EFFECT OF CUCURBITA PEPO L. SEED OIL ON TRIBOLOGICAL BEHAVIOUR IN PIN ON DISC TEST RIG

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FORWARDING CERTIFICATE

This is to certify that the dissertation entitled, "EFFECT OF CUCURBITA PEPO L. SEED OIL ON TRIBOLOGICAL BEHAVIOUR IN PIN ON DISC TEST RIG" submitted by Mr. Ikramul Hossain Mondal to Assam Science and Technology University, Assam, is a record of bona fide Project work carried out by him/her under my/our supervision and guidance and is worthy of consideration for the award of the degree of Master of Technology in Energy Engineering.

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ABSTRACT

In modern world, most of the work or industrial processes are done with a machine. To increase the life of the machines there is an increase in demand for lubricants. To meet this demand Bio-lubricant can be used as an alternative source. In recent years Bio-lubricants much desired in various applications because it is a renewable resource, has higher biodegradability, and produce fewer pollutants compared to mineral-based oil. Thus in this paper, the friction and wear experiments were performed using a pin-on-disc tribotester. The effect of Bio-lubricant is studied with different load conditions and compared with commercially available lubricant SAE 20W40. Tests were conducted with different loads of 10N, 50N and 100N at a constant speed of 3m/s for 60 minutes to evaluate the behaviour of friction coefficient and wear for Al-Mg-Si alloy with 0.8% Sn. The test was done using Cucurbita Pepo L. (pumpkin) oil as lubricating oil. Results show that the friction reduction (Coefficient of friction) and wear resistance (anti-wear properties) of CPO were found relatively inferior to commercially available SAE 20W40. But CPO has better performance properties in terms of wear resistance for higher load conditions.

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Ikramul Hossain Mondal

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LIST OF ABBREVIATIONS

Abbreviation	Description
COF	Coefficient of Friction
C. pepo L.	Cucurbita pepo L.
CPO	Cucurbita Pepo L. seed oil
SAE	Society of Automotive Engineers
SEM	Scanning Electron Microscopy
VI	Viscosity Index

CHAPTER 1: INTRODUCTION

Lubricants are used since ancient times. Archaeological surveys show that ancient Egypt used lubricants to move large stones and other heavy objects. They primarily used olive oils as a lubricant when the wheel was discovered then animal fats were used to lubricate chariot excel, with the advancement of human civilization many types of mechanical systems are introduced to maximize the life of this mechanical system the wear and friction between the moving parts should be minimized. There are many ways to minimize wear and friction and lubrication is one of them. Since lubrication is important so a continuous development of lubrication can be used in the engineering system. It is important to increase the life of the mechanical system due to this continuous development of lubricants, there are many types of lubricants available in the market, which are oil-based, grease, and penetrating lubricants and dried lubricants. Conventional mineral-based lubricants are used widely in mechanical industries and cause environmental pollution due to their toxicity. Generally, it has a highly flammable characteristic that may lead to environmental pollution. In the last decade, about 38 million metric tons per year of lubricant were used globally, the majority of which were mineral-based. Thus, to overcome this issue CPO is introduced.

In agriculture and food Industries, the CPO will be an important factor and there are chances of lubricant leakage. Till 19ththe -century vegetable oils and animal fats were solely used for lubricating purposes. Only after the industrial revolution the “classical” lubricant gradually replaced by mineral-based oil due to its high stability. But nowadays biodegradable vegetable lubricants are becoming popular again because intensive improvements have been done in stability and their characteristics. In the last 25 years, there is an increase in demand for the biodegradable product. This change is driven by environmental problems that highlighted the need to Limit pollution from lubricant-based Mineral oil. Vegetable oils are a potential substitute for mineral-based not only because their environment-friendly, renewable, and less toxic but also because they have excellent lubricant properties such as high viscosity index, high lubricity and low volatility. Mostly Oilseeds are the source of vegetable oils, though they can be extracted from other parts of fruits. India grows a significant number of plants that produce oil seeds. India annually produces about 10 million tons of vegetable oils from oilseeds [1]. Groundnut, castor, sesame, rapeseed, niger, mustard, linseed, soybean, sunflower, cottonseed, rice bran, coconut, and palm oil are the major sources of vegetable oil in the country. In the present study, lubricant oil is produced from Cucurbita Pepo L. (Pumpkin) seed, because it has high oil yielding. Bikash et al. (2017) [2] find out that the oil content in Cucurbita pepo L. seed is to be 48%. About 1 kg of oil seeds can be obtained from 15kg of Cucurbita pepo L. fruits.

Motor oil or engine oil is a lubricant that is used in the internal combustion engine. In the engine, some parts move against each other and the friction between them converts useful power to waste heat energy. So, proper lubrication can decrease fuel consumption, decrease waste power and increase engine life. Lubricating oils create thin separating film between the surfaces of moving parts, thus reducing the direct contact between the parts, decreasing frictional heat and reducing wear, thus protecting the engine. The Society of Automatic Engineers (SAE) has established a numerical code system for grading engine oil according to the viscosity characteristics known as SAE J300. The original viscosity grades were all mono grades like SAE 30. All the oils' viscosity decreases when heated. So, to get the right film thickness at operating temperature the oils were manufactured as thick oil. But in the cold weather, it would be difficult to start the engine as the oil was too thick to crack. However, oil additive Technology was introduced that allowed oil to thin more slowly, this allowed selection of thinner oil to start with. Thus "SAE 20W 40" is a product that acts like an SAE 20 at cold temperature (20W for winter) and as an "SAE 40" at 100° C. Kinematic viscosities is created by measuring the time to flow a standard amount of oil through a standard orifice at standard temperature. The longer it takes the higher the viscosity and thus higher the SAE code. A larger SAE number means thicker lubricants. It is also observed that SAE20W50 gives better performance than the SAE20W40. But manual of the two-wheeler recommends SAE20W40 because SAE20W50 has more viscosity improver, which will cause more sludge than the SAE20W40. In winter some cold starting issues may occur due to their high viscosity [3]. This is why the Bio-lubricant is compared with SAE20W40 engine oil.

Aluminum has a low density and it has high environmental corrosion resistance. Components which are made from pure aluminum are relatively soft, durable, lightweight, ductile, and malleable. Baruah and Borah (2021) [4] studied the effect of micro-alloying Sn (0.08% wt.) on the abrasive wear behavior of the cast Al-Mg-Si alloy.

The tests were done at constant load 10N and 70mm wear track diameter, 1.09m/s sliding speed, and a total sliding distance of 71.5m. Their study showed that micro-allying Sn increases the amount of hard Mg_2Si particles and marginally improves the hardness and wear resistance of the Al-Mg-Si alloy. Further, they suggest that the presence of Sn added alloy acts as a solid lubricant and thus resulting decrease in COF and improving the wear resistance of Al-Mg-Si Alloy. For this improved wear resistance and lower COF, the Al-Mg-Si with 0.08%Sn alloy is chosen as pin material. The wear test was done using a pin with flat contact surface against a plain steel disc. The experiment presents the results of experimental evaluation of the tribological performance with Bio-lubricant.

CHAPTER 2: REVIEW OF LITERATURE

Several researchers have observed that the variation in friction and wear depends on conditions of normal load, geometry, relative surface motion and sliding speed of surfaces [5] [6]. Trivedi and Bhatt (2017) [3]showed that viscosity and variation of load play a vital role to characterize the behavior of frictional force and wear. Researchers from Malaysia Nuraliza et al., (2015) [7]found that palm oil has better fiction reduction properties (Co-efficient of friction) and higher resistance (anti-wear properties) at low and high speed compared to mineral-based oil. Tribological tests are done mainly on pin-on-disk, four ball testers, block-on-ring, abrasive wear tester, etc. Mainly factors like applied load, sliding speed, sliding distance and temperature are varied during tribological testing to study the variation in wear rate and friction coefficient. The researchers have also carried out hardness and microstructure studies of the materials to evaluate the hardness improvement and wear behavior of the materials [8]. Trivedi and Bhatt (2017) [3] shows that viscosity and variation of load play a vital role to characterize the behavior of frictional force and wear. Authors found that high weight loss with incremental load and SAE20W40 and SAE20W50 have better performance compared to SAE10W30.

Bio-lubricant is interpreted as a lubricant obtained from natural raw materials both vegetable and animal oils, renewable and non-toxic to humans and other living things, as well as environmentally friendly. Bikash et al.(2017) [2] studied the physicochemical properties of Cucurbita pepo L. seed oil and compared it with other biodiesel products along with Petroleum diesel and found out that its properties are comparable to petroleum diesel. The oil content of C. pepo L. seed is around 48% which is higher than the Soybean and Jatropha seed. Vegetable oil used for the production of Bio-lubricant can be obtained from plant seeds, such as vegetable oil that can be consumed or which cannot be consumed. Some of the vegetable oil can be used as Bio-lubricant i.e. castor oil [9], Karanja, Neem, Rice Bran, Rapeseed, Castor, Linseed, Mahua [10], Palm oil [11] [7], sunflower oil, coconut, soybean, olive and canola [12], pumpkin seed [13]. Bio-lubricant is a lubricant made from vegetable oil that can reduce environmental pollution. Choudhury et al. (2021) [13] studied the tribological properties of Cucurbita pepo L. Oil (CPO) and compared with Commercially available oil SAE 20W40 and other vegetable oils. They suggest that CPO can be a potential alternative to petroleum-based mineral oil.

For the past few decades, Al alloy has gained the interest of many researchers who studied its tribological behavior. The researchers studied the effect of different testing parameters such as applied load, sliding speed, and the volume fraction of reinforcement on the tribological characteristics of the material. The studies were carried out mostly on a pin-on-disk tribotester using Al-Mg-Si as pin material. Some of the researchers have used Pin on disk, and reciprocating wear tester for their experiments.

Studies regarding the wear behavior of Al-Si have mainly been carried out by varying the reinforcement volume fraction. The common parameters varied for studying the wear behavior of Al-Sic are applied load or pressure, sliding speed and temperature. The effect of the applied load was studied using an applied load range of 10-110N [4] [14] [15]. Baruah and Borah (2021) [4] choose a load of 10N for their study. Nuraliza et al., (2015) [7] used a load of 10N, 50N and 100N for the wear test. Some of the researchers used a high load range to study the wear behavior. Straffelini et al. (2004) [16] selected a load range of 100-800N to study the wear behavior of Al-Sic in a wide load range. The wear rates increase with the increase in applied load [7]. For most of the studies sliding speed was kept constant in the range of 0-3m/s. Some of the researchers studied the effect of sliding speed on the wear behavior [17].

CHAPTER 3: METHODOLOGY

A pin on disc machine with a data acquisition system was used to evaluate the wear characteristics and friction coefficient of the Al-Mg-Si alloy lubricated with CPO and compared it with petroleum-based mineral oil SAE 20W40.

3.1 Materials Preparation

3.1.1 Pin

For the wear characterization of Al alloy with Bio-lubricant Al-Mg-Si alloy with 0.08% Sn was used as a pin material, which was prepared by Baruah and Borah (2021) [4] using the casting route. The chemical composition of Aluminium alloy is summarized in Table 3.1. The rectangular-shaped plate of Al alloy as shown in Figure 3.1 (a) was cut from the base plate, then with the help of a lathe machine, the materials were turned into cylindrical pins. Cylindrical-shaped pins of 10mm in diameter and 30mm in length were prepared for the experiment as shown in Figure 3.1 (b) and Figure 3.1 (c).

(a) (b) (c)

Figure 3. 1: (a) Al-Mg-Si alloy with 0.08% Sn Plate (b) Pin specimen (c) Pin dimensions (mm)

Total 6 numbers of pin specimens were prepared for wear characterization for different applied loads with CPO and SAE 20W40 engine oil. Three pins were used for friction and wear characterizations of Al-Mg-Si alloy at different loads (10N, 50N and 100N) with CPO and the rest of the pins were used with SAE 20W40 engine oil.

Table 3. 1: Composition (wt.%) of Al-Mg-Si alloy with 0.08% Sn [4]

Elements	**Alloy**
Mg	.91
Si	.37
Fe	.24
Cu	.05
Mn	.12
Sn	.08

3.1.2 Disc

The Disc specimens are made of steel. A total of 3-disc specimens were used, before each experiment disc was cleaned with acetone and a fresh side of the disc was used. The wear track diameter of the disc specimen is 60mm as shown in Figure 3.2.

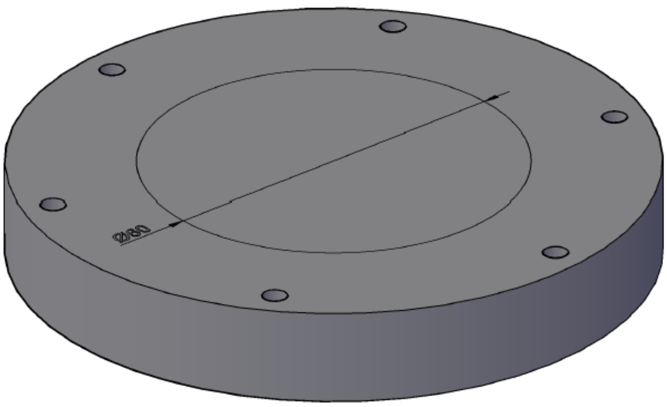


Figure 3. 2: Wear track diameter of disc

3.1.3 Bio-lubricant

The seeds of Cucurbita pepo L. were collected from the local market at Guwahati. The Cucurbita pepo L. seeds were unshelled and then sun-dried for 7 days [13]. For this study, the kernels were sieved and grounded to a smaller size. N-hexane (40-60° C) is mixed with the sample and using the Soxhlet extraction method the oil is extracted from the sample as shown in figure 3.3 (a). The n-hexene solvent was removed from the oil with the help of

(a) (b)

Figure 3. 3: (a) Soxhlet extractor and (b) Rotatory vacuum evaporator

a rotatory vacuum evaporator (IKA, RV-3V, Germany) as shown in figure 3.3 (b) [13]. Then the extracted oil is weighed to estimate the extraction yield. The yield of CPO was calculated using Eq. 3.1 [13].

$$\left(\text{Yield of CPO} = \frac{\text{mass of CPO}}{\text{Mass of the sample}}\right) \times 100\% \tag{3.1}$$

3.2 Wear Test Set-up

The wear specimens were tested with Bio-lubricant and SAE-40 engine oil in accordance with ASTM-G99 standards using a pin-on-disc sliding wear testing machine. The apparatus consists of a still disc with a wear track diameter of 60 mm. The pin was clamped in the holder and held against the rotating disc at a distance of 30 mm from the Centre of the disc as shown in figure 3.4. The present investigation was done on three different loads 10N, 15N and 100N with a constant speed of 3 m/s [7]. The RPM of the disc was fixed at 955, which is equal to a sliding distance of 10.8 KM when the machine continuously runs for 60 minutes.

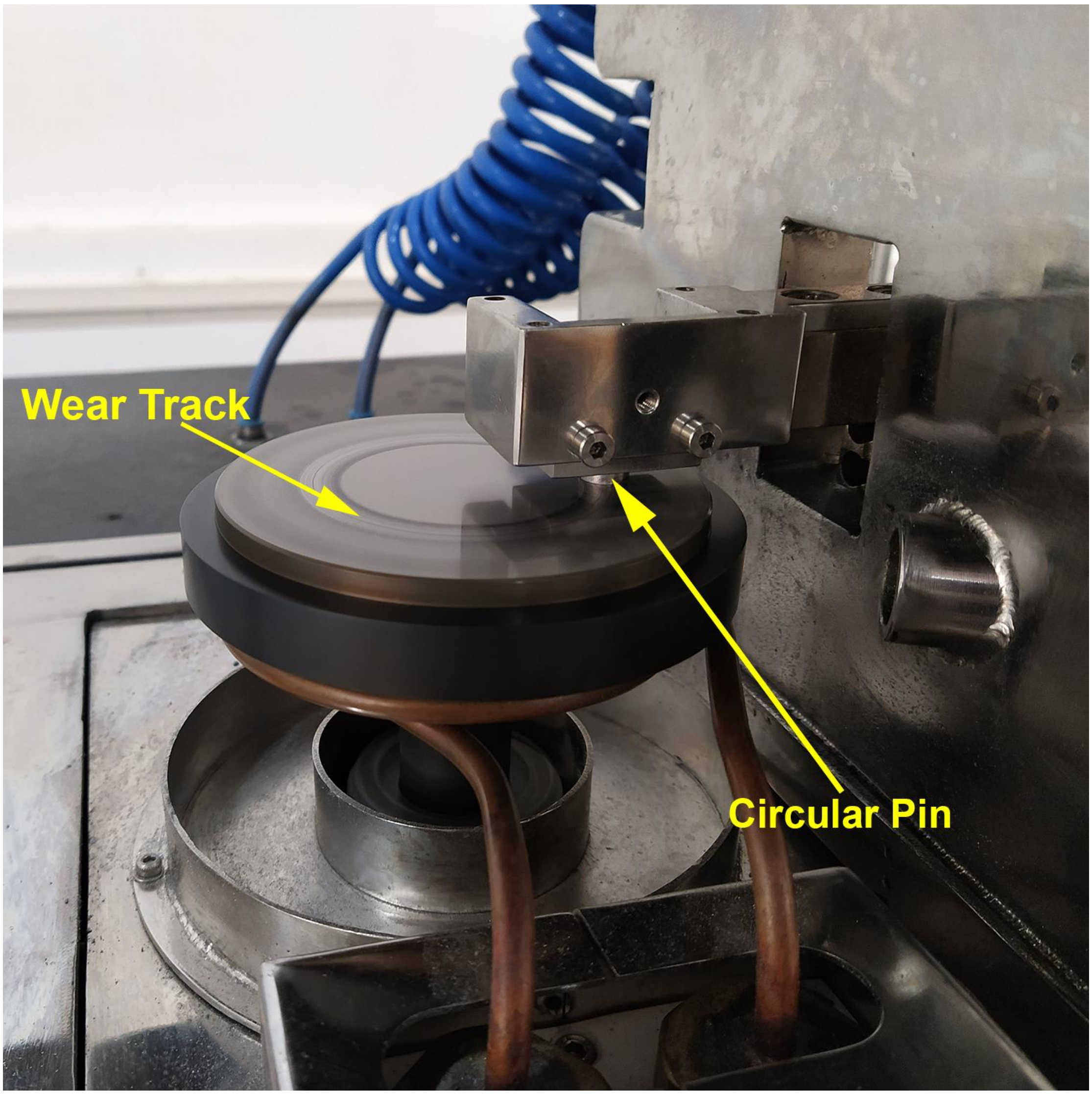


Figure 3. 4: Wear test Set-up

In this study wear and friction coefficient of aluminum alloy lubricated with CPO was studied with different loads and compared with commercially available SAE 20W40. Wear rate and friction coefficient were recorded for each particular test on the computer. The experiment was repeated three times for each type of lubricant with different loads. Before each test, the specimen's contact surface was polished with 1000 grit emery paper and cleaned with acetone [4] [7]. Every test was done on a fresh disk surface which is cleaned with acetone to remove any foreign materials.

Specimen pins were weighed before and after the experiment with an electric weighing scale of accurate to 0.0001g. The sliding wear loss was Computed using the weight loss of the pin before and after the experiment. Abrasive wear performance was calculated as specific wear rate. The specific wear rate (SWR) was expressed in Eqn. 3.2 [4].

$$SWR = \frac{\Delta m}{\rho \times \mathrm{R} \times \mathrm{F}} \tag{3.2}$$

Where, Δm is the weight loss in milligram of the test specimen, ρ is the density of the pin (21.7g/cm3), R is the sliding distance (10.8 km) and F is the applied normal load 10N, 50N, 100N.

The surface of the worn specimen was cleaned gently with Acetone and observed using a microscope. Since the hardness of the steel disc was far higher than the aluminum so its wear volume was very small. So, the wear properties of the discs were not studied.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Rheological properties of CPO

In this study, the lubricant yield of 13.5% was obtained from Cucurbita pepo L. (pumpkin) seed. The rheological properties of CPO and SAE 20W40 are shown in Table 4.1.1 High viscosity is an essential requirement for a good-quality lubricant. Thicker lubricants can reduce wear and friction force. If the viscosity lies between 5 to 15 mm^2/s, then the lubricant can be used in industrial applications. The viscosity of CPO was 54.171 mm^2/s at 40°C and 11.36967 mm^2/s at 100°C which is comparable to commercial lubricants. The viscosity index (VI) of CPO was 180 which is similar to other vegetable oil. Most vegetable oils have a VI in the range of 159-275 [13]. The higher value of VI of CPO as compared to commercial lubricants shows that high stability of CPO tribo films at high temperatures compared to commercial mineral oils. It can be observed from Table 4.1 that there is a little variation in viscosity for CPO oil at 100°C. Thus the viscosity-temperature relation of CPO is less affected at a higher temperature. As shown in Table 4.1 there is a large variation in viscosities of CPO and SAE 20W40 at low temperatures, while the viscosities are nearly similar for higher temperatures. So at high temperatures, the strength of lubricating film for CPO and SAE 20W40 are similar.

Table 4. 1: Rheological Properties of CPO and SAE 20W40

Oil Type	Kinematic Viscosity (mm^2/s) at 40°C	Kinematic Viscosity (mm^2/s) at 100°C	Viscosity Index
CPO	54.17	11.36	180
SAE 20W40	121.88	14.2	116

4.2 Frictional Behaviour

A series of experiments are conducted to find out the frictional characteristics of the pin using a pin on disc driver tester using lubricants at different loads for a sliding distance of 10,800 m. The frictional behavior of various lubricants can be seen in Figure 4.1, Figure 4.2 and Figure 4.3 at constant loads of 10 N, 50N and 100N respectively. It is observed from the figure that the nature of the curve is similar for these lubricants during the initial run there is significant variation in the friction coefficient and then follow steady-state up to the end. The reason is the initial roughness of the sliding pair hence high asperity contact generates which results in a high coefficient of friction.

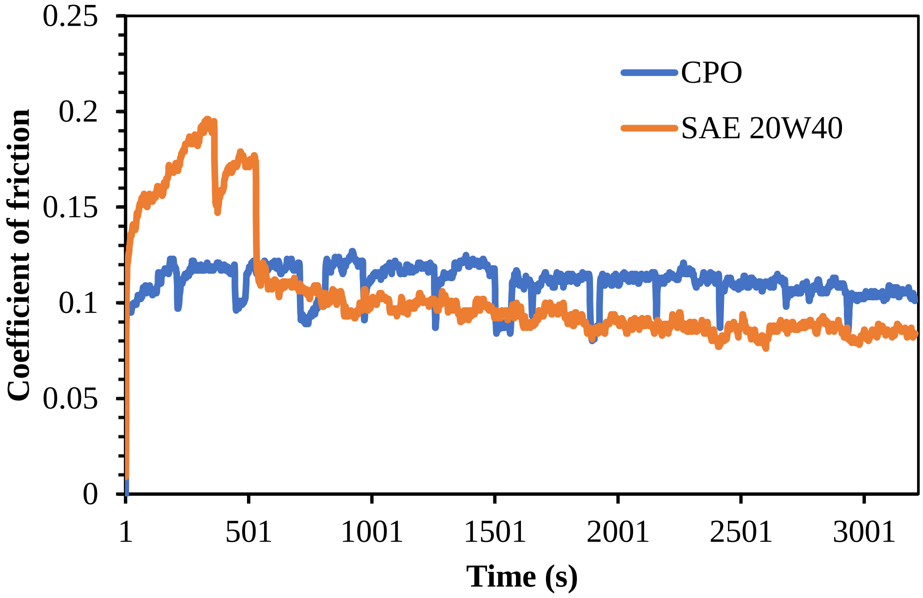


Figure 4. 1: Coefficient of friction variation with time for 10N load

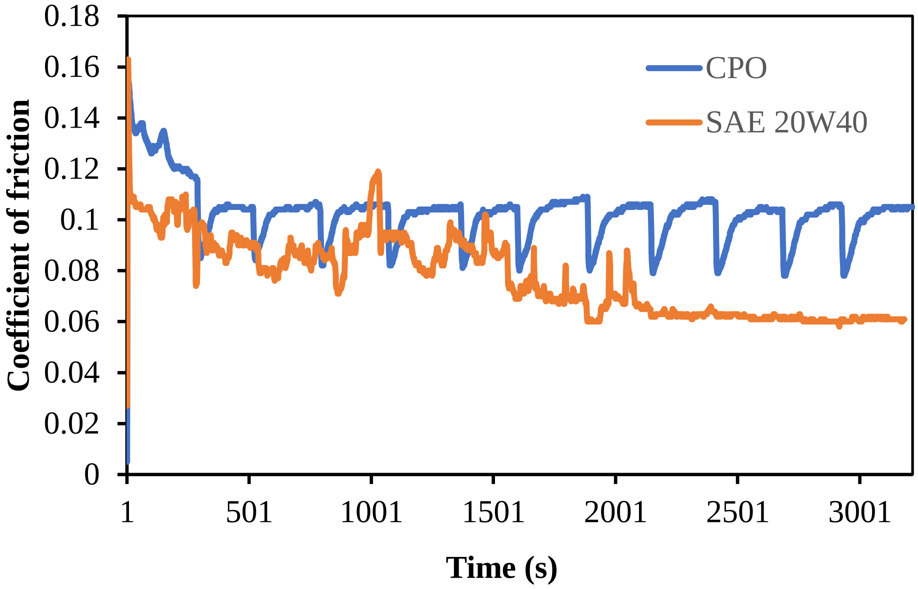


Figure 4. 2: Coefficient of friction variation with time for 50N load

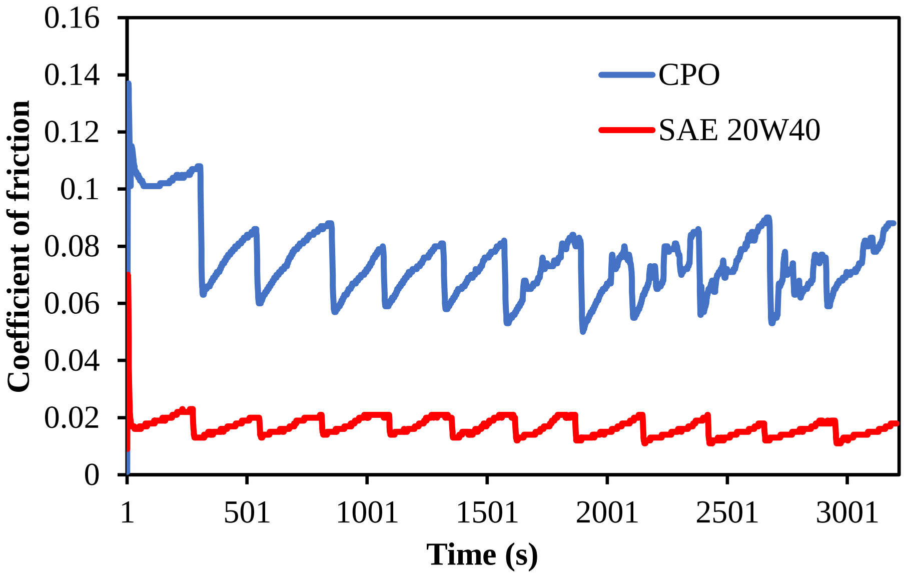


Figure 4. 3: Coefficient of friction variation with time for 100N load

During the experiment, the gradual degradation of the surface is the only source of the increase in friction force. The oil film formation may not develop sufficient between the components during the initial run which results in high frictional force.

Further, increase over time, a constant fluid film formed in a mixed lubrication regime developed between the pair hence partial load-carrying capacity increases up to a certain extent which results in the coefficient of friction being nearly constant. There is a sudden drop and rise in coefficient of friction every 5 min because the lubrication was provided between the contact surface of the pin and disc at a time interval of 5 min.

By comparing the two lubricants, CPO which has less viscosity produced the highest frictional force. This is because when a lubricant has lower viscosity it produces a thin lubricating film, which increases the possibility of direct surface contact between the moving parts and increases the friction force.

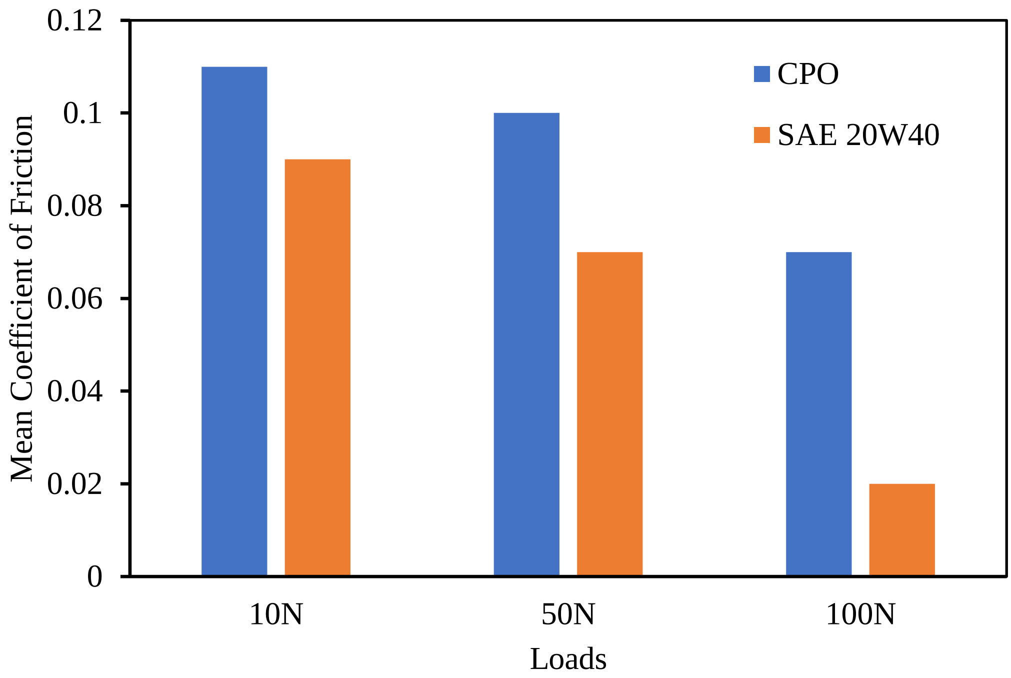


Figure 4. 4: Decrease of mean COF with the increase in load for different Lubricants

For load 10 Newton the average value of COF was recorded pin lubricated with CPO as 0.11 at a sliding speed of 3 m/s. In construct, the average COF value is 0.09 for a pin lubricated with engine oil at the same sliding speed. Meanwhile, for load 50 N the average value of COF is recorded for pin lubricated with CPO as 0.10 and the average value of COF of SAE 20W40 is 0.07. The result is affected by that applied load during this experiment and the coefficient of friction decreases with load increases. Then for load 100 N the average value of COF for CPO lubricated pin is 0.07 and COF for pin lubricated with SAE 20W40 is 0.02.

Figure 4.4 summarises the effect of different lubricants on the coefficient of friction for the various loads. The graph clearly shows that the coefficient of friction goes decreasing as the load increases [7]. These results strongly suggest that COF is inversely proportional to the applied load.

4.3 Wear Behaviour

Wear data were collected from the same experiment. For constant load wear increases with time. During the initial run condition surface irregularities of the specimen contributes a major role in the increase in wear rate. Surface irregularities increase the real contact area between the sliding surfaces which causes maximum wear. After traveling some distance, the specimen becomes somehow smooth and stable fluid film develops then the wear rate reduces and becomes stable [3]. The variation of wear with time is shown for 10N, 50N and 100N load in figure 4.5, figure 4.6 and figure 4.7 respectively.

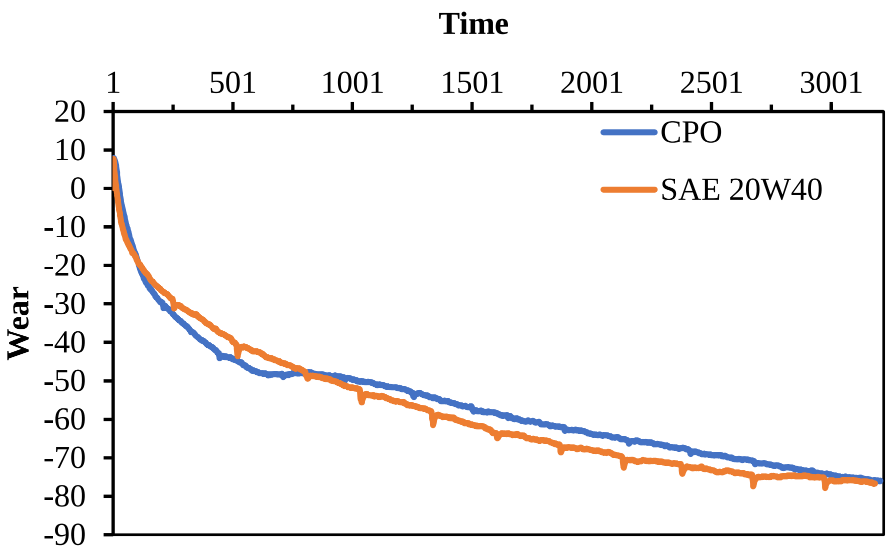


Figure 4. 5: Wear variation with time for 10N load

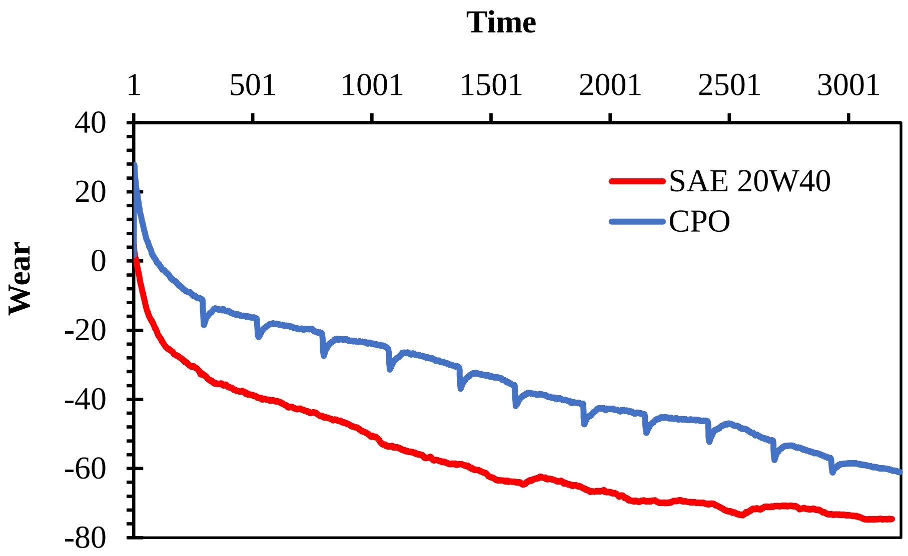


Figure 4. 6: Wear variation with time for 50N load

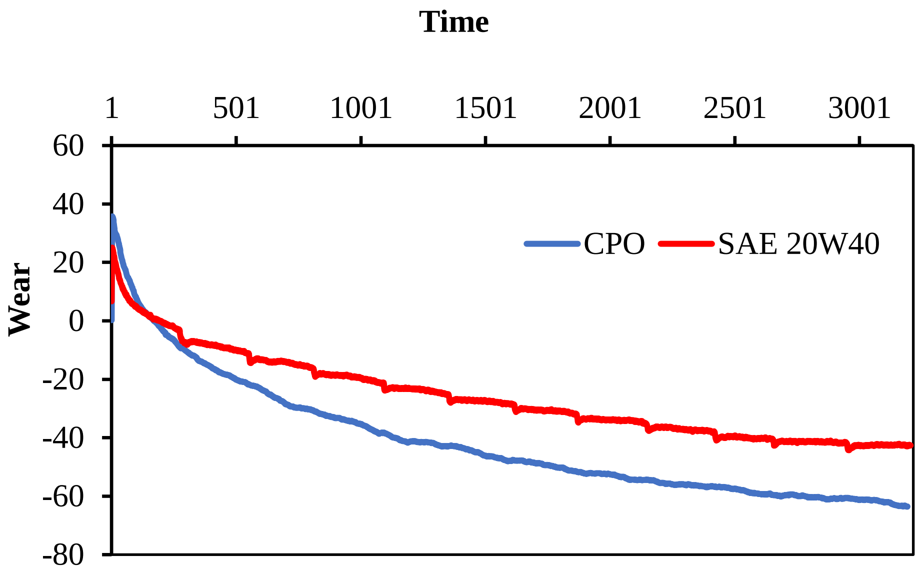


Figure 4. 7: Wear variation with time for 100N load

When the lubricant is applied between the surface then a lube layer is formed, which prevents direct contact between the surface thus reducing the wear. In this experiment the wear is shown as negative in the graph this is because when the pin rubs on the surface of the disc heat is generated due to this heat generation the pin gets elongated. The pin-on-disc testing machine measures the changes in the length of the specimen from starting condition, normally due to wear the length of the pin decreases so the wear is shown as positive. But in this case decrease in length due to wear is less than the increase in length due to the heat generated, so the pin length overall increases with time and the wear is shown as negative wear. So, the graph plotline having less negative value has a higher wear rate.

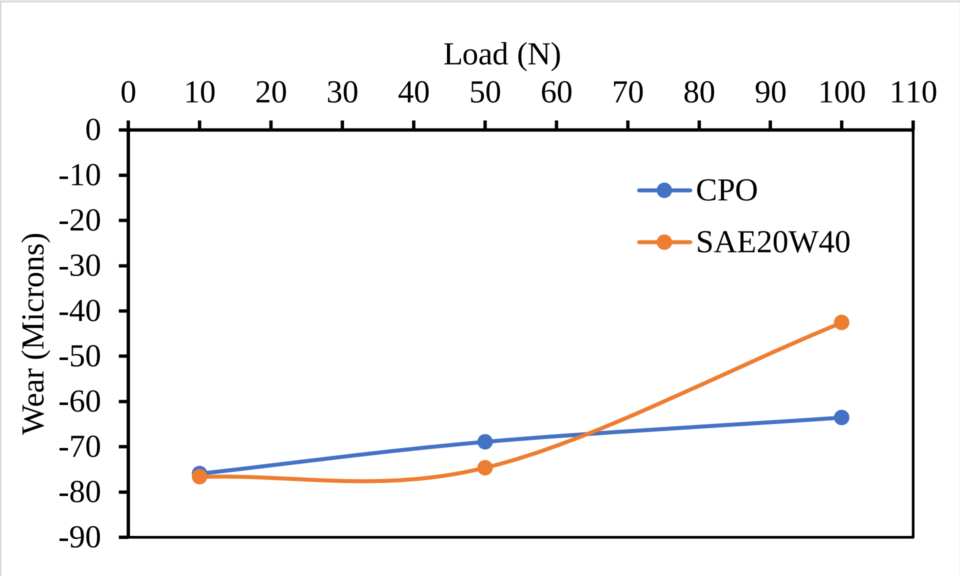


Figure 4. 8: Variation of wear with an increase in loads for CPO and SAE20W40

From experimental data, it is clear that CPO has a higher wear rate compared to engine oil at 10N and 50N applied load. But in the case of the 100 N load, the wear in the Al alloy pin lubricated with CPO is less than the pin lubricated with SAE 20W40. Pin lubricated with CPO has a wear rate of -75.947 microns at a sliding speed of 3m/s with 10N load and a wear rate of -76.66 microns for pin lubricated with engine oil. For pins lubricated with both CPO and Engine oil, the trend line indicates that when the load increased the wear rate also increased. A good lubricant is expected to reduce the wear rate. In this study, at lower load, SAE 20W40 performs well and CPO performs well in higher load conditions. To further confirm this statement a tribological behaviour test will be done on the pin lubricated with CPO at 150N load the result will be compared with the pin lubricated with SAE 20W40 at the same load condition.

4.4 Weight loss of the Pin

Wear can be expressed as mass loss in grams. To measure the weight loss specimen, the weight of the specimen was taken before and after each experiment. Figure 4.9 shows the comparison of weight loss of specimen at different loads for various lubricants. From the figure it is clear that an increase in load offers more weight loss for both lubricants.

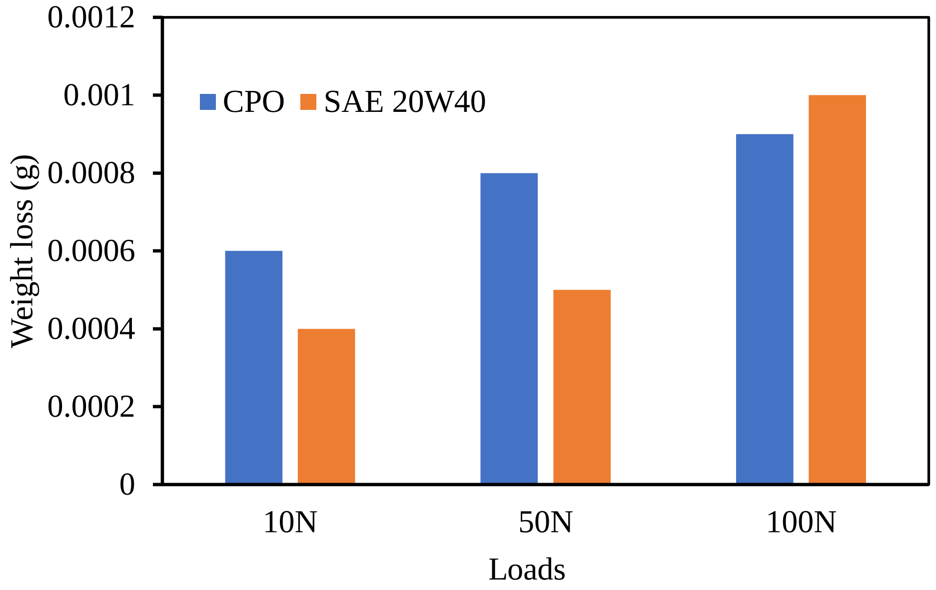


Figure 4. 9: Increment of Weight loss with an increase in loads for different lubricants

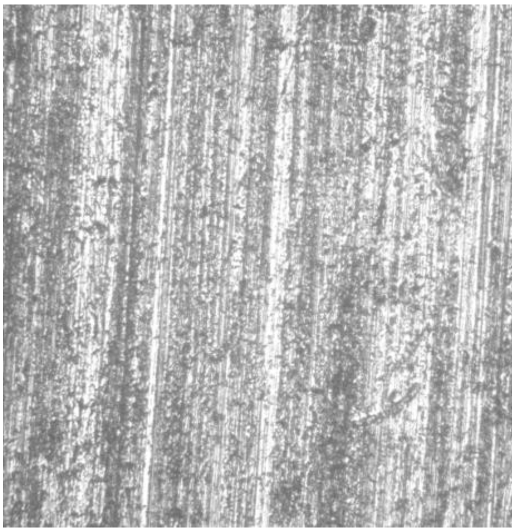
Pin lubricated with SAE 40 engine oil has the lowest value of weight loss is .0004g at 3m/s speed with 10N load and the highest value of weight loss is .001 for the pin lubricated with engine oil 100N load. Pins lubricated with CPO have higher weight loss in 10N and 50N load compared to SAE 40 lubricants. But in the case of 100N load, the weight loss of Engine oil is higher than CPO.

When a thick lubricating layer is formed between the contact surfaces, then there are fewer chances of direct metal to metal contact between pin and disc surfaces, compared to a thin lubricating layer. Thus when a thick lubrication layer is present between surfaces there is a chance of less wear. In room temperature, the viscosity of SAE 20W40 is higher than the CPO. So, the SAE 20W40 produces a thick lubricating layer at a lower temperature. From figure 4.9 it is clear that the pin lubricated with SAE

20W40 oil has a lower wear rate compared to CPO at 10N and 50N. But viscosity index of CPO is higher compared to SAE 20W40 indicating higher stability of CPO tribo films at a higher temperature compared to commercial mineral oils [13]. So, in case of an applied load of 100N wear in pin lubricated with CPO less than the pin lubricated with SAE 20W40.

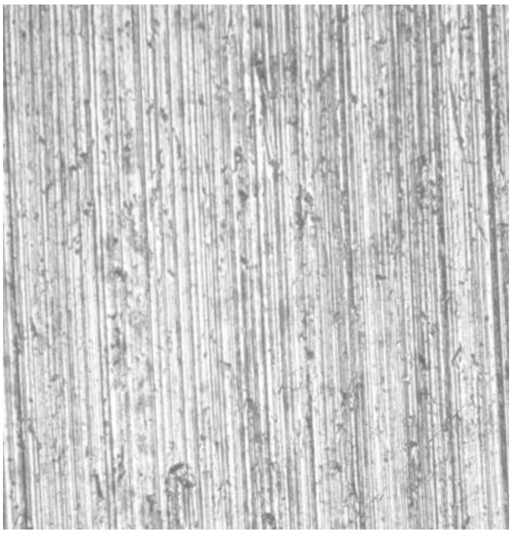
4.5 Examination of the worn Surface

It can be seen from the microscopic image that a lot of parallel, continuous and deep plunging groups exist on the wear surface of the pin specimen. The wear surface is in some places reveals purchase from where the material was removed from the surface of the specimen during wear. The ware in surface lubricated with CPO shows a smoother surface compared to the pin lubricated with SAE 20W40 for 10N and 100N applied load. But for 10 N load pin lubricated with SAE 20W40 has a smoother surface compared to the pin lubricated with CPO. Theoretically, metal-material contact area will increase in increase and produce an increase in wear scare, while less metal contact

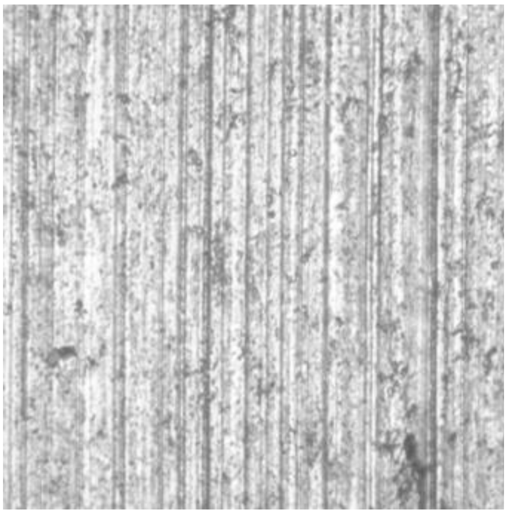


CPO, 10N

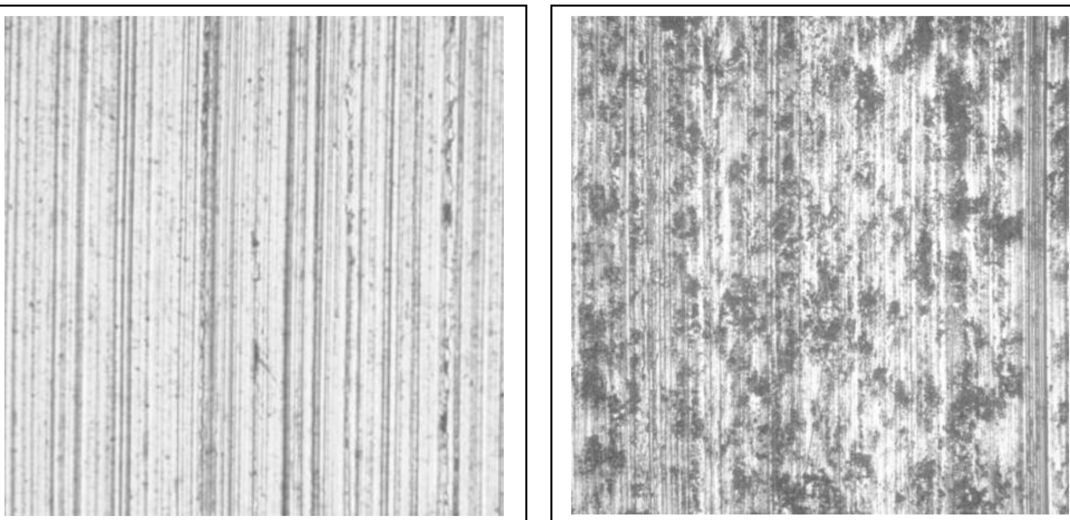
SAE 20W40, 10N



CPO, 50N



SAE 20W40, 50N



CPO, 100N   SAE 20W40, 100N

Figure 4. 10: Images of wear worn surfaces observed using a microscope (10X)

occurs shows smaller wear scare. As the load increases from 10N to 100N, the wire scare track of the pin surface observes that the pin lubricated with CPO shows a smoother Image of wear worn surfaces observed using a microscope surface compared to the ware scare track lubricated with SAE 20W40. The greater the wire scares the worse the lubricity [7]. For this reason, lubricity is also termed as a substantial anti ware property.

CHAPTER 5: SUMMERY AND CONCLUSION

The present work indicates that CPO can be potential alternative to petroleum-based mineral lubricant. The coefficient of friction decreases as the load is increased. Pin lubricated with CPO has higher coefficient of friction for 10N load and for 100N load COF is lowest. The results strongly suggest that COF is inversely proportional to the load applied. The result also showed that pin lubricated with SAE 20W40 oil has a lower wear rate compared to CPO at 10N and 50N. But viscosity index of CPO is higher compared to SAE 20W40 indicating higher stability of CPO tribo films at a higher temperature compared to commercial mineral oil. So, in case of an applied load of 100N wear in pin lubricated with CPO is less than the pin lubricated with SAE 20W40. This suggests that CPO performs well in higher load conditions. Further research need to be done to determine tribological properties of CPO for higher load conditions.

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