecule. In the absence of water molecules then the graphite nanoparticle may scratch the steel surface, the edge acting as a cutting tool. The situation is different in the case of carbon nano-onions. Carbon nano-onions have typically no edge and they can easily slide and even roll on the surface.

L. Joly-Pottuz [8] suggested that nanodiamond particles are often used as precursor to carbon onions synthesis. The effect of the presence of a diamond core inside the carbon onions on tribological properties. The two samples were produced by different annealing procedures: the first one contains a residual diamond core and the second one is only composed of graphitic carbon layers. The presence of diamond core inside the carbon onion is found to be detrimental for the anti-wear properties of COs. The presence of this core possibly leads to poor elastic properties of the nanoparticles. Their good dispersion in oil was difficult to obtain.

L. Joly-Pottuz [9] studied that the catalyst particles that were initially protected inside carbon structures have been exposed to environment inside the contact area during the friction experiment. Carbon onions submitted to high pressures are crushed since nickel nanoparticles are released inside the contact area. Ni-doped carbon material which is formed like a coating inside the wear scar. This Ni-doped carbon material may be composed of crushed nanotubes or crushed carbon onions and nickel nanoparticles. This kind of structure could have interesting tribological properties.

H.L. Yu [10] observed that the tribofilm is a multi-apertured oxide layer on which micrometric alumina particles embedded, and serpentine nano-particles adsorbed. It is obvious that the film consists of three typical structures: (1)oxide layer with excellent nano-mechanical properties,(2)micro-apertures with alumina particles embedded, and (3)third bodies formed by nano-scale serpentine particles. A hard oxide layer can provide a sufficient resistance not only to the embedding of abrasive particles but the plastic deformation of materials in sliding friction as well, the abrasive wear can be accordingly reduced that can be displayed in Fig. 6. Serpentine particles in oil to partly dehydrate due to the local overheating, high flash temperature and high contact stress during the sliding of contact surfaces is shown in Fig. 7. Once dehydration reaction occurred, the size of serpentine particles was refined and its hardness was reduced.

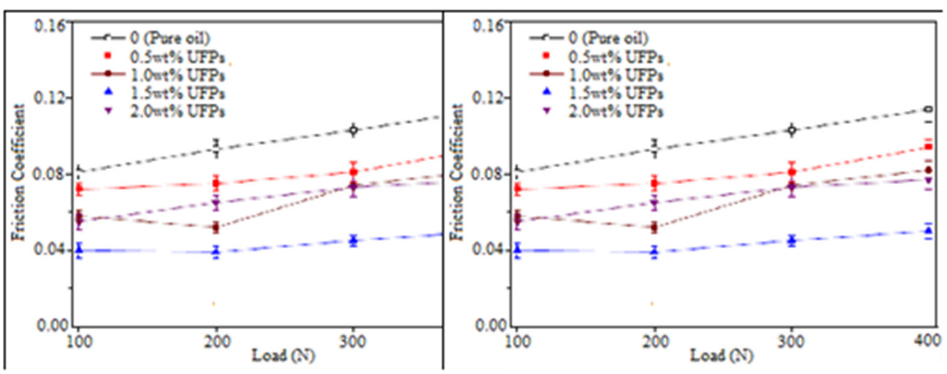

Fig. 6 Variation of friction coefficient with normal load

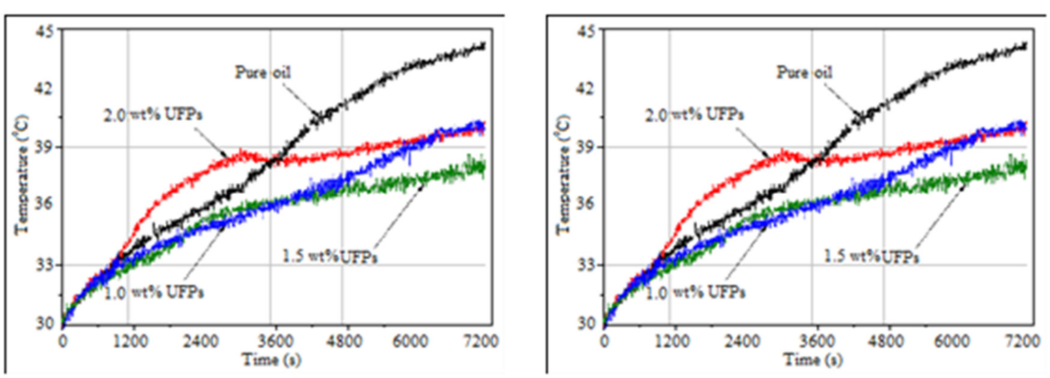

Fig. 7 Friction time dependency of specimen temperature (Normal load=200 N)

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D.X. Peng [11] found that an organic modification agent is adsorbed around the surface of the nanoparticles, reducing their surface energy, the surface modification layer effectively prevents the agglomeration of nanoparticles. The nanoparticles modified by oleic acid exhibit good dispersivity and stability in liquid paraffin. The SiO2 nanoparticles cannot settle easily due to light specific gravity and small diameter. Thus, the SiO2 nanoparticles dispersivity and stability are better than those of nanodiamond in liquid paraffin. The SiO2 nanoparticles are not only cheap and easily obtained but also exhibit the same excellent tribological behaviors as diamond nanoparticles in liquid paraffin is shown in Fig. 8. The micro-grooves are formed and then more spherical nanoparticles roll into the contact area like tiny ball bearing, reducing the sliding friction.

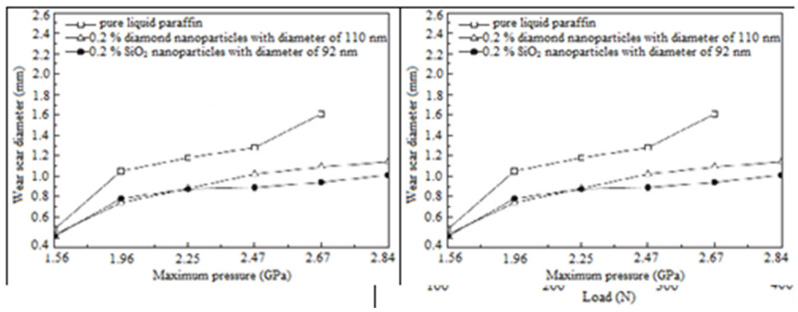

Fig. 8 Wear scar diameter as function of maximum pressure lubricated with pure liquid paraffin, liquid paraffin added by 0.2 wt% diamond and SiO2 nanoparticles.

III. Conclusion

Nano lubricants and raw lubricants were compared using a pin-on-disk tribotester, focusing on the influence of the graphite nanoparticle additive. The friction coefficients and wear rate of the lubricated surfaces were evaluated by varying the applied pressure and sliding speed. The results show that the addition of graphite nanoparticles to the lubricant enhanced the lubrication characteristics. The presence of nanoparticles between the friction surfaces reduced contact between the plates by acting as ball-bearing spacers. The wear rate increased with pressure and speed. Maximum wear rate was observed during dry sliding while the minimum for the oil plus graphite lubricant mixture; intermediate wear response shown by the samples in the oil lubricant. Suppressed cracking tendency of the material and enhanced possibility of the formation of more stable lubricating film was observed to be responsible for better wear response of the material in presence of the external lubricant.

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