NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s4-010

Research Article

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Comparative Study and Analysis of Tribological Performance of Nano Powder Blended Bio-lubricants

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Received: September 15, 2023
Accepted: November 20, 2023
Published: November 23, 2023

Citation: Puvvada NLP, Ronanki P, Satuluri S. 2023. Comparative Study and Analysis of Tribological Performance of Nano Powder Blended Bio-lubricants. *NanoWorld J* 9(S4): S55-S61.

Published by United Scientific Group

Abstract

Many trials have been conducted to develop petroleum-based oil alternatives in response to oil reserves and the harm that excessive utilization of oil causes to the environment. Due to reduced pollutants and increased lubricating effectiveness, the use of vegetable-based lubricant has thus been thoroughly explored. The examined nanoparticles can be introduced to base lubricants as additives to provide the greatest tribological capabilities owing to their unique qualities, such as sphericalness and high surface area along with low environmental risk. Vegetable oils, due to their potentiality can be employed as a base stock for these lubricants when combined with the appropriate additives. Nano powders are mixed with vegetable oils like sunflower and soybean oils. Nano powder ZnO (zinc oxide) is added to vegetable oil to apply it as a lubricant. The tiny interactions between surfaces that come into mechanical contact and rub against one another are the determining factors for the frictional coefficient of friction (COF) and wear. The objective of the ongoing study is to investigate EN-8 steel's durability in the presence of nano lubricant. Speed, time, and load are among the input parameters that are variable. The study examined the wear and frictional qualities of an EN-8 steel disc using a pin-on-disk tribometer with varying loads ranging from 10 - 90 N and speeds ranging from 100 - 900 rpm over predetermined operation period. ZnO nanoparticles are synthesized with the precipitation process to achieve a particle size of 20 - 30 nm, and are then applied to EN-8 steel discs in the experiments utilizing aluminum, brass, and copper pins. The results are compared to those of another nano lubricant consisting of sunflower oil and aluminum oxide. The comparison shows that the soybean + ZnO is having less fluctuations in frictional force and wear when the copper pins are used under various input factors (load, time, and speed).

Keywords

Precipitation method, Nano lubricant, Wear, Frictional force, Coefficient of friction

Introduction

Tribology, which includes use of principles of friction, lubrication, and wear, is the engineering and scientific study of surfaces that interact in relative motion. It is crucial to the advancement of efficient energy technology at several levels, including manufacturing, enabling components to perform with extended life and minimal friction during usage, and making new, powerful engines and transmissions possible. The primary source of mechanical energy loss is friction, which can be decreased by lubrication using mineral oils. The emphasis has shifted from non-renewable to renewable because of non-biodegradability of mineral oils, mounting global lubricant consumption, and limited crude oil resources. Wear and friction issues are inherent in engineering applications and pose additional environmental hazards due to the increased use of fuel and debris. Using an oil base when combined with various additives is a method that will yield the best results from this process. Shafi et al. [1] found that due to the rising worldwide demand for lubricating oils and scarce crude oil supplies, people are exploring for using non-renewable to renewable oil sources.

The performance of lubricants can be enhanced by adding nanoparticles as additions. Metals, metal oxides, and sulfides are the most widely utilized nanoparticles. Various mechanisms have been observed for metallic particles like Ag, Au, Zn, Cu, Ni, Fe, ZrO_2, TiO_2, Fe_3O_4, Al_2O_3, ZnO, CuO, and sulfides like MoS_2, Cus, WS_2, and $NiMoO_2S$. It has also been revealed that the varied properties of nanoparticles, in addition to operational factors, control how effective lubricants are. They include particle size, morphology, agglomeration, and its concentration. Cermak et al. [2] and Erhan and Asadauskas [3] recognized the key problems connected using vegetable oils, including as oxidation stability and performance at low temperatures. Fatty acid chain of triglycerides can be adjusted or modified, and the oxidation resistance can be strengthened by dimerization, selective hydrogenation, the synthesis of oleic estolides, or the addition of chemicals that block the radical formation that causes oxidation. Alves et al. [4] dealt with the study of oxides of nanoparticles in vegetable oil related lubricants. In order to achieve severe pressure, ZnO and CuO nanoparticles are used as additions while investigating the effect of the oil basis on tribological behavior. The findings demonstrated that the tribological properties of conventional lubricants can be significantly enhanced by introducing nanoparticles. On that worn surface, a tribal film that is smoother and much more compact forms, which reduce frictional wear. Additionally, specially formulated oils from vegetable extracts are a better substitute for mineral oils in terms of its performance qualities. However, using vegetable-based lubricants in boundary lubricating situations with nanoparticles does not effectively reduce wear.

Gulzar et al. [5] have chemically synthesized palm oil combined of CuO and MoS_2 nanomaterial which showed improved anti-wear and perhaps even high-pressure characteristics. The investigation of AW/EP features plus sliding wear attributes of the formulations were assessed by using a four-ball tester. Scanning electron microscope (SEM), energy dispersion X-ray spectroscopy and micro-Raman have been explored for the analysis of worn surfaces. Indications are there for MoS_2 nanoparticles to be better AW/EP properties as compared to CuO nanoparticles. Incorporation of 1 wt.% oleic acid as a surfactant resulted in the decrease of nanoparticles agglomeration. Keshtiban et al. [6] SiO_2 nanoparticles at varying weight concentrations were utilized at a study to elevate the lubricating performance of vegetable-based lubricants. Standard compression tests and friction calibration curves were employed to set overall friction coefficient. According to experimental data, using SiO_2 nanoparticles to base lubricants significantly improved lubrication performance and minimized COF and surface roughness. Noorawzi and Samion [7] examined both wear, frictional attributes of double fractionated palm oil as lubricant using pin-on-disk Tribo-tester. SKD 11 (alloy tool steel) disc and aluminum pins are utilized to test hydraulic fluid and engine oil (SAE 40). The worn-out surfaces are analyzed using optical microscopy. From the results of the experiments, it is recognized that the degree of COF increased when the glide rate and load were high. It also shows that palm oil could be employed as a lubricant, which would be beneficial in significantly reducing world demand for petroleum-based lubricants.

Masjuk et al. [8] compared the wear, friction, viscosity, oil deterioration, and exhaust emissions of palm and mineral oil for which a reciprocating universal wear machine was used to evaluate wear and friction, accompanied by a 2-stroke gasoline Yamaha portable generator set, ET 950. The viscosity, TAN value, and oxidation level of post-bench test lubricating oils were examined using an ISL viscometer, a TAN/TBN analyzer, and FTIR spectroscopy, respectively. The experimental findings showed that perhaps the palm oil-based oil performed better when it comes to wear, but the mineral oil-based lubricating oil performed better in relation to friction. $AlCl_36H_2O$ and aluminum powder were used as raw materials in the low-cost precipitation method used by Hassanzadeh-Tabrizi and Taheri-Nassaj [9] to produce Al_2O_3 nano powder. The effect of the heat treatment on the crystallization and phase change of the precipitate is being investigated using XRD, thermogravimetry, TG-DTA, and FTIR techniques. According to the SEM findings, the particles' sizes range from 30 to 95 nm. Ghorbani et al. [10] have come up with a simple method of producing ZnO nanoparticles using zinc nitrate and potassium hydroxide in aqueous solution. The precipitated substance was calcined and examined by UV-Vis spectrometer, electron microscopy with dynamic light transmission and diffusion. The result of the distribution of particle sizes is done by technique DLS and its findings revealed that perhaps the particles are within the range of 30 ± 15 nm. Several processes to produce Al_2O_3 nanoparticles were investigated by Ziva et al. [11]. Because it is the easiest and simplest approach, precipitation has been the most effective way of producing Al_2O_3.

Less pollution occurs during production because it may be made using cheap raw materials. It has a lot of benefits over competing products because of its high purity, excellent thermal stability, nearly homogenous size distribution of the nanoparticles, and control over the size of the required particles. The process of precipitation to generate Al_2O_3 nanoparticles can be considered as an industrial prospect project to be made on a big scale economically, as per Kurniadianti et al. [12]. When compared to other manufacturing methods, the precipitation approach has a higher possibility of garnering consumer interest. According to Gholizadeh et al. [13] who synthesized pure-alumina nanoparticles using the co-precipitation approach, the results demonstrate that spherical alumina nanoparticles with average diameters in the range of 19 - 23 nm are formed with varied concentrations of precipitation agent. It was also demonstrated that the concentration did not have a significant effect on nanoparticle morphology. Ghanizadeh et al. [14] utilized precipitation and high thermal treatment techniques to synthesize and compared with alumina nanoparticles. According to Luo et al. [15], the use of modified Al_2O_3/TiO_2 nanocomposites significantly improved the lubricating oil's tribological performance. The anti-friction mechanism is based on the development of an impermeable layer over the worn surface and the transition of wear behavior from sliding friction to rolling friction during the friction process.

The present research attempts on the following: (1) Precipitation technique for the fabrication of ZnO nanoparticles, (2) Nano powders blended with vegetable oil to increase lubrication performance, and (3) Wear attributes of bearing materials such as aluminum, brass, and copper when nano lubricants are used.

Experimentation

Materials

- Method: Pin-on-disc configuration.
- Disc material: EN-8 steel.
- Pins material: Aluminum (pure); brass (pure), and copper (pure).
- Lubrication: Soybean oil + ZnO nano powder (20 - 30 nm) and sunflower oil + ZnO nano powder (20 - 30 nm).

Methodology

The pin-on-disc wear testing machine is easy to use and practical. This is employed for measuring COF as well as for wear testing. This equipment makes it easier to analyze the friction and wear characteristics in sliding situations under different settings. The stationary pin slides against the revolving disc. To suit the tests, we might change the standard load, rotating speed, and track diameter.

Materials for pin and disc samples are needed to be selected. In the current study three materials like copper, aluminum, and brass made as pins and are tested on EN-8 steel disc. The methodology adopted for the study is displayed in figure 1. The soybean oil is selected as bio-lubricant and metal oxide, ZnO is blended as additive to improve the performance of lubricating properties, in turn, be useful in the enhancement of tribological properties. Precipitation method has been used to process the metal oxide such as ZnO to the required particle size on average of 20 - 30 nm [10]. To avoid the agglomeration of particles, an electric stirrer has indeed been employed and stirring is done approximately for 5 h. The nano bio-lubricant is formed by taking 99% of soybean oil and 1% of ZnO nanoparticles. The combinations of process variables are framed by taking speed, load and time at five different levels. Minitab 16.0 software was employed to design L25 orthogonal array. To evaluate tribological characteristics including wear, frictional force, COF, experiments are conducted with these 25 combinations.

The current work attempts to investigate wear characteristics of EN-8 steel under the influence of nano lubricants taking the variable input parameters include speed, time, and load. Using aluminum, brass, and copper pins, variable weights of 10 to 90 N, rotating speeds of 100 to 900 rpm, and an EN-8 steel disc lubricated with nano bio-lubricants are used in a specific operation time. The specifications for the pin on the disk machine used are presented in table 1 and table 2.

Preparation of ZnO nanoparticles by precipitation method

First 50 ml each of ethanol and water is to be mixed to get 100 ml of the resultant solution. One set of 100 ml is taken in a conical flask and 8.78 g of zinc acetate is added to it. Another set of 100 ml is taken in beaker and 1.6 g of sodium hydroxide pallets are added to it. Now the sodium hydroxide is taken in burette and is titrated with zinc acetate solution at 1600 rpm by using magnetic stirrer. After titration, precipitate is formed which goes under centrifuge process with water, ethanol and again water to remove water from precipitate. Now the precipitate is kept in Incubator at 120 °C for 12 h and finally the precipitate is grinded to get the powder particles. The preparation of ZnO nano powders by precipitation method are shown in figure 2. Figure 3 shows pin-on-disc and various specimen samples.

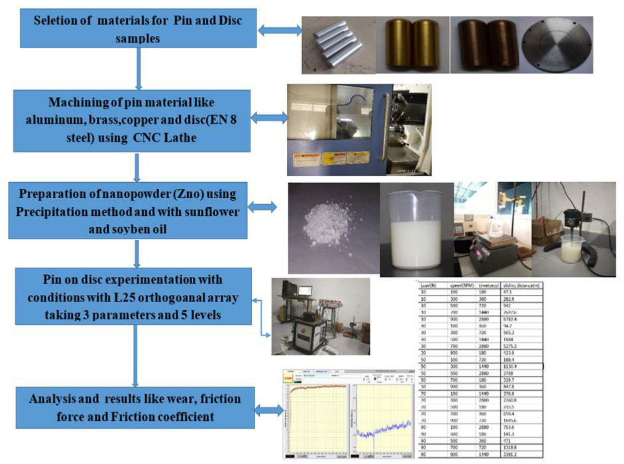

Figure 1: Experimental methodology flowchart.

Table 1: Electrical specification and power requirement.

Electricity required	230/1/50, 5A
Power consumption	0.5 kW
AC motor specification	0.5 hp,1380 rpm, 1.05 A, flange mounting, make: Siemens
VF drive specification	230 V, 0.5 hp, make: OPTI DRIVE
MCB specification	C6, 2 pole, make: Indokupp

Table 2: Machine specifications.

S. No.	Parameter	Specification
1	Wear disc diameter	Dia 100 mm, 6 to 8 mm thick
2	Pin diameter, length	4 to 8 mm dia in steps of 2 mm, 20 - 30 mm long
3	Ball diameter	10 mm
4	Wear track diameter	Min 50 mm and max 80 mm, infinitely variable
5	Disc speed	Min 100 rpm, max 1000 rpm
6	Normal load	Min 10 N, Max 100 N
7	Frictional force	Max 100 N
8	Wear	0 to 2000 micron
9	Test duration	99.59.59 h

Design of experiments using the Taguchi approach

Taguchi approach is used to frame the better combinations between the input variables shown in table 3 by taking 5 levels. Minitab 16.0 software is used to get the L25 orthogonal array as shown in table 4.

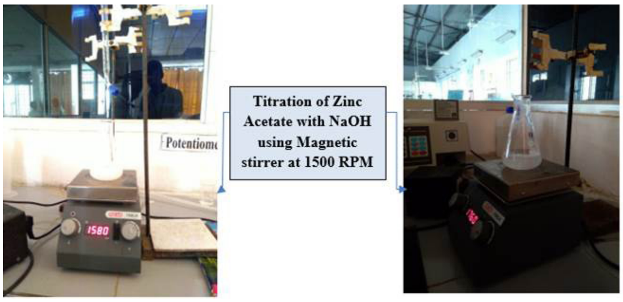

Figure 2: Experimental methodology for preparation of ZnO nano powders by precipitation method.

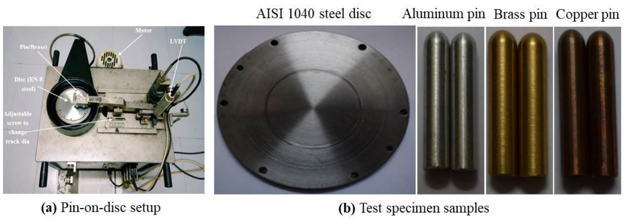

Figure 3: Experimental Setup.

Table 3: Experimental conditions.

Load (N)	Speed (rpm)	Time (s)	Sliding distance (m)
10	100	180	47.1
30	300	360	282.6
50	500	720	942
70	700	1440	2637.6
90	900	2880	6782.4

Table 4: Design of experiments (L25 array).

Load (N)	Speed (rpm)	Time (s)	Sliding distance (m)
10	100	180	47.1
10	300	360	282.6
10	500	720	942
10	700	1440	2637.6
10	900	2880	6782.4
30	100	360	94.2
30	300	720	565.2
30	500	1440	1884
30	700	2880	5275.2
30	900	180	423.9
50	100	720	188.4
50	300	1440	1130.4
50	500	2880	3768
50	700	180	329.7
50	900	360	847.8
70	100	1440	376.8
70	300	2880	2260.8
70	500	180	235.5
70	700	360	659.4
70	900	720	1695.6
90	100	2880	753.6
90	300	180	141.3
90	500	360	471
90	700	720	1318.8
90	900	1440	3391.2

Results and Discussion

After each tribometer test, the graphs displaying the change of wear, frictional force, as well as COF are collected by using WINDUCOM software and presented on the PC linked to a pin-on-disc tester. Some of them are shown in figure 4, figure 5, figure 6, figure 7, figure 8, and figure 9.

Wear vs sliding distance of soybean oil

As illustrated in figure 10, the graphs are depicted considering sliding distance and wear on the X and Y-axes. The graph shows that during the application of soybean oil as lubricant medium, the aluminum, copper has the highest and lowest wear values. Brass and aluminum pin shows high wear of 231 μm at 90 kg load, speed of 100 rpm at a sliding distance of 753.6 m. Copper pin shows maximum wear of 25 μm at a sliding distance of 5000 m.

Frictional force vs sliding distance of soybean oil

The graphs are plotted by taking sliding distance on abscissa and frictional force on ordinate as shown in figure 11. From the graph it is observed that the comparison among soybean lubricant with brass, aluminum, and copper pin materials respectively is the aluminums pin material will take the highest frictional force and copper pin material will take lowest frictional force among them. Aluminum and brass pin shows high frictional force of 5.5 to 6.0 N at minimum values of sliding distance of 0 - 600 m. Copper pin shows low frictional force of 1.7 N at a sliding distance of 50 m and increased to 2.6 N at sliding distance of 6800 m.

COF vs sliding distance of soybean oil

As illustrated in figure 12, the graphs are created by plotting sliding distance and frictional coefficient on the X and Y-axes. The comparison graph between brass, aluminum, and copper pin materials using soybean as lubricant shows that brass and copper materials have the greatest and lowest COF. Aluminum and brass pins have the greatest COF at minimum sliding distance, when load and speed values are of 50 N and 100 rpm. Brass has a COF of 0.02 at 6700 m sliding distance, but copper pin has a high COF of 0.053 at 6800 m sliding distance.

Frictional force vs sliding distance of sunflower oil

The graphs are created by plotting sliding distance on the X-axis and frictional force on the Y-axis, as illustrated in figure 13, the graph shows a comparison of sunflower with brass, aluminum, and copper pin materials, in that order. The aluminum pin material will take the highest frictional force and copper pin material will take lowest frictional force among them. Aluminum pin material shows high frictional force of 7.2 N at sliding distance of 2637.6 m and load of 10 kg at speed of 700 rpm. While copper shows least frictional force. Brass pin shows high frictional force of 5.6 N at sliding distance of 753.6 m, but comes to an average value of 2.3 N at the sliding distance of 6700 m.

Wear vs sliding distance of sunflower oil

The graphs are plotted by taking sliding distance on abscis-

Figure 4: Variation of wear in relation to time (Soybean oil + aluminum pin, load - 30 N, Speed - 100 rpm, and time 360 s).

Figure 5: Variation of wear, frictional force, and COF in relation to time (Soybean oil + aluminum pin, load - 30 N, Speed - 100 rpm, and time 360 s).

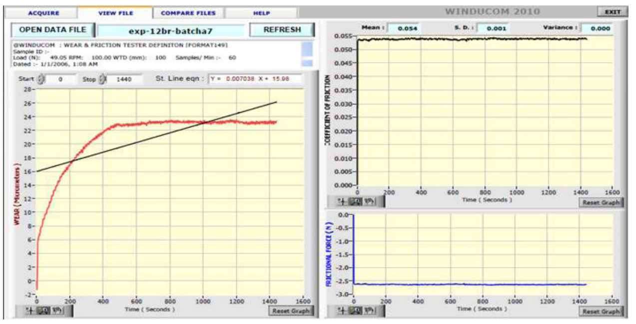

Figure 6: Variation of wear in relation to time (Soybean oil + brass pin, load - 50 N, Speed - 300 rpm, and time 1440 s).

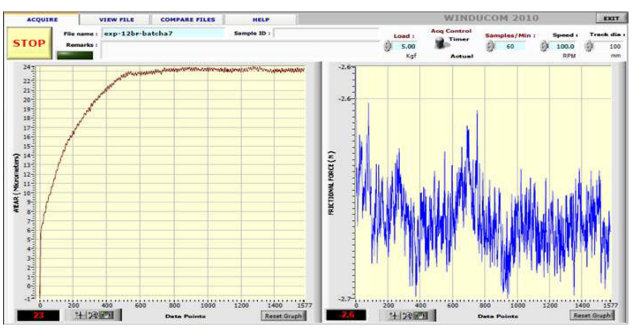

Figure 7: Variation of wear, frictional force, and COF in relation to time (Soybean oil + brass pin, load - 50 N, speed - 300 rpm, and time 1440 s)

sa and wear on ordinate as shown in figure 14. From the graph it is observed that the comparison among sunflower lubricant with brass, aluminum, and copper pin materials respectively is the aluminum pin material takes the highest wear and brass

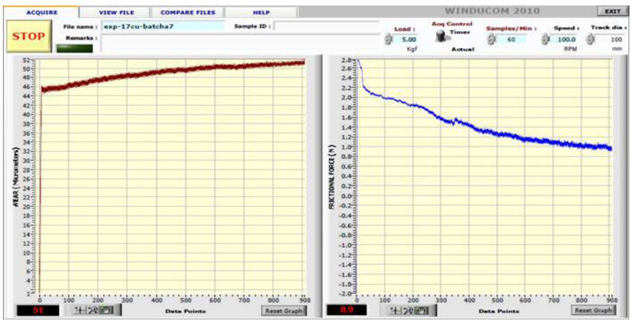

Figure 8: Variation of wear in relation to time (Soybean oil + copper pin, load - 70 N, speed - 300 rpm, and time 2880 s).

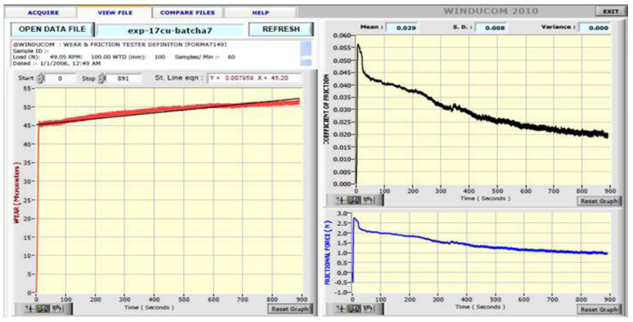

Figure 9: Variation of wear, frictional force, and COF in relation to time (Soybean oil + copper pin, load - 70 N, speed - 300 rpm, and time 2880 s).

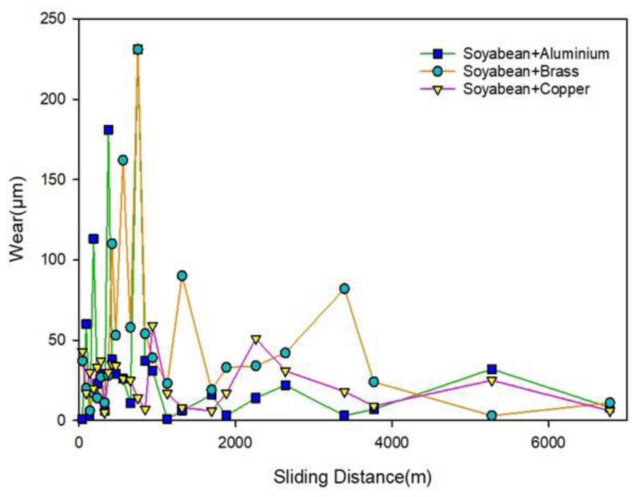

Figure 10: Variation of wear in relation to sliding distance of soybean oil.

pin material takes lowest wear among them. Aluminum pin shows high wear rate of 305 µm at sliding distance of 753.6 m and load of 90 kg at speed of 100 rpm. Brass pin whose wear rate is low at the minimum values of sliding distance increased to maximum value of 79 µm. Copper pin shown an average wear of 25 µm with slight variations at all conditions.

COF vs sliding distance of sunflower oil

Graphs are plotted by taking sliding distance on abscissa and COF on ordinate as depicted in figure 15. From graph it is observed that the comparison among sunflower lubricant with brass, aluminum, and copper pin materials respectively is the brass pin material will take the highest COF and copper pin material will take lowest COF among them. Brass pin has

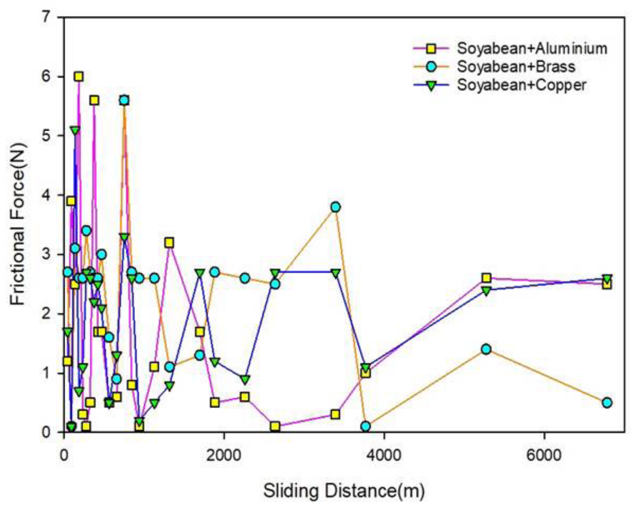

Figure 11: Variation of frictional force in relation to sliding distance of soybean oil.

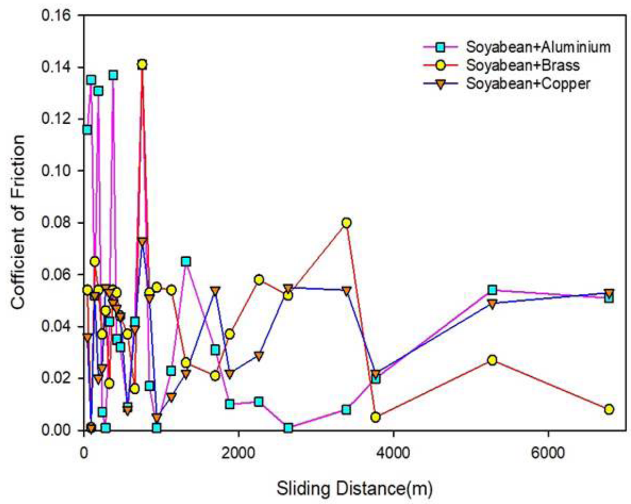

Figure 12: Variation of COF in relation to sliding distance of soybean oil.

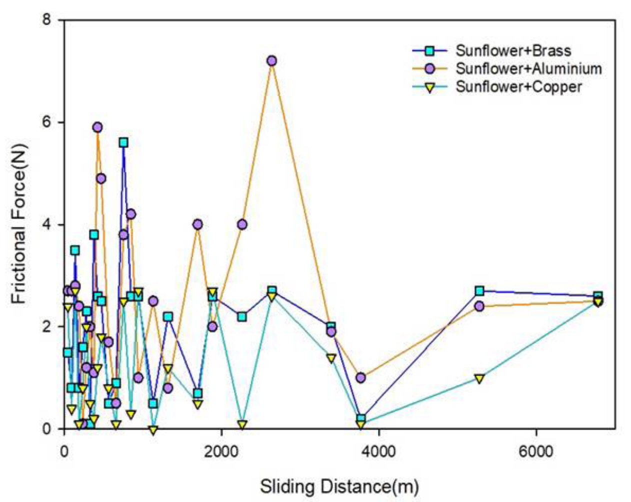

Figure 13: Variation of frictional force in relation to sliding distance of soybean oil.

a high COF around 0.12 at quite a sliding distance of 753 m and a load of 90 kg at a speed of 100 rpm, but copper has a low

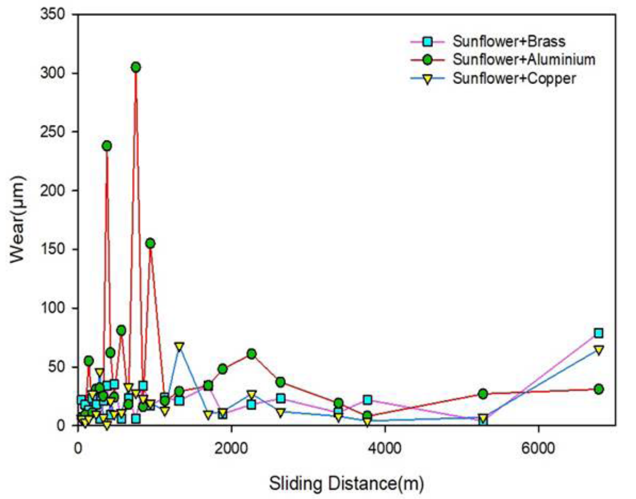

Figure 14: Variation of wear in relation to sliding distance of sunflower oil.

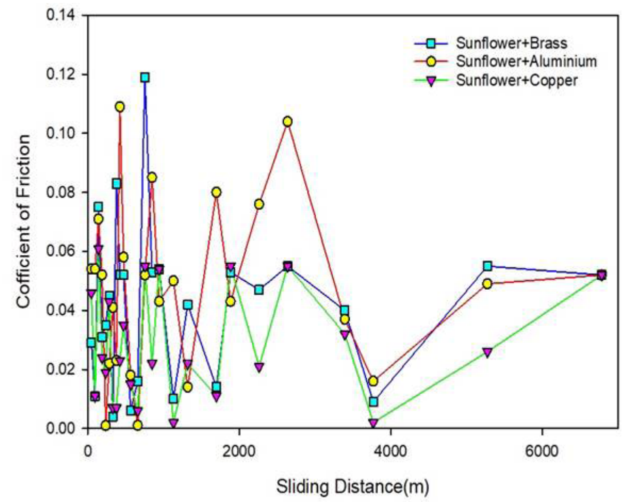

Figure 15: Variation of COF in relation to sliding distance of sunflower oil.

COF under the same conditions. Aluminum exhibited high COF value of 0.10 at sliding distance of 2637 m and load of 10 kg at a speed of 700 rpm.

Conclusions

This study aims to investigate how bio-lubricants affect wear and frictional properties in bearing applications. EN-8 Steel is used as the disc material and aluminum, brass, and copper are used as the pin materials in the experiments, which are conducted using a pin-on-disc tribometer. The results of this experimental study are used to make the conclusions that are presented below. Bio-lubricants are replacement of conventional mineral oils in the lubrication of bearings.

- Using Taguchi L25 array provides superior combinations of input variables, which aids in understanding the tribological efficacy of nano bio-lubricants.
- Aluminum pin material shown highest wear and frictional force with soybean and sunflower lubricants, respectively.
- Brass pin material with sunflower oil and copper pin material with soybean oil showed lowest frictional force, respectively.

- Brass material with soybean and sunflower oil obtained highest COF.
- Copper pin material with soybean and sunflower oil exhibited lowest COF.

Acknowledgements

We acknowledge GMR Institute of Technology, Rajam for their support related to the work completion.

Conflict of Interest

Authors declare no conflicts of interest.

Funding

This is a self-financed work and has not received funds from external agencies.

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