Investigation of tribological properties of lithium grease with SiO2 nanoparticles

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Abstract. The aim of the work was to investigate the effect of the SiO2 nanoparticles concentration in the lithium grease and of contact pressure on the spinning friction coefficient in the contact zone between a steel plate and a ball. The investigations were carried out using the a tribotester for the spinning friction torque in the contact between the ball and the plate. Ball rotated relative to the plate axis at a constant speed and was loaded by the a force increasing in a stepwise manner for the consecutive series. The contact zone was lubricated with a pure lithium grease - pure or with the grease with suspended SiO2 nanoparticles. The friction coefficient decreased with the increase of contact pressure for the pure lithium grease. For the concentration $\phi = 6\text{wt.\%}$ of SiO2 nanoparticles in the grease friction coefficient decreased and for the other concentrations it increased with the increase of the contact pressure. If the values of average contact pressure were below 550 MPa, the friction coefficient values for pure lithium grease were higher than those for lithium grease with suspended SiO2 nanoparticles. For higher values of the contact pressure, the values of the friction coefficient for the pure lithium grease could be lower, equal or higher than those for lithium grease containing SiO2 nanoparticles depending on the value of SiO2 the concentration.

1. Introduction

The use of nanoparticles as a lubricant additive for various devices is more and more popular [1]. Nanoparticle additives can reduce friction and wear due to different mechanisms. Such mechanisms can be linked to direct and indirect effects of nanoparticle additives on the friction and wear processes [2]. Studies described in [3–5] show that nanoparticle additives can decrease friction and wear in ball bearings. Further studies [6–8] show that nanoparticle additives can also form a protective film over friction surfaces. Liu et al. [9] describe the formation of nanoparticle additive depositions on mating surfaces which compensate the loss of material. Nanoparticle additives can also decrease the roughness of mating surfaces due to their abrasive action [10]. Nair et al. [11] report a study on the effect of nanoparticle additives on journal bearings using the finite element method.

Shenoy et al. [12] study the effects of nanoparticle lubricant additives on the performance of externally adjustable fluid film bearings. The studies described in [11, 12] point out an increase in the load-bearing capacity and stability of journal bearings using a nanoparticle-dispersed lubricant. Binu et al. [13] describe a novel method for evaluating the load-bearing capacity of journal bearings operating with lubricants containing nanoparticle additives. It was found that variations in lubricant shear viscosity due to the nanoparticle additives can be simulated accurately using a modified Krieger-Dougherty viscosity model. According to Nam et al. [14] the most popular method for preparation of nano-grease is the ‘Direct mixing method’. In this method, the nano-particles are directly mixed with grease under heavy mechanical stirring. Rashed & Nabhan [15] investigated tribological behaviour of mineral 20W-50 and semi-synthetic 15W-50 oil dispersing by different amounts (0.5 and 1.0%wt. oil) of SiO2 nanoparticles. Experiments were carried out using tribometer test-rig under normal load at different temperature values from range 40 °C to 100 °C. The addition of SiO2 to engine oils had not reduced the friction coefficient to a great extent. Li et al. [16] dispersed ultrasonically 0.3 wt.% of SiO2 nanoparticles in ST5W/30 mobile oil. Such nanolubricant was studied using a reciprocating tribotester and a four-ball tribotester. As a result the frictional coefficient
decreased in relative to pure ST5W/30 gas mobile oil. Peng et al. [17] found that the SiO2 nanoparticles oleic dispersed in acid exhibited the same excellent tribological behaviour as diamond nanoparticles in liquid paraffin. During friction the micro-grooves are formed and then more spherical nanoparticles roll into the contact area like tiny bearing, balls which reduce the sliding friction. Rawat et al. [18] studied frictional behaviour of a paraffin grease with dispersed SiO2 nanoparticles. The paraffin grease was developed using paraffin oil as a base oil and 12-lithium hydroxy stearate as a thickener. The concentration of the thickener was of 14 wt.%. The SiO2 nanoparticles were synthesized by a modified sol–gel method and dispersed in paraffin grease by the in-situ method. The frictional characteristics of the paraffin grease with SiO2 admixture were studied with use of a four-ball tester. The addition of SiO2 nanoparticles to the paraffin grease enhanced its tribological performance as compared to the pure paraffin grease. The maximum reduction of the friction coefficient was ~ 20% at concentration of 0.03% wt.%. He et al. [19] prepared SiO2 nanoparticles encapsulated in lithium grease. Friction tests were conducted with use of a a four-ball friction tester for the pure lithium grease and for the one containing SiO2 nanoparticles. The addition of the SiO2 nanoparticles to the grease reduced the friction coefficient of the base grease. When the content of the SiO2 nanoparticles in the grease was of 0.3 wt.%, the value of the friction coefficient decreased by 26% compared with that for the base grease. For the content of the SiO2 nanoparticles 0.3 wt.% the grease exhibited the lowest average friction coefficient at the load of 342 N, and the value of the friction coefficient decreased by 39% as compared with that for the base grease. The aim of work was to investigate the effect of the SiO2 nanoparticles concentration in the lithium grease and of the contact pressure on the spinning friction coefficient in the contact zone between steel plate and ball.

2. Materials and methods

2.1 Samples preparation

Steel balls rotating against fixed steel plate counterparts were used. Two steel balls with diameters of 14 and 8 mm with polished surface were used. Each ball rotated with a constant speed and was loaded by the tribotester head with a constant force. The mating counterpart contained the steel plane plate immersed in an epoxy resin and chemically cured in the steel ring. The contact zone was lubricated with lithium grease with or without the addition of 2, 4, 6, 8 and 10 wt.% of SiO2 nanoparticles of a size 10–20 nm and delivered by SIGMA-ALDRICH [20]. The grease was mixed with the SiO2 commercial product using the High-Speed Planetary Mixer THINKY SR-5000. The grease was then treated with ultrasonic waves in the GT Sonic VGT-800 Ultrasonic Cleaner for only 2 min., to avoid agglomeration or the structural break of the nanoparticles.

2.2 Investigation of the friction coefficient

The friction coefficient in the contact zone between the rotating steel ball and the steel plate lubricated with the lithium grease containing different content of SiO2 nanoparticles was estimated using the available tribotester [20] (Figure 1). This tester allowed the measurement of the spinning friction torque in the contact zone between ball (4) and its counterpart (5), on the base of the twisting angle of the string (7) supported by the aerostatic bearing in the tabble 9. The twisting angle was read on the shield (8). Measurements were carried out at a constant rotating speed of the shaft 1 equal to 36 rpm and at a constant load of the set of weights 3 increasing in a constant step manner for the consecutive series from 7.2 N to 27.2 N. The friction coefficient was estimated using the modelled contact zone between steel ball (4) and steel plane plate (5). The courses of the friction torque values against an average contact pressure were obtained for the 0, 2, 4, 6, 8 and 10 wt.% of SiO2 nanoparticles in the lithium grease. The averaged contact pressure \( p_{\text{aver}} \) and radius \( a \) of the contact zone were estimated using equations (1) and (2) [21].

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p_{\text{aver}} = F/(\pi a^2) \quad (1)
\]

\[
a = [3Fr(1-\nu^2)/E]^{1/3} \quad (2)
\]
Figure 1. The ball-on-plate tribotester for measurement of the spinning friction torque; a) photo of the tester. 1 - shaft, 2 - electric motor, 3 - weights, 4 - ball, 5 - plane steel counterpart, 6 - outlet of compressed air, 7 - string, 8 - shield for measurement of twisting angle, 9 - table with aerostatic bearing [22]; b) Scheme of the tester. F - filter, G - weight, M - electric motor, N - tachometer, K - shield for measurement of twisting angle, S - compressor, ST – string, R - reducer, Z - power supply.

3. Results

Results of measurements of the friction coefficient an against average contact pressure for the ball radius \( r = 7 \) mm and pure lithium grease are given in Figure 2. The value of the friction coefficient decreased from 0.25 to 0.07 with the increase of contact pressure. The courses of the friction coefficient against average contact pressure for the ball radius \( r = 7 \) mm at different concentrations of SiO\(_2\) nanoparticles in the lithium grease are shown in Figure 3. The value of the friction coefficient decreased from 0.16 to 0.116 with the increase of the contact pressure for the concentration of SiO\(_2\) nanoparticles \( \varepsilon = 6\)wt.\%. For the other SiO\(_2\) concentrations the friction coefficient was increasing with increasing the contact pressure, from 0.073-0.08 for \( \varepsilon = 2\)wt.\%, from 0.072-0.094 for \( \varepsilon = 4\)wt.\%, from 0.086-0.1 for \( \varepsilon = 8\)wt.\%, and from 0.081-0.096 for \( \varepsilon =10\)wt.\%, respectively. The courses of the values of the friction coefficient against an average contact pressure for the ball radius \( r = 4 \) mm and different concentrations of SiO\(_2\) nanoparticles in the lithium grease are shown in Fig. 4. The value of the friction coefficient decreased from 0.16 to 0.116 with the increase of the value of the contact pressure for the concentration \( \varepsilon = 6\)wt.\%. For the other concentrations the friction coefficient increased with contact pressure, from 0.067-0.117 for \( \varepsilon = 2\)wt.\%, from 0.091-0.1 for \( \varepsilon = 4\)wt.\%, from 0.073-0.093 for \( \varepsilon = 8\)wt.\%, and from 0.1-0.11 for \( \varepsilon =10\)wt.\%, respectively.

Figure 2. Plot of the the values of the friction coefficient against average contact pressure for the ball radius \( r = 7 \) mm and concentrations of SiO\(_2\) nanoparticles in the lithium grease of 2, 4, 6, 8 and 10wt.\%.
Figure 3. Plot of the values of the friction coefficient against an average contact pressure for the ball radius $r = 7 \text{ mm}$ and concentrations of SiO$_2$ nanoparticles in the lithium grease of 2, 4, 6, 8 and 10wt.%.

Figure 4. Plot of the values of the friction coefficient against an average contact pressure for the ball radius $r = 4 \text{ mm}$ and concentrations of the SiO$_2$ nanoparticles in the lithium grease of 2, 4, 6, 8 and 10wt.%.

4. Summary
The value of the friction coefficient value decreased with the increase of an average contact pressure for the pure lithium grease used as lubricant. The addition of SiO$_2$ nanoparticles had a different effect depending on the SiO$_2$ nanoparticle concentration $\varepsilon$ in the lithium grease and on the range of the value of the contact pressure. For the case of $\varepsilon = 6\text{wt.}\%$, the value of the friction coefficient decreased and for the other SiO$_2$ concentrations it increased with the increase of the value of the contact pressure. If the values of the contact pressure $p_{\text{aver}}$ were below 550 MPa, the values of the friction coefficient for pure lithium grease were higher than those for lithium grease with admixture of SiO$_2$ nanoparticles. For higher values of the contact pressure $p_{\text{aver}}$, the values of the friction coefficient values for pure lithium grease could be lower or higher than those for lithium grease with admixture of SiO$_2$ nanoparticles depending on the concentration of the latter. This result is in agreement with the results reported in [22].

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