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Tribological characteristics of SCM 440 bearing steel under gas and oil lubricant in the cylinder block tractor engine

Okka Adiyanto, Pandu Sandi Pratama, Wonsik Choi,

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Okka Adiyanto
Department of Industrial Engineering, Ahmad Dahlan University, Yogyakarta, Indonesia
Pandu Sandi Pratama
Life and Industry Convergence Research Institute, Pusan National University, Miryang, Republic of Korea, and
Wonsik Choi
Department of Bio Industrial Machinery Engineering, Pusan National University, Miryang, Republic of Korea

Abstract

Purpose – This paper aims to examine the friction coefficient and wear rate characteristics of SCM 440 bearing steel used in the cylinder block of a tractor engine with gas lubrication and oil lubrication.

Design/methodology/approach – Friction tests were performed using a pin-on-disc tester with loads of 2 to 10 N and sliding velocities of 0.06 to 0.34 m/s. The experiment was done with and without nitrogen, and paraffin oil lubricant was used to prevent wear during process.

Findings – The nondimensional characteristic number from the Stribeck curves indicated that the lubrication regime is hydrodynamic. As the velocity and load increased, the friction coefficient of the SCM 440 increased and greater applied load resulted in a smaller friction coefficient. The range of the friction coefficient was 0.017001 to 0.092904 with paraffin oil lubrication and 0.01614 to 0.4555 with nitrogen lubrication. Nitrogen is effective in reducing the friction coefficient of materials that are in contact and subjected to a load and velocity.

Originality/value – The experiments confirm that nitrogen is effective for reducing the friction coefficient of SCM 440 materials that are in contact with each other and subjected to a load and velocity.

Keywords Tribology, Wear, Friction, Nitrogen, Paraffin, SCM 440

Paper type Research paper

1. Introduction

Tribology is the science and technology of interacting surfaces in relative motion and focuses on friction, wear and lubrication (Stachowiak and Batchelor, 2013). Tribology is applied to engineering and bioscience and some applications include fluid film bearings, rolling element bearings, seals, gears (Li *et al.*, 2016), cams, viscous dampers, human joints and magnetic storage devices (Tichy and Meyer, 2000). Friction is a typical nonequilibrium process, and sliding often leads to wear that is highly stochastic. The reported friction coefficients and wear rates typically show wide variation, even for nominally identical tests, and the origin of these variations is often not known (Novak and Polcar, 2014).

In most cases, the relationship between friction and lubrication is characterized based on oil viscosity, sliding velocity and normal load (Wakuri *et al.*, 1988). Lubrication can reduce wear of one or both surfaces that are in close proximity and moving relative to each other. Lubricants can be categorized as solid lubricants, gas lubricants and liquid lubricants (Kalam *et al.*, 2012). The gas lubrication was used in special application such as bearing lubricant in coolant motor was introduced by Ford *et al.* (1956) and its dynamic characteristics was studied by Jia *et al.* (2017). A tractor diesel engine has a cast iron cylinder head, which is integrated with an inlet manifold. Lubricant can be used to prevent wear on the cylinder head and piston.

The tribological characteristics of piston rings in engine was investigates by Qin *et al.* (2017). Recently, the friction behavior of CNx coated Si_3N_4 disk sliding against CNx coated Si_3N_4 ball in the N_2, Ar and O_2 gas was studied (Wang and Adachi, 2014). In the nitrogen condition, the friction coefficient decreases to 0.01 at the end of the given number of sliding cycles (Tokoroyama and Umehara, 2007). They reported a superflow friction coefficient lower than 0.01 without a lubricant which had been obtained when amorphous CNx coating slid against a Si_3N_4 ball after several 10-10^3 cycles in nitrogen gas. Nitrogen gas is important for thermochemical surface treatments used to improve wear and corrosion resistance and the fatigue endurance of steel parts (Pye, 2003). This study examines paraffin oil and nitrogen gas for lubrication in the SCM 440 bearing steel material. Paraffin oil both with and without

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additives has been used as a liquid lubricant (Maru and Tanaka, 2007).

2. Experimental

2.1 Specimens and lubricants

Pin and disc samples were made of SCM 440 carbon steel. 4140 is the SAE-AISI designation for this material, 1.7225 is the EN numeric designation and G41400 is the UNS number. Figure 1 gives a schematic of the pin and disc. Test samples are prepared as per ASTM standards. SCM440 round rods are taken and cut in to cylinders of required lengths as per ASTM standards. The sample pieces are thoroughly cleaned to remove oil and dirt. The pin has a thickness of 1 mm and diameter of 4 mm, while the disc specimen is 60 mm in diameter and 5 mm in thickness. The faces are finished by removing the burr to maintain flat surface. To achieve the surface roughness less of 0.8 μm, the material was polished. The chemical composition and mechanical structure of the disc and pin are shown in Tables I and II.

2.2 Experiment conditions

Friction tests and wear measurements were conducted with a pin-on-disc tribometer, as shown in Figure 2. The tribometer is operated according to the ASTM G99-95a standards. The device consists of a rotating disc and a stationary pin that is placed under a specified load. The pin and disc were ultrasonically cleaned in acetone for 15 min and then put on the tribometer plate. The loads were varied to 2, 4, 6, 8 and 10 N, and the speed was varied to 0.06, 0.10, 0.14, 0.18, 0.22, 0.26, 0.30 and 0.34 m/s. The test conditions are shown in Figures 3 and 4. Friction tests were first done using only paraffin oil as in Figure 3 and then with nitrogen gas flow around the disc, as shown in Figure 4. The test conditions are shown in Table III.

Figure 1 Schematic of pin and disc specimens

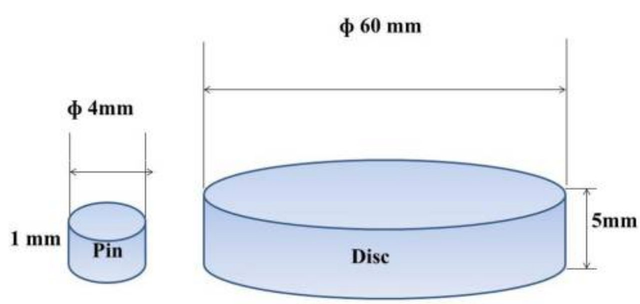


Figure 2 Tribometer schematic

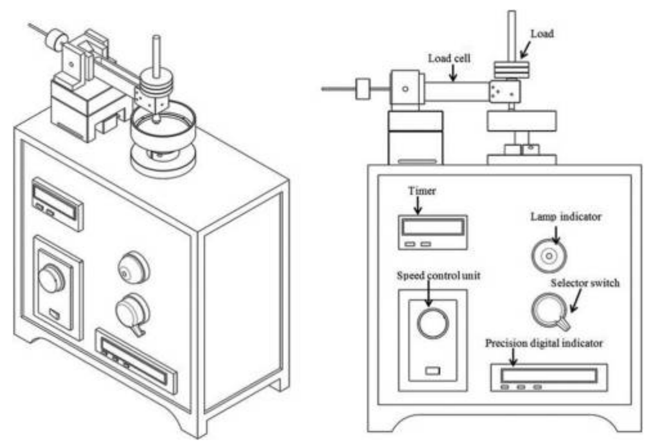
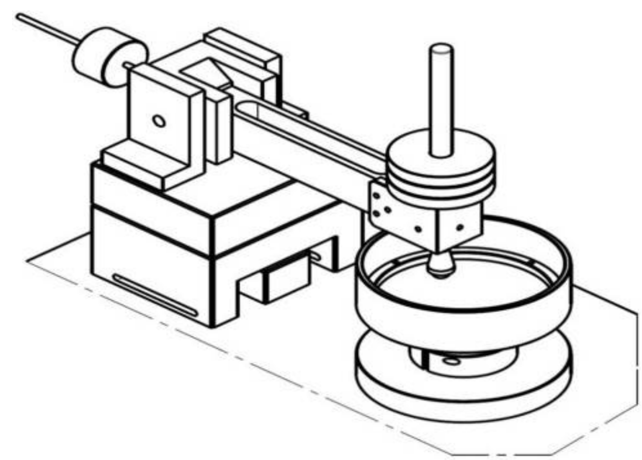


Figure 3 Friction test with paraffin lubricant



2.3 Friction test

Figure 5 shows a schematic of the force direction in the friction tests. Normal load (W) is applied on the pin and the disc is rotated at constant angular velocity (ω). The rotation result in friction between two surface contacts. The normal load exerted

Table I Chemical composition of SCM 440

Fe	Cr	Mn	C	Si	Mo	S	P
96.8-97.8	0.8-1.1	0.75-1	0.38-0.43	0.15-0.35	0.15-0.25	0-0.04	0-0.035

Table II Mechanical properties of the pin and disc

Element material	Tensile strength (kgf/mm^2)	Yield strength (kgf/mm^2)	Elongation	Hardness (HB)
SCM440	75	90	14%	255–321

Figure 4 Friction test with nitrogen lubricant

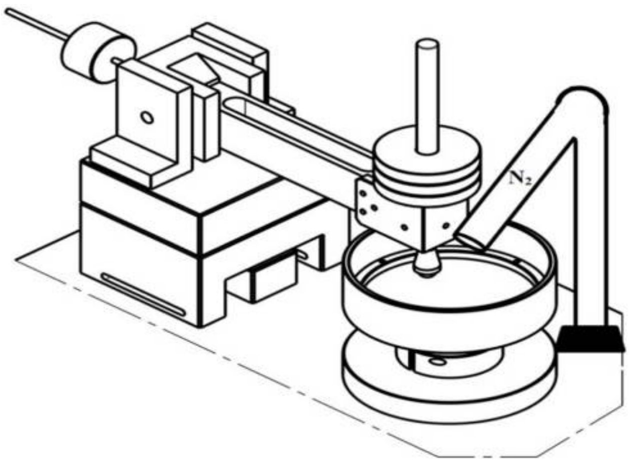
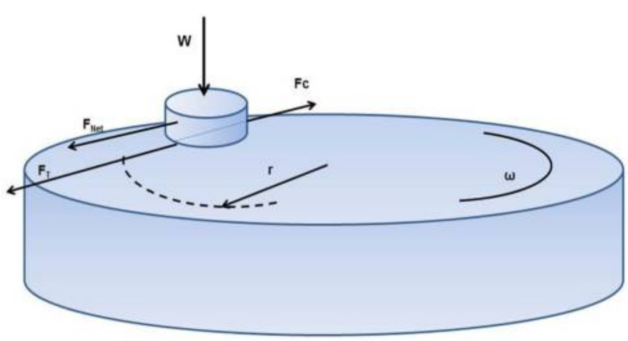


Table III Test conditions

Parameters	Conditions
Contact type	Pin-on-disk
Disk material	SCM 440 carbon steel
Pin material	SCM 440 carbon steel
Surface roughness	0.008 Ra,
Pin (μm)	0.016 Ra
Surface roughness	0.039 Ra
Disk (μm)	0.052 Ra
Normal load range (N)	2, 4, 6, 8, 10
Pressure range (MPa)	0.25-2.05
Speed range (m/s)	0.06-0.34

Figure 5 Forces acting in the pin-on-disc test



on the pin surface has a specific distance, defined by (r) from the center of the disc. In Figure 5, the torque on the disc is notated as F_{app}. The value of F_{app} is equal to F_T. The static friction force F_C acts in the opposite direction. The difference between F_T and F_C is the net force F_{Net}. F_{Net} and the tangential force F_{tf} represent the dynamic friction force. The tangential force is equal to the net force:

$$F_T = F_{app} \tag{1}$$

$$F_C = \mu_s W \tag{2}$$

$$F_T - F_C = F_{Net} \tag{3}$$

$$F_{Net} = \mu_d W \tag{4}$$

$$F_{Net} = F_{tf} \tag{5}$$

$$\mu = \frac{F_{tf}}{W} \tag{6}$$

2.4 Wear tests

Wear analysis was conducted with a tribometer with conditions similar to those in friction analysis. However, in the wear analysis, we must measure the weight from the pin before and after tests. In the experiment, the pin and disc rotate and slide for 10 min, and then we measure the weight from the pin. The loads were varied to 2, 4, 6, 8 and 10 N, and the speed was varied to 0.22 and 0.34 m/s. The wear rate is estimated by the Archard equation. This equation is a simple model used to describe sliding wear and on the theory of asperity contact. The Archard equation was developed from physical conclusions that the volume of removed debris because of wear is proportional to the work done by friction forces. Q is the wear rate, K is the wear factor, F_N is the normal load, v is the sliding speed, and H is the hardness.

$$Q = K\frac{F_N v}{H} \tag{7}$$

3. Results and discussion

3.1 Comparative friction test of SCM 440 under paraffin oil and nitrogen gas lubricant

The typical trends of the friction coefficient under different conditions are summarized in Figures 6 and 7. Figure 7 gives an overview of the frictional behavior of the material with paraffin

Figure 6 Friction coefficient of load as a function of velocity with nitrogen

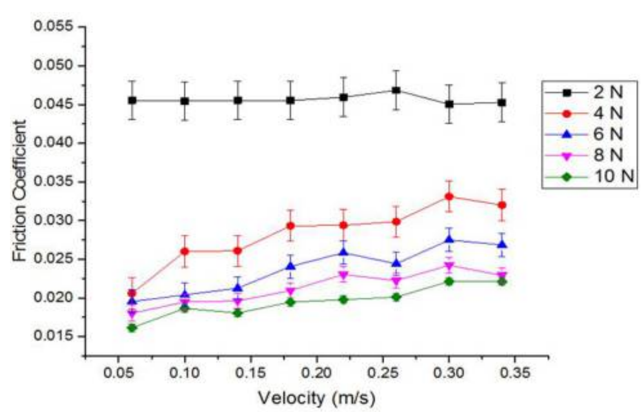


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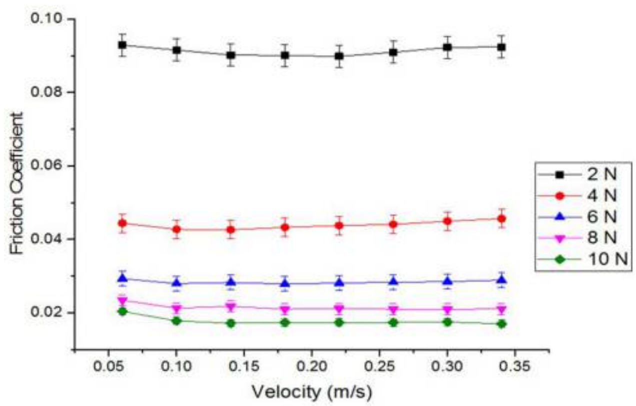
Figure 7 Friction coefficient of load as a function of velocity with paraffin oil



oil. The range of the friction coefficient with paraffin lubrication is 0.017001 to 0.092904.

The greater the applied load, the smaller the friction coefficient will be. The variation of the velocity significantly affects the friction coefficient. At higher velocity, the friction coefficient approaches a constant, and the lubrication approaches the hydrodynamic lubrication regime. The paraffin oil plays an important role in supporting the two surface contacts.

The friction coefficient curves with different loads obtained using nitrogen are shown in Figure 6. The run-in behaviors are similar to each other but significantly different from those without nitrogen. The range of the friction coefficient with nitrogen lubrication is 0.01614 to 0.4555. The friction coefficient with nitrogen is smaller than that without nitrogen. Thus, nitrogen is effective in reducing the friction coefficient of materials that are in contact and subjected to a load and velocity.

3.2 Wear behavior of the specimens

In this analysis, the only two speeds are 105 and 162 RPM (Figures 8 and 9), where the wear rate experiences instability. Loads will generate increasing wear rate. The speed will decrease if the applied load increases. This tendency occurs

Figure 8 Comparison of nitrogen and paraffin conditions at 105 RPM

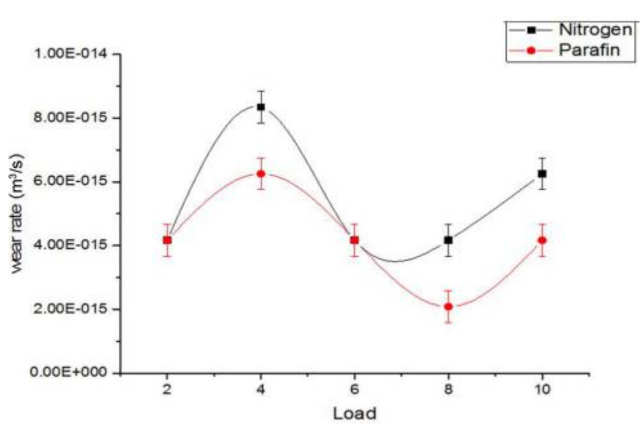
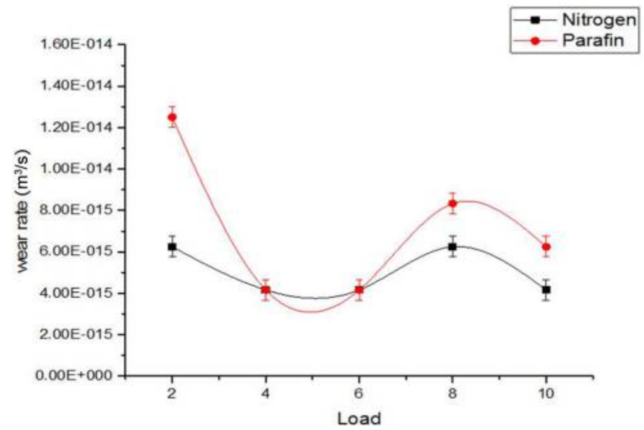


Figure 9 Comparison of nitrogen and paraffin conditions at 162 RPM



because the weight lost with each load and condition is not the same. Suppose at some loads that additional weight is lost. This causes the wear particles to stick to most surfaces.

The use of nitrogen shows a greater wear rate than that of paraffin as lubricant. During sliding, as the surface of the pin is deformed under the applied load, particles in the pin after sliding are out, leading to a decrease in the contact area between the pin and the disc. This apparently leads to a decrease in the weight loss of the pin.

3.3 Microstructure

The appearance of the SCM 440 surface is shown in Figures 10 and 11. The wear occurs as scratch patterns on the SCM 440 surfaces in the rotational direction. Scratches that were generated during testing using nitrogen appear sleeker than those generated without nitrogen. These results also suggest that the nitrogen is effective in reducing the scratches of materials that are in contact with each other.

Figure 10 Track left by tribometer on the workpiece surface under nitrogen

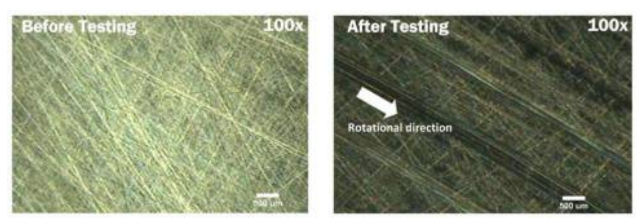
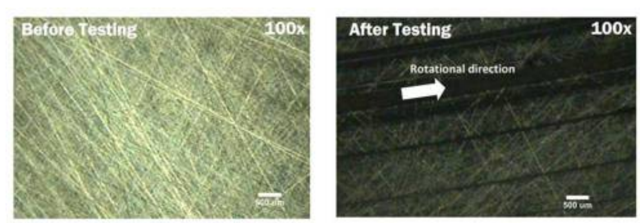


Figure 11 Track left by tribometer on the workpiece surface with paraffin



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Scanning electron microscopy images of the worn surface were obtained after the tests (Figures 12 and 13). In Figure 12, we can see the abrasively worn surface from the SCM 440 under nitrogen conditions. The surface shows a high concentration of debris and a thick track, which indicated high abrasive wear. The wear surface with paraffin oil has little damage compared to the other treatment (Figure 13). The wear sheet is the damaged surface layer created as debris from the wear process (specimen material and SCM 440 particle debris) eventually reattaches to the wear surface of the pin from the force and heat generated by the relative motion of the disc and pin specimen.

3.4 Stribeck curve

The Stribeck curve was used to study the state of lubrication. The curve distinguishes the lubrication status using the friction coefficient and a nondimensional number. It can be divided into three zones: boundary lubrication, mixed lubrication and hydrodynamic lubrication. The curve plays an important role in identifying these three regimes.

Figure 12 Scanning electron microscope image of SCM 440 under nitrogen lubrication

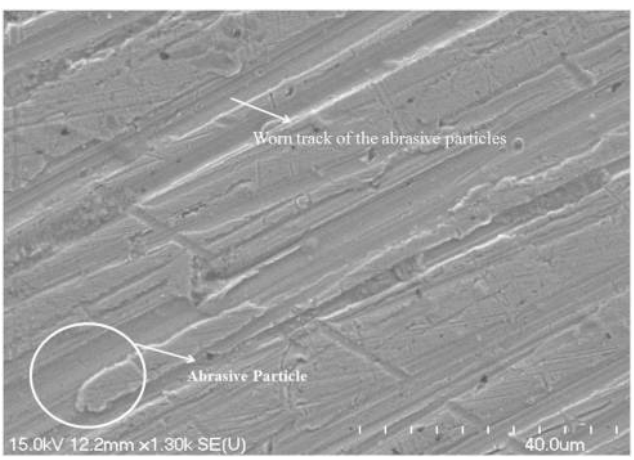


Figure 13 Scanning electron microscope image of SCM 440 under paraffin oil lubrication

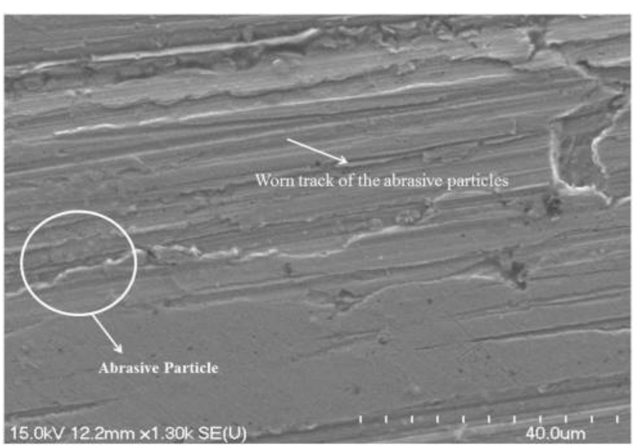


Figure 14 shows that the range of the friction coefficient without nitrogen is 0.01614 to 0.4555, and Figure 15 shows that the range with nitrogen is 0.017001 to 0.092904. The Stribeck curve for contact with fully wetted surfaces under nitrogen has smaller values than those without nitrogen, as shown in the figures. The characteristic number in the figures is a nondimensional number that indicates that the lubrication regime is hydrodynamic.

4. Conclusion

Friction tests were conducted on SCM 440 with different conditions. The results were as follows:

- As the velocity and load increased, the friction coefficient of SCM 440 increased and greater applied load resulted in a smaller friction coefficient. The range of the friction coefficient with paraffin oil lubrication was 0.017001 to 0.092904 and that with nitrogen lubrication was 0.01614 to 0.4555. Nitrogen is effective in reducing the friction coefficient of materials that are in contact and subjected to a load and velocity.
- In the wear analysis at 105 RPM and 162 RPM, nitrogen lubricant generated a greater wear rate than that with paraffin oil lubricant.
- The Stribeck curve was used to study the state of lubrication. The nondimensional characteristic number from the Stribeck curves indicated that the lubrication regime is hydrodynamic.
- The microstructures have scratches after friction processing under all conditions. The surface of SCM 440

Figure 14 Stribeck curve of SCM 440 under nitrogen lubrication

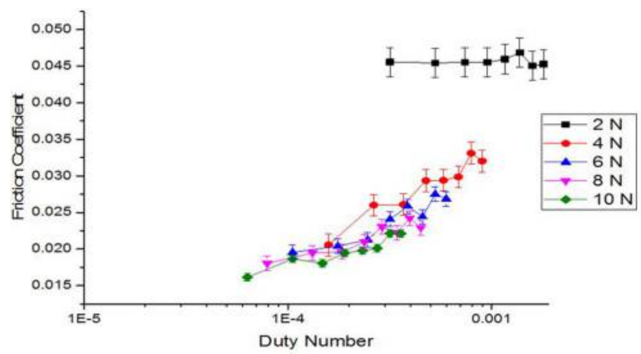
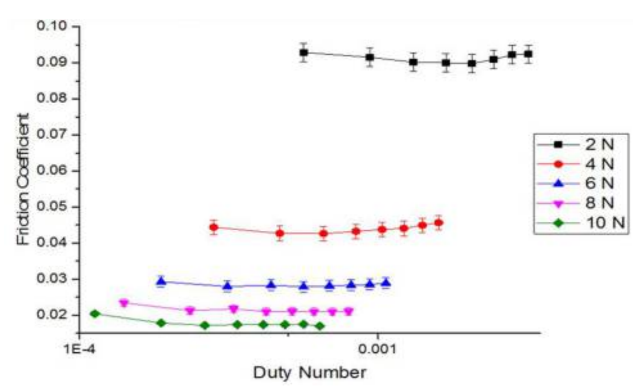


Figure 15 Stribeck curve of SCM 440 under paraffin oil lubrication



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Corresponding author

Okka Adiyanto can be contacted at: okka.adiyanto@ie.uad.ac.id