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Coefficient of friction and wear rate effects of different composite nanolubricant concentrations on Aluminium 2024 plate

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Abstract. Wear of sliding parts and operational machine consistency enhancement can be avoided with good lubrication. Lubrication reduce wear between two contacting and sliding surfaces and decrease the frictional power losses in compressor. The coefficient of friction and wear rate effects study were carried out to measure the friction and anti-wear abilities of Al_2O_3-SiO_2 composite nanolubricants a new type of compressor lubricant to enhanced the compressor performances. The tribology test rig employing reciprocating test conditions to replicate a piston ring contact in the compressor was used to measure the coefficient of friction and wear rate. Coefficient of friction and wear rate effects of different Al_2O_3-SiO_2/PAG composite nanolubricants of Aluminium 2024 plate for 10-kg load at different speed were investigated. Al_2O_3 and SiO_2 nanoparticles were dispersed in the Polyalkylene Glycol (PAG 46) lubricant using two-steps method of preparation. The result shows that the coefficient friction and wear rate of composite nanolubricants decreased compared to pure lubricant. The maximum reduction achievement for friction of coefficient and wear rate by Al_2O_3-SiO_2 composite nanolubricants by 4.78% and 12.96% with 0.06% volume concentration. Therefore, 0.06% volume concentration is selected as the most enhanced composite nanolubricants with effective coefficient of friction and wear rate reduction compared to other volume concentrations. Thus, it is recommended to be used as the compressor lubrication to enhanced compressor performances.

1. Introduction

For mechanical machines, lubrication is important to avoid wear of sliding parts and operational machine consistency enhancement. Failure due to surface wear at the sliding boundary is the commonly problem arise for mechanical systems with sliding contacts [1]. Lubrication reduce wear between two contacting and sliding surfaces and decrease the frictional power losses in compressor and avoid rust and corrosion [2]. Frequent usage of the systems without proper lubrication cause increment in wear rate and coefficient of performance (COP) on the system. Tribological behaviour mainly refer to coefficient of friction (COF) and wear rate plays an important role to identify the tribological performance of nanolubricant additives. Encouragement to this problem, different properties lubrications are studied to be utilised in many applications especially in transportation, heavy industries, energy generation and refrigeration system.

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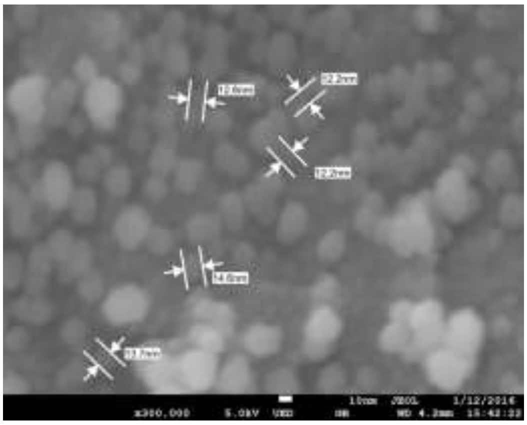
From literature, a few scientists focused on in enhancing lubricant properties for the energy efficiency increment. Recent development in increasing efficiency of lubricant is by dispersing nanoparticle in lubricant base and most well known as nanolubricant. Tribological performance can be further improve when nanolubricant are used as additives in automotive engines [2] through protective film formation and a rolling effects friction surfaces [3, 4]. Nanolubricants has benefits in reducing the friction of coefficient and wear rate [5]. Nanoparticles dispersed in mineral oils has effective effects in reducing wear and enhancing load carrying capacity [6]. Friction controlled through nanolubricants usage reduced wear [2]. Thus, this behaviour helps in reducing maintenance cost and improve the compressor performance.

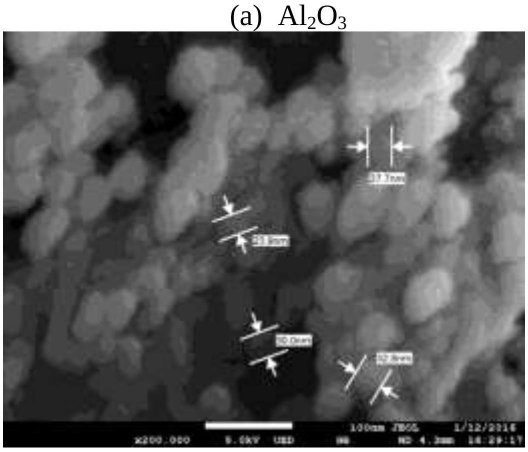
Tribological properties of piston ring in a compressor using Al_2O_3-SiO_2/PAG composite nanoparticles as nanolubricant additives have been studied in this recent work. The coefficient of friction and wear rate effects study were carried out to measure the friction and anti-wear abilities of Al_2O_3-SiO_2 composite nanolubricants. The properties were investigated using three different speeds with a 10 kg load. Optimum composite nanolubricant volume concentration is suggested for further investigations.

2. Materials

In preparation of composite nanolubricants, different metal oxides nanoparticles namely Al_2O_3 and SiO_2 are used. Al_2O_3 (99.8% purity) with 13 nm in size and SiO_2 (99.5% purity) with 30 nm in size. These nanoparticles are procured from Sigma-Aldrich. The properties of the nanoparticles are given in Table 1**.** The characterizations of these nanoparticles are obtained by the field emission scanning electron microscopy (FESEM) technique. The images of FESEM are shown in Figure 1. PAG 46 lubricant properties at the atmospheric pressure is given in Table 2.



(a) Al_2O_3



(b) SiO_2

Figure 1. FESEM analysis nanoparticles [7].

Table 1. Properties Al_2O_3 and SiO_2 nanoparticles [8-10].

Properties	**Al_2O_3**	**SiO_2**
Molecular mass, g mol^{-1}	101.96	60.08
Average Particle diameter, nm	13	30
Density, kg m^{-3}	4000	2220
Thermal Conductivity, W m^{-1} k^{-1}	40	1.4
Specific heat, J kg^{-1} K^{-1}	773	745

Table 2. Properties of polyalkylene glycol (PAG 46) [11, 12].

Properties	**PAG 46**
Density, g.cm^{-3}@ 20.0°C	0.9954
Flash Point, °C	174
Kinematic viscosity, cSt @ 40°C	41.4-50.6
Pour Point, °C	-51

A Sanden SD 7H10 piston type compressor is used in the investigation [13]. Prior the tribology test, Positive Material Identification (PMI) method is done on the compressor cylinder wall to identify the wall's material. Further examination on hardness and surface roughness are done consequently. Table 3 shows the result of the investigations. Aluminium Al 2024 was used as sample plate in tribology investigation. Table 4 shows the properties of Al 2024.

Table 3. Compressor Cylinder Wall Properties.

Properties	Outcome
Material	Al 2024
Hardness (Rockwell B)	74.52
Surface roughness, Ra, (μm)	0.121

Table 4. Properties of Aluminium 2024 [14].

Properties	**Aluminium 2024**
Ultimate Tensile Strength, psi	70,000
Yield Strength, psi	50,000
Brinell Hardness	120
Rockwell Hardness	B75

3. Methodology

3.1. Composite nanolubricant characterization

The two-step method was used in the preparation of composite nanolubricant for 0.02 to 0.1% volume concentration. During first part of preparation, all nanolubricants used in the experiment; Al_2O_3/PAG nanolubricant and SiO_2/PAG nanolubricants were prepared separately. The volume concentrations of the composite nanolubricant were calculated using equation (1) [7, 9, 15].

$$\phi = \frac{m_p / \rho_p}{m_p / \rho_p + m_l / \rho_l} \times 100 \tag{1}$$

The composite nanolubricants were then mixed and homogenized together by a 50:50 mixture ratio for each volume concentration for two hours. The ultrasonic bath was used for stabilization and for the reduction of agglomerates size of the composite nanolubricant. Nanoparticles are unable to spread homogeneously without sonication in the base fluid [16]. Colloidal stability of the composite nanolubricant dispersions was then measured for each volume concentration using UV-Vis Spectrophotometer (with wavelength accuracy of ±1 nm) within wavelength range 190 to 1800 nm at room temperature. This step is important to measure stability of composite nanolubricants as it is possible that agglomeration of nanoparticles would occur causing damage to the sliding surfaces [2]. Dispersion stability of the composite nanolubricant was visually observed after preparation and after 14 days.

3.2. Test rig description

The tribology test rig bench was designed to imitate the lubricated reciprocating sliding motion of the piston ring interface of compressor. Figure 3 illustrates the piston ring assembly of designated tribology test rig bench. The test was conducted in according to ASTM G181-11 [17] standard. Coefficient of friction performance and specific wear rate for composite nanolubricant were evaluated using test rig. Tribology test was operated under a reciprocating movement which similar to the piston head operating in real condition and contact occurred when the attached piston ring around the piston head had a sliding contact with the cylinder wall. Material that were used for the ring segment is cast iron which is the common material for the piston ring. The main structural features of the test rig are shown in Figure 2.

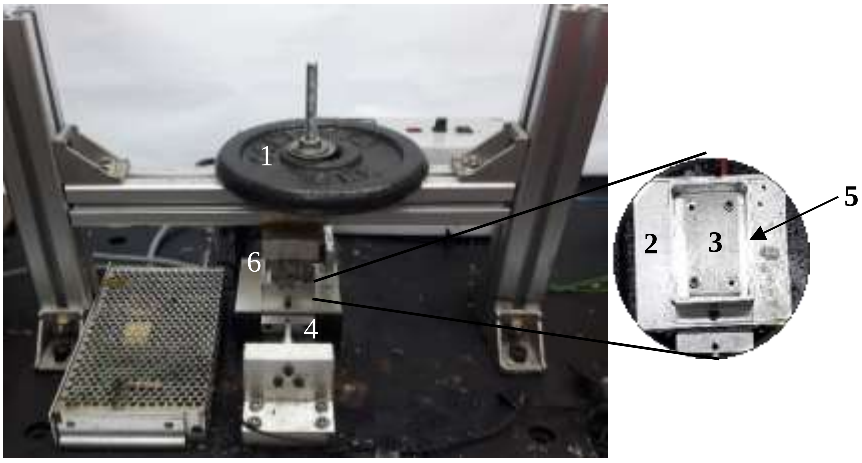


Figure 2. Tribology test rig bench. The main component of the test rig; 1- load, 2-holder, 3- specimen, 4- force sensor, 5- specimen bath, 6- ring segment.

Load was applied to the test rig by placing the load on the bearing lever above the specimen plate. A 10 kg load was chosen and the experiments were conducted for 5 minutes for each specimen with different speed ranging from 200 to 300 rpm. To generate larger friction in compressor, low speed intervals (200 rpm to 300 rpm) were used during testing [18]. A small amount of 7 ml composite nanolubricants was supplied between ring segment and specimen (in the specimen bath). The coefficient of friction was then measured and recorded using ARDUINO Software. Wear rate (k_i) was then calculated by calculating using the following equation (2):

$$k_i = \frac{V}{F_n S} \qquad (2)$$

where V is volume loss, and can be determine using equations (3) and (4) meanwhile F_n is the applied load on ring and S is the sliding distance.

$$V = \frac{1}{\rho}(\Delta W) \tag{3}$$

$$\Delta W = W_1 - W_2 \tag{4}$$

The tests were carried out at least three times under the same conditions in an effort to replicate experimental results then the average results were taken to minimize measurement error. Before tests were done, specimen surface polishing was done to minimize the surface roughness of the sample plates and to avoid unnecessary test rig vibration during test. Furthermore, surface polishing is important to imitate the real roughness of cylinder wall and piston head in the real AAC compressor system. Tribology properties such as friction of coefficient and the wear rate reflect the tribological performance of Al_2O_3-SiO_2 composite nanolubricant.

4. Results and discussion

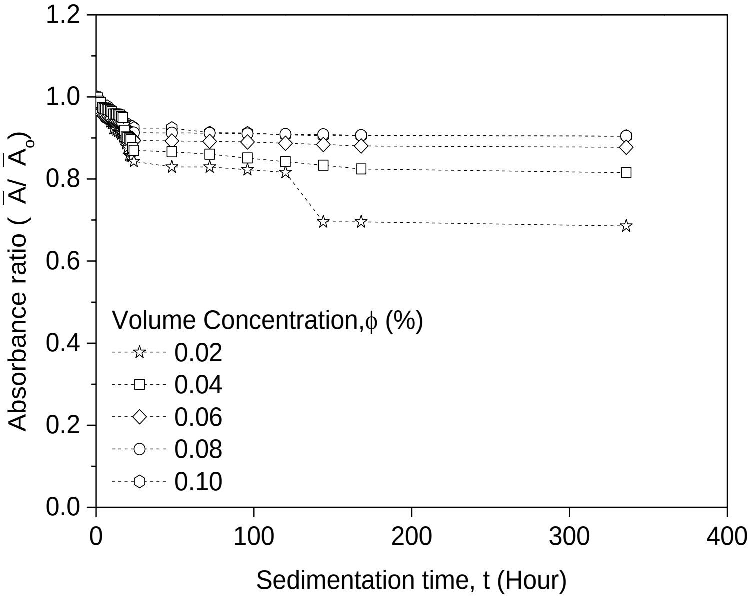
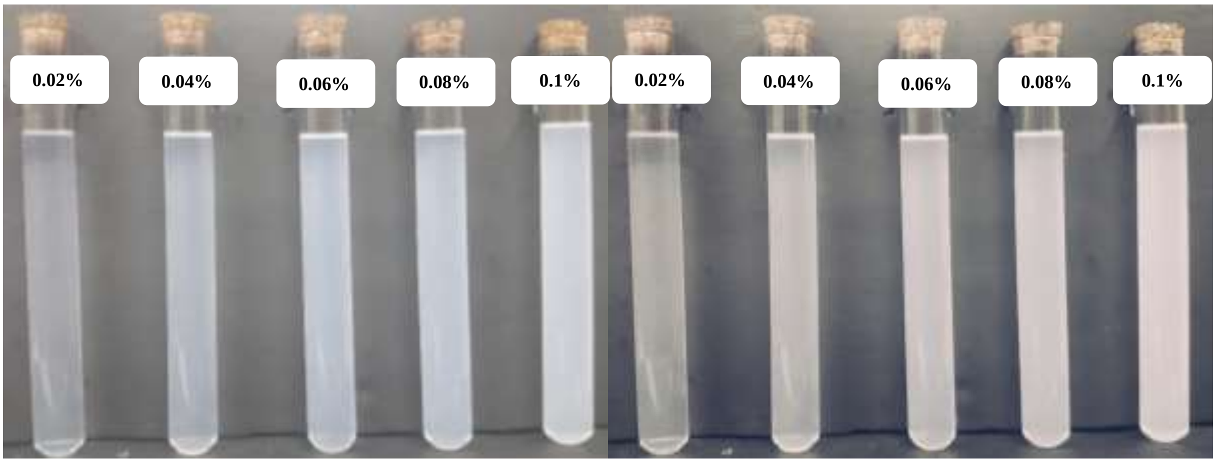


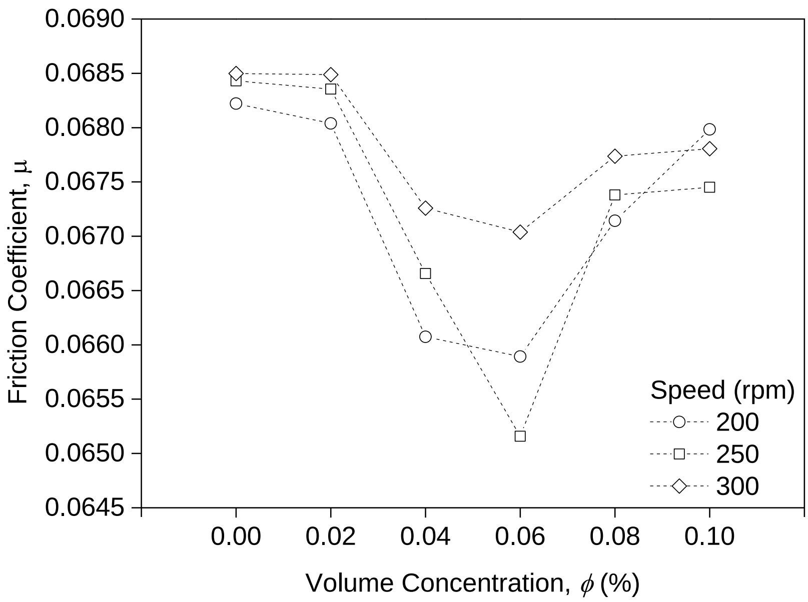
Figure 3. Absorbance ratio versus sedimentation time.

Figure 3 shows the absorbance ratio against sedimentation time for different volume concentration. The highest absorbance ratio represents the most stable nanolubricant. Absorbance ratio is observed to be more than 80% for all volume concentrations with exception of 0.02%. The 0.02% volume concentration absorbance ratio dropped to less than 80% and then maintained. Hence, it can be concluded Al_2O_3-SiO_2/PAG composite nanolubricant for all concentrations in this work were stable over a time period of 400 h sedimentation time. The dispersion stability of the composite nanolubricant was observed visually for all samples with conditions after preparation and fourteen days later. It was observed that no sedimentations occurred in the samples as shown in Figure 4**.** It should be noted that no surfactant was used in this preparation.

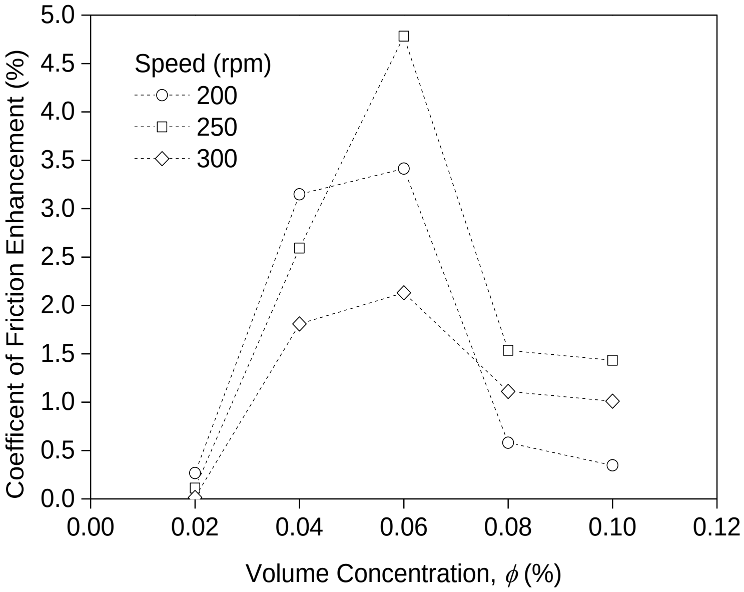


(a) After preparation (b) After 14 days

Figure 4. Composite nanolubricant (a) after preparation (b) after 14 days.



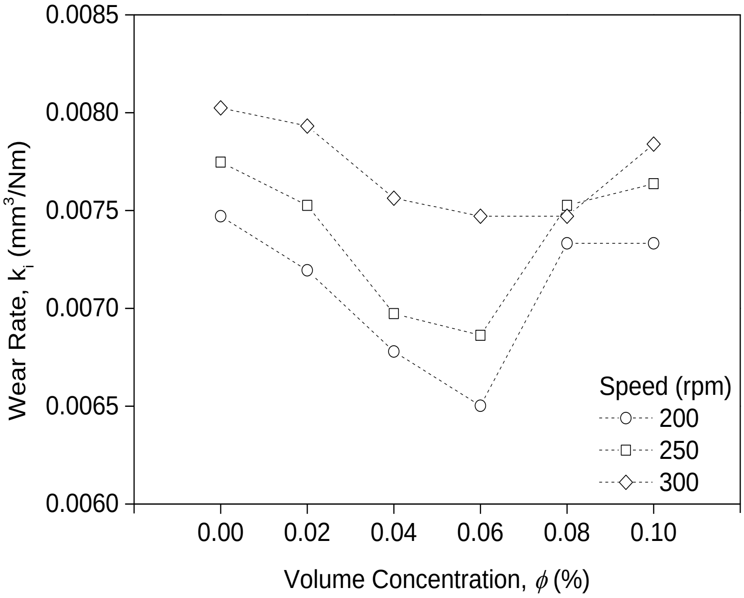
(a) Coefficient of friction vs volume concentration for 10 kg load.



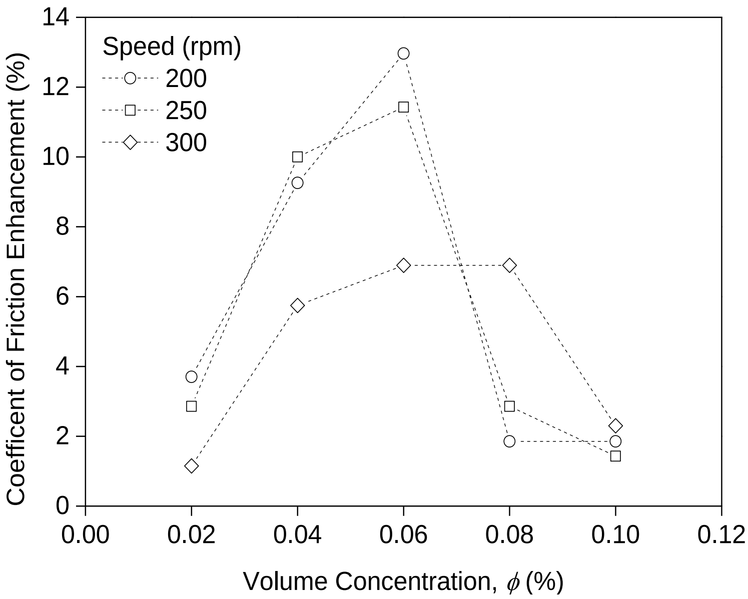
(b) Coefficient of friction enhancement.

Figure 5. Coefficient of fiction.

Figure 5(a) illustrates the effect of composite nanoparticles concentration on coefficient of friction for different speeds and a contact load of 10 kg. All volume concentrations of Al_2O_3-SiO_2 composite nanolubricants showed a decrement pattern in the coefficient of friction. Based on the obtained results, it was observed that the composite nanolubricants with 0.06% volume concentration of nanoparticles was the best sample out all nanolubricants investigated. All enhancement of coefficient of friction for all volume concentrations of Al_2O_3-SiO_2/PAG composite nanolubricant are shown in Figure 5(b). From Figure 5(b), the maximum reduction achievement for friction of coefficient by Al_2O_3-SiO_2/PAG composite nanolubricants by 4.78% with 0.06% volume concentration. Meanwhile, the lowest is recorded at 0.01% for 0.02% volume concentration. Based on the obtained results, 0.06% volume concentration is the most optimum concentration composite nanolubricant for reducing coefficient of friction. The friction coefficient was reduced due to nanoparticles mechanism [2]. This mechanism involves converting sliding into rolling friction. Beside that, tribo-films formation on the sliding surfaces enhanced the compressor efficiency.



(a) Wear rate vs volume concentration for 10 kg load.



(b) Wear rate enhancement.

Figure 6. Wear rate.

The effect of composite nanoparticles concentration on wear rate is illustrated in Figure 6(a) for different speeds and a contact load of 10-kg. All volume concentrations of Al_2O_3-SiO_2 composite nanolubricants show a decrement pattern in the coefficient of friction. Figure 6(b) shows the enhancement of wear rate for all volume concentrations of Al_2O_3-SiO_2/PAG composite nanolubricant. From Figure 6(b), the maximum reduction achievement for wear rate by Al_2O_3-SiO_2 composite nanolubricants by 12.96% with 0.06% volume concentration. Meanwhile, the lowest is recorded at 1.15% for 0.02% volume concentration. Based on the obtained results, 0.06% volume concentration is the most optimum concentration composite nanolubricant for reducing wear rate. Ali et al [2] noted that optimum concentration of nanoparticle is a crucial parameter to investigate tribological performance as can negatively effect the performance because of the excess of nanoparticles.

5. Conclusions

Coefficient of friction and wear rate of composite nanolubricant were determined at 0.02 to 0.1% and various speed from 200 to 300 rpm with a 10 kg load. Al_2O_3-SiO_2/PAG composite nanolubricant with 0.06% volume concentration recorded the highest COF reduction of 4.78%. while, the maximum wear rate reduction of 12.96% recorded with the same 0.06% volume concentration sample. The present composite nanolubricant was intended to be tested in automotive air conditioning systems that use compressors and lubricated by polyalkylene glycol (PAG). Therefore, it is recommended to use the Al_2O_3-SiO_2/PAG composite nanolubricants with volume concentrations of 0.06% for application in refrigeration systems as it yields higher enhancement in coefficient of friction and wear rate which were important in tribological performance. Further investigations on the tribological performance using the Al_2O_3-SiO_2/PAG composite nanolubricants are required to extend the present work.

Acknowledgment

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