STLE 70th Annual Meeting & Exhibition
Dallas, USA, May 17 – 21, 2015

Effect of Nanoparticles on the Running-in Behavior in Lubricated Point Contact

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INTRODUCTION

Experimental and numerical studies on material properties has been conducted at different length scales of continuum [1], meso [2-4], and nano [5-6]. Nanoscience has been impacted many disciplines. In the case of tribology, the properties of lubricants has been highly improved by adding the nanoparticles [7-8]. In the current work, the anti-wear behavior of lubricants with Nano-particles copper oxide (CuO) and zinc oxide (ZnO) during running-in period is experimentally studied. The experiments are performed using a pin-on-disk test rig. The selected variables are type and quantity of nanoparticles. Running-in distance (L_r), initial friction coefficient (μ_0), steady-state friction coefficient (μ_s) and disks' weight loss (WL) are measured in this study. The results illustrate that the nanoparticles improve the tribological properties. The results show that Oil No. 10 (1 wt% CuO and 0.5% ZnO) has generally the best performance compared to the other lubricants which reduces the initial friction coefficient, steady-state friction coefficient, and weight loss up to 16%, 23%, and %60, respectively.

Results and discussions

During running-in, the friction coefficient and roughness profile of contacting elements experience changes as a result of asperities deformation and wear. Thus, the operating conditions of running-in period play an important role in the steady-state performance of mechanical elements such as gears, cam-followers, and bearings [9]. First, an experimental study on the effect of operating conditions of the running-in period on the properties of a tribe system in the presence of basic SAE 10W30 is conducted. The experiments are performed using a pin-on-disk test rig and the disk is made of ST37 steel. The selected variables are load, speed, and surface roughness and properties such as running-in distance, friction coefficient changes, and weight loss are measured as the outputs. Then using the least-square method, separate curve fits are developed to relate these parameters to load, velocity, and surface roughness.

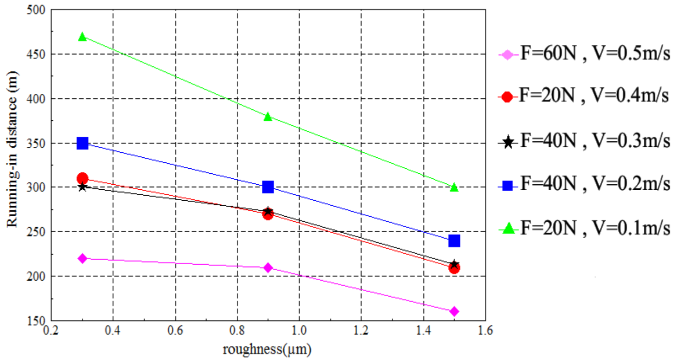


Fig.1. Running-in distance versus surface roughness.

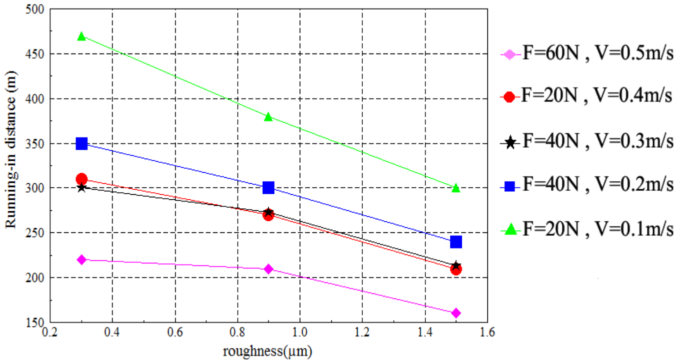


Fig. 2. Running-in distance versus relative velocity.

To have a better understanding of the effects of each parameter, it is better to formulate the results. Here, the least square method is incorporated [10]. A primary function is first assumed. Next, the constants are determined using Eqs. (1) and (2) as follows:

$$[A] = (\mathrm{X}^T X)^{-1}\mathrm{X}^T\mathrm{Y} \tag{1}$$

$$ln(\mathrm{Y}) = \mathrm{a}_0 + \mathrm{a}_1 ln(\mathrm{F}) + \mathrm{a}_1 ln(\mathrm{R}_a) + \mathrm{a}_1 ln(\mathrm{V}) \tag{2}$$

where F is normal load, R_a is surface roughness, and V is relative velocity between two surfaces in contact. Also, X and Y are defined as below:

$$\mathrm{X} = \begin{bmatrix} 1 & ln(\mathrm{F}_1) & ln(\mathrm{R}_{a1}) & ln(\mathrm{V}_1) \\ 1 & ln(\mathrm{F}_2) & ln(\mathrm{R}_{a2}) & ln(\mathrm{V}_2) \\ \vdots & \vdots & \vdots & \vdots \\ 1 & ln(\mathrm{F}_n) & ln(\mathrm{R}_{an}) & ln(\mathrm{V}_n) \end{bmatrix}, \mathrm{Y}_1 = \begin{bmatrix} \mathrm{L}_{r1} \\ \vdots \\ \mathrm{L}_{rn} \end{bmatrix}, \mathrm{Y}_2 = \begin{bmatrix} \mu_{s1} \\ \vdots \\ \mu_{sn} \end{bmatrix}, \mathrm{Y}_3 = \begin{bmatrix} \mathrm{WL}_1 \\ \vdots \\ \mathrm{WL}_n \end{bmatrix}, \mathrm{n} = 39 \tag{3}$$

Figs. 1 and 2 present the variation of running-in distance versus roughness and velocity, respectively, for various values of loading. Using Eqs. (1)-(3), the running-in distance is described as a function of F, R_q, and V as follows:

$$\begin{gathered} ln(\mathrm{L_r}) = 5.82 - 0.193ln(\mathrm{F}) - 0.213ln(\mathrm{R}_a) - 0.292ln(\mathrm{V}) \\ \mathrm{L_r} = 337.23(\mathrm{F}^{-0.193})(\mathrm{R}_a^{-0.213})(V^{-0.292}) \end{gathered} \tag{3}$$

Fig. 1 shows that the effect of surface roughness on the running-in distance L_r is linear, and surprisingly L_r decreases as the roughness increases. Here, it is assumed that wear in first phase of contact would be more effective due to the fact that the primary friction is massively larger in surfaces with bigger roughness.

Initial friction coefficient μ_0 is only a function of surface roughness. However, Fig. 3 shows that the steady-state friction coefficient (μ_s) is a function of velocity V, roughness R_a, and normal load F. The relation function is obtained using the least square method as follows:

$$\begin{gathered} ln(\mu_s) = -2.154 - 0.014ln(\mathrm{F}) + 0.023ln(\mathrm{R}_a) - 0.108ln(\mathrm{V}) \\ \mu_s = 0.116(\mathrm{F}^{-0.014})(\mathrm{R}_a^{0.023})(V^{-0.108}) \end{gathered} \tag{4}$$

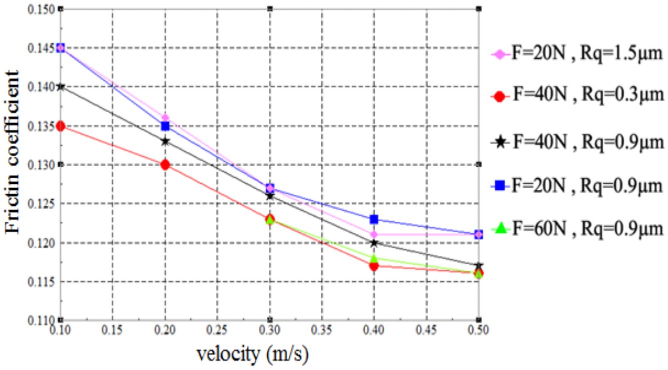


Fig.3. Steady-state friction coefficient versus relative velocity.

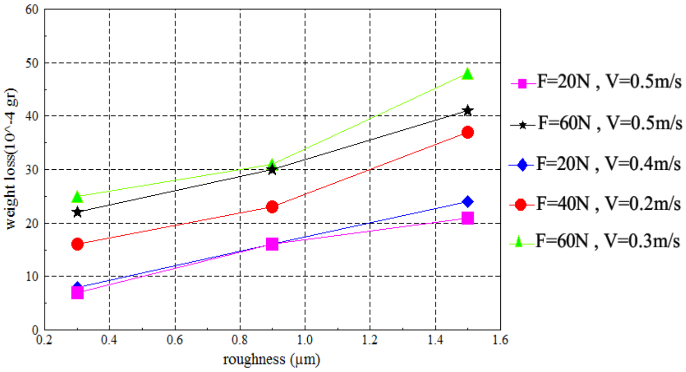


Fig. 4. Weight lost versus surface roughness.

Fig. 4 presents the effect of surface roughness on weight loss. The relation between the weight loss and other parameters is obtained using the least square method as follows:

$$\begin{gathered} ln(\mathrm{WL}) = 0.76 + 0.631ln(\mathrm{F}) + 0.528ln(\mathrm{R}_a) - 0.196ln(\mathrm{V}) \\ \mathrm{WL} = 2.145(\mathrm{F}^{0.631})(\mathrm{R}_a^{0.528})(V^{-0.196}) \end{gathered} \tag{5}$$

Now, the effects of nanoparticles on running-in behavior of contacted surfaces is studied by adding the nanoparticles to the to basic 10W30 oil. The characteristics of the utilized nanoparticles are presented in Tables 1 and 2. Twelve different lubricants have been used in the experiment with the same basic oil (10W30) but variuos percentage of nanoparticles which is presented in Table 3.

Table 1. Characteristics of ZnO

Color	White
Morphology	Elongated
Specific surface area (SSA)	35-50 M2/G
Average particle size	20-30 NM
Pore volume	0.115 CM3/G
True density	5.6 G/CC
Average pore size	127.86
Purity (content of Zno)	+99%

Table 2. Characteristics of CuO

Color	Black
Morphology	Elongated
Specific surface area (SSA)	35-50 M2/G
Average particle size	15-25 NM
Pore volume	0.055 CM3/G
True density	1.1 G/CC
Average pore size	105.82
Purity (content of Zno)	+99%

The nanoparticles are stabilized in the oil using the mechanical methods in three steps. First, the oil and nanoparticles are mixed for 15 minutes at 4040 ℃ degree of centigrade temperature using mechanical mixer. Next, the suspension is mixed using magnetic mixer. Now, the suspension looks like a solution, however, after about 10 minutes, some instability was observed. Finally, an ultrasonic mixer is used to mix the solution. Ultrasonic waves breaks down bigger particles into smaller ones, and prevent them from joining together again. Fig. 5 shows that the oil viscosity decreases as the mixing time increases. It is due to the fact that as the particle becomes smaller, the friction between particles decreases which decreases the viscosity.

Table 3. Nano lubricant formulation.

Lubricant Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
ZnO%	-	0.5	1	1.5	-	-	-	0.5	1	0.5	1	1.5	0.5
CuO%	-	-	-	-	0.5	1	1.5	0.5	0.5	1	1	0.5	1.5

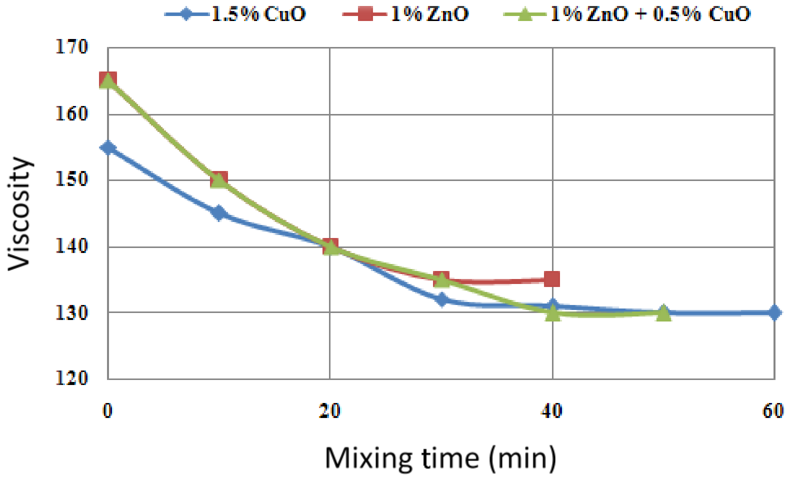
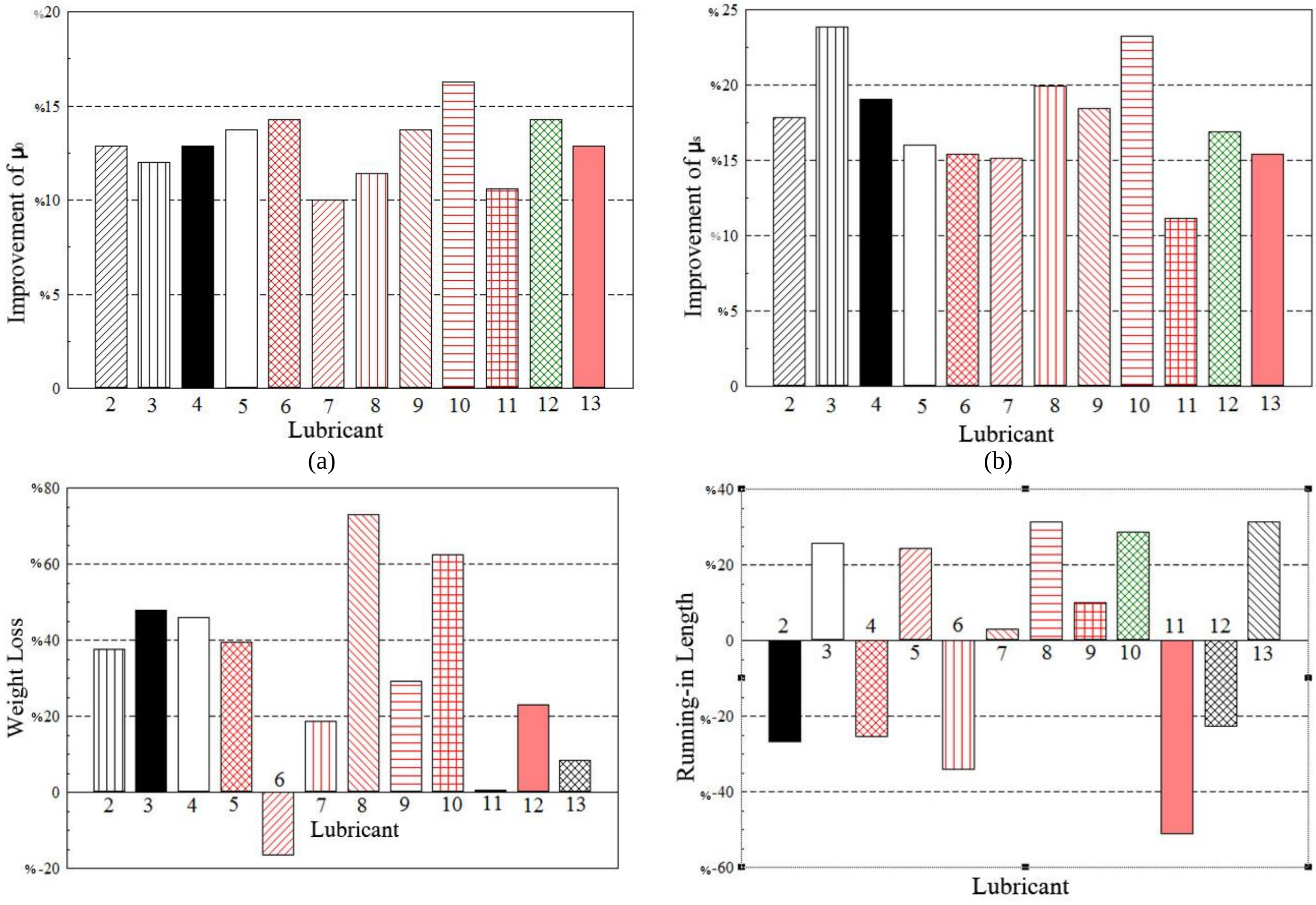


Fig. 5. Variation of viscosity as a function of mixing time.

Fig. 6 shows the effects of different lubricants, which are presented in Table 3, on the initial friction coefficient (μ_0), steady-state friction coefficient (μ_s), weight loss (WL), and running-in length (L_r). The results show that Oil No. 10 (1 wt% CuO and 0.5% ZnO) has generally the best performance compared to the other lubricants which reduces the initial friction coefficient, steady-state friction coefficient, and weight loss up to 16%, 23%, and %60, respectively.

Conclusion

In the current work, several experiments are conducted to investigate the effects of running-in operating conditions such as normal load, relative velocity, and surface roughness on the running-in distance, weight loss, and initial and steady-state friction coefficients. A pin-on-disk test rig is utilized in the presence of lubricant under the mixed lubrication regime. A number of curve fits are developed using the least square method. The obtained equations relate the running-in distance, weight loss, initial friction coefficient, and steady-state friction coefficient to the running-in operating conditions. It is shown that the higher the running-in velocity leads to the greater film protection and the smaller weight loss. Also, the running-in will last longer. Increasing the normal load results in more asperity-asperity contacts and hence the weight loss increases. It is shown that under constant velocity and roughness, increasing the applied load results in the decrease of the running-in length by about 13%. Doubling the speed with keeping the load and roughness constant results in 19% decrease in the running-in length. Next, CuO and ZnO nanoparticles are added to the lubricant with the objective of reducing wear quantity in Running-in period. The results indicate that the Nano lubricant with 1% wt. zinc oxide and 0.5% copper oxide has generally the best performance which reduces the initial friction coefficient, steady-state friction coefficient, and weight loss up to 16%, 23%, and %60, respectively.



(a) (b)

(c) (d)

Fig. 6. Effects of different lubricants on (a) initial friction coefficient μ_0 (b) steady-state friction coefficient μ_s (c) weight loss (d) running-in length.

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KEYWORDS

Wear, Running-in, Pin-on-disk, Least square method, Modeling, Nanolubricant