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# Tribological Evaluation of Mineral Oil and Vegetable Oil as a Lubricant

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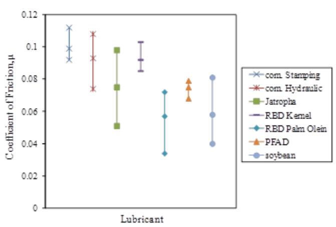
**Graphical abstract**




**Abstract**

Environmental pollution issue has made humankind tend to choose plant based oil instead of mineral based oil especially in lubrication usage. This decision is make based on several useful characteristic of plant oil where they are rapidly biodegradable, renewable, excellent lubricants and inexpensive to produce. Even though this oil show poor stability of oxidation and unfavorable properties at low temperature, currently researchers have proven that by altering the structure of plant oil it could solve this problem. Thus, several vegetable oil has been selected which are palm oil, jatropha oil and soybean oil to be test their performance in lubrication system for stamping and hydraulic purpose. These plant oils will be tested according to ASTM D 4172 and ASTM D 2783 by using four-ball tester machine. This experiment will be focus on the performance of plant oil as a lubricant and the effects of wear on the ball bearing based on the influence of the characteristics of plant oil itself.

*Keywords*: Four-ball tester machine; anti-wear and extreme pressure condition; wear behaviour

**Abstrak**

Isu pencemaran alam sekitar telah membuatkan ramai orang memilih minyak berasaskan tumbuhan berbanding sumber lain sebagai pelinciran. Keputusan ini dibuat berdasarkan beberapa ciri yang berguna dalam minyak tumbuhan seperti sifat biodegradasi, boleh diperbaharui, pelinciran dan murah untuk dihasilkan. Walau bagaimanapun, minyak ini menunjukkan ciri pengoksidaan yang rendah dan tidak menjadi pilihan penggunaanya pada suhu yang rendah. Para penyelidik telah membuktikan bahawa dengan mengubah struktur minyak tumbuhan dapat menyelesaikan masalah ini. Oleh hal demikian, beberapa minyak sayuran telah dipilih seperti minyak sawit, minyak jatropha dan minyak kacang soya untuk menguji prestasi sistem pelincirannya dalam penekapan dan sistem hidraulik. Minyak-myak ini diuji mengikut ASTM D 4172 dan ASTM D 2783 dengan menggunakan mesin four-ball. Fokus eksperimen ini, untuk melihat prestasi minyak tumbuhan sebagai pelincir dan kesan-kesan kehausan pada bebola galas berdasarkan pengaruh ciri-ciri minyak tumbuhan yang digunakan.

*Kata kunci*: Mesin penguji four-ball; anti-kehausan dan keadaan tekanan terlampau; sifat kehausan



## ■1.0 INTRODUCTION

Greenhouse effect and pollution phenomenon that occurred are attributed by mineral based oil usage. Mineral oil has contributed in the erosion of ozone layer and affect to the soil and waterways in long term period. This is occurs due to the effect of the toxic and non-degradable properties of mineral oil. Besides, the carbon percentage that released in the air will increase cause by reaction of mineral oil.

Now days, it can be see that the amount of petroleum demand is high due to the increasing industrialization, modernization and development. It has been recorded that the final energy consumption in Malaysia during year 2008 has risen at an annual growth rate of 7.2% from 1990 [1,2]. In European Union, it has been reported that their petroleum consumes is approximately 320,000 tonnes per year. This petroleum is use in the purpose of metalworking fluids where this mineral oil-base fluid can increase productivity, acting as coolant by giving high quality of manufacturing operation and as lubricant during metal cutting and forming process. Even though this oil is very useful, it also contributes to environmental hazard which at least two-thirds of used oil needs to be disposed. There has a report state that about 80% of all occupational diseases of operators were due to skin contact with cutting fluids. For example in USA, approximation about 700,000 workers of one million is exposed to the metalworking fluids. The complex composition of this fluid and the amount of microbial toxin contain could give harm to the human skin such as irritation or allergy [1-3].

Many countries have realized that vegetable oil has highly potential to be commercial in industrial and automotive sector. Therefore researchers around the world try to study deeply about vegetable oil that is high availability in each area. For example soybean is produce in large quantity in United States for food products and now the function has been improve in automotive sector as soybean biodiesel and becoming primary sources for biodiesel in this country. Other research has study the differential between commercial available biodegradable hydraulic oil fluids with soybean oil. The result shown that soybean is not very useful due to their poor oxidation stability. However, mid-oleic soybean oil and high-oleic soybean oil gives excellent thermo-oxidation stability and low temperature flow property when blended with polyalphaolefin (PAO) and additive combinations, and is acceptable for most industrial applications [4-6]. In United States it is possible to produce soybean oil in good quality and in large quantity because this country is one of the world's leading producers and exporters of soybean oil.

In Malaysia country, the highest demand of vegetable oil is from palm oil and this oil also been considered as potential alternative fuel for diesel engine. Previous research has tested palm oil for milling process; palm oil has proved that the surface roughness produce much smooth and tool life become longer. The result is also same to the sunflower oil when been tested to drill machine [7,8].

In India, coconut oil could be considered as high availability oil in this country and there has a case that this oil is been used as lubricant in two stroke engine. From the other research, coconut oil has been test for machining application which is metal cutting. The result is the coconut oil showed the best performance at depth of cut, cutting speed and the feed rate. Beside the surface roughness produce at the specimen surface is smooth compare to the mineral oil. This high demanding oil now days has been testing to be used in industrial sector [9-11].

Even though there has technology to extract oil from soybean, palm and coconut, later those producing country will face problem to meet demand for food, automotive and industrial sectors. Competition of edible oil sources as food with fuel makes edible oil not an ideal feedstock for biodiesel and lubricant production [12-14]. Researcher has found that jatropha oil which is non-edible oil has potential to be used as biodiesel oil and it also been tested to be used as lubricant in industrial sector. There have several researches that study the performance of jatropha oil [15,16]. However, a research has proven that different location of jatropha plantation will give different result. For example, jatropha oil obtain from Guantanamo and the derived fatty acid ethyl esters (FAEE) have higher acid, peroxide and p-anisidine values compared to the jatropha oil and derived FAEE from the jatropha planted in San Jose. It is not worth to plant jatropha in Malaysia because the properties of jatropha oil will give different value compare to the other place even though this plant is drought-resistance plant capable of surviving in abandoned and followed agricultural land. The best way is by comparing the non-edible palm oil with any jatropha oil.

Previous research has compared the performance of jatropha oil, palm oil and soybean oil. Jatropha oil has less activation energy value than palm oil and this causes that jatropha oil reflect less sensitive toward changing of temperature. Jatropha oil gives good result in wear test while palm oil shows better friction behavior. Due to the higher saturated molecule content, palm oil bio-lubricant shows much more stability than jatropha oil. Besides jatropha oil shows the same value in viscosities index with palm oil which is 186 while soybean oil a little bit higher which is 190. Viscosities index represent the index of lubricant viscosities characteristic when temperature changes are applied. This shows that when the lubricant has high viscosity index, it viscosity is less change at high temperature. This kind of lubricant is more preferable because it can maintain their performance by maintaining their viscosity [17].

**Table 1** Properties of plant based bio-lubricant

| Fluid | Crude jatropha oil | Palm oil bio-lubricant | Esterified soybean oil |
|---|---|---|---|
| Viscosity (Cst) | | | |
| 40(°C) | 51.73 | 52.4 | 56.58 |
| 100(°C) | 10.75 | 10.20 | 10.90 |
| Viscosity Index (VI) | 186 | 186 | 190 |
| Pour point (°C) | 8 | -5 | -6 |

Even though previous research has state that vegetable oils is less effective when comparing the mineral oil for extreme load, it should be some way to overcome this problem and the vegetable oils can be used for stamping or hydraulic application. In this experiment, seven different oil have been test which are commercial stamping oil, commercial hydraulic oil, jatropha oil, PFAD, RBD Palm olein oil, Palm kernel oil and soy bean oil.

## ■2.0 EXPERIMENTAL

The main component that involve in this experiment is four-ball tester machine, bearing and lubricant. The lubricant will be test through ASTM D 4172 and ASTM D 2783 [18]. The way to evaluate both properties of for ball-test are different which is by measuring wear scar diameter and the normal load where welding occur for anti-wear and extreme pressure condition respectively [21-23]. The increment of applying load for extreme pressure will begin at 80kg load and stop after all vegetable oils have failed functioning.

The wear scar is measured purposely to identify the effectiveness and the limit of lubricant as a lubrication of a system. The diameter of wear scar is used as an indicator for the comparison of different lubricant and condition. By using CCD microscope, the wear scar at the three balls bearing can be measured right after finish a set of experiment. The diameter of wear scar is measured by using either ellipse or line tools with accuracy of 10 micrometer. While wear scar surface will be look under optical microscope at 1000x magnificent. Wear condition can be categorized into three major types which are adhesive, abrasive and corrosive [19,20].

## ■3.0 RESULTS AND DISCUSSION

The result for this experiment will discuss in two sections which are section 3.1 and section 3.2 for anti-wear and extreme pressure condition respectively.

### 3.1 Anti-Wear Condition

Vegetable oil has produce lowest value of coefficient of friction at two rubbing metal compared to the mineral based oil is due to fatty acid molecule contained inside the vegetable oil structure [17, 18]. In Figure 1, jatropha oil has performed as good as mineral based oil in term of friction coefficient while the rest of vegetable oil give lower value than jatropha oil except RBD kernel. However, the rubbing metal that been lubricated by vegetable oil has resulting higher mean value of wear scar diameter compared to mineral based oil as shown in Figure 2. Commercial stamping oil lubricant has produced mean wear scar diameter value around 800µm and if compared to the wear value after using vegetable oil as lubricant, it can be see that the different is not to high and show that this vegetable oil has some characteristic to prevent wear from happened. This higher value of wear scar diameter is happened because of presenting free fatty acid inside the vegetable oil. This free fatty acid is the product of hydrogenation process that takes place during running the experiment and it will contribute to the corrosive effect to the metal. Due to rubbing process, the protective layer of ball bearing has wear out and causes the inner part to be exposed to free fatty acid of the vegetable oil. The inner metal surface has high possibility to be oxidized by reacting with this free fatty acid within one hour time rubbing process. This will cause the physical properties of inner metal surface change to brittle and experience corrosive wear instead of erosive wear. Besides, this is also one of the factors that cause the surface roughness of wear scar become worst. By referring to Figure 4, surface roughness value when use vegetable oil as lubricant is mostly is high except soybean oil lubricant. Soybean oil always shows good behavior in anti-wear testing and this must be affecting with their high value of viscosity at 75°C compared to other vegetable oils. In addition, the mean value of flash temperature parameter (as shown in Figure 3) for soybean oil is quite high compared to the other vegetable oil and this shows that this oil could sustain the applying load and well perform as a lubricant at this condition. Figure 5 shows the correlation between the wear scar surface roughness and the coefficient of friction.

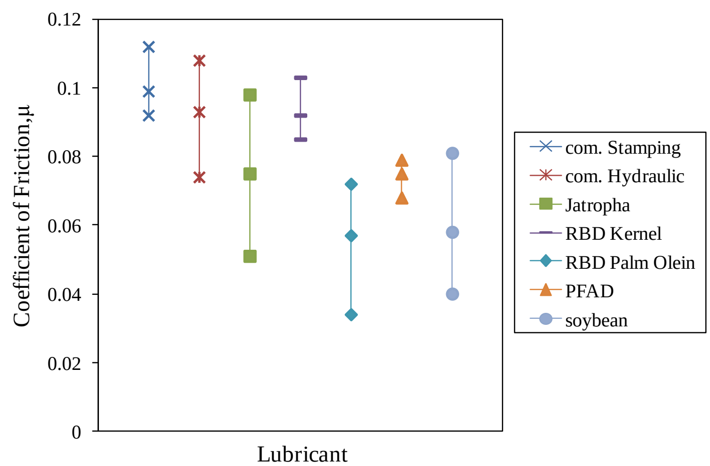



**Figure 1** Coefficient of friction distribution for all experimental conditions

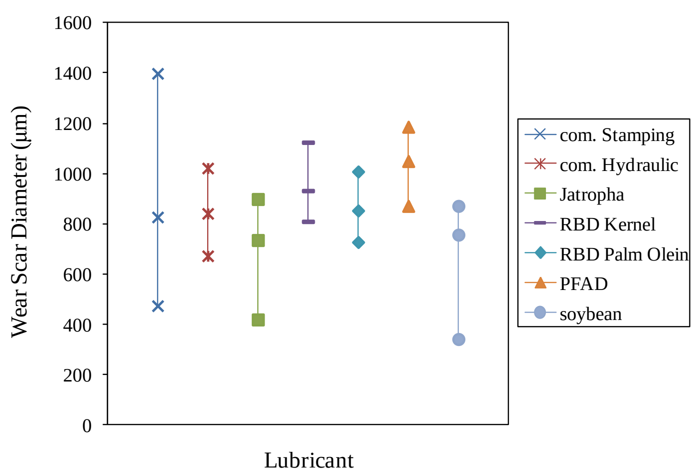



**Figure 2** Wear scar diameter distribution for all experimental conditions

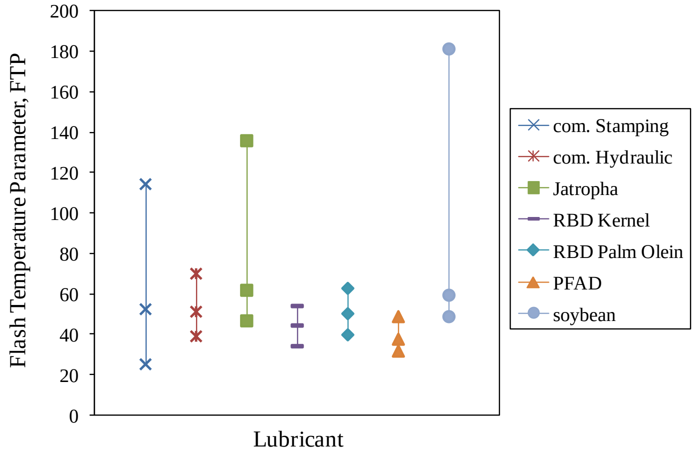



**Figure 3** Flash temperature parameter distribution for all experimental conditions

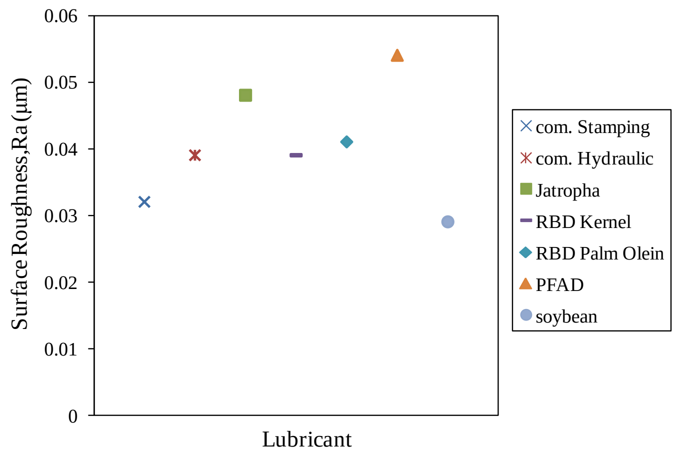



**Figure 4** Surface roughness of worn scar for all experimental conditions

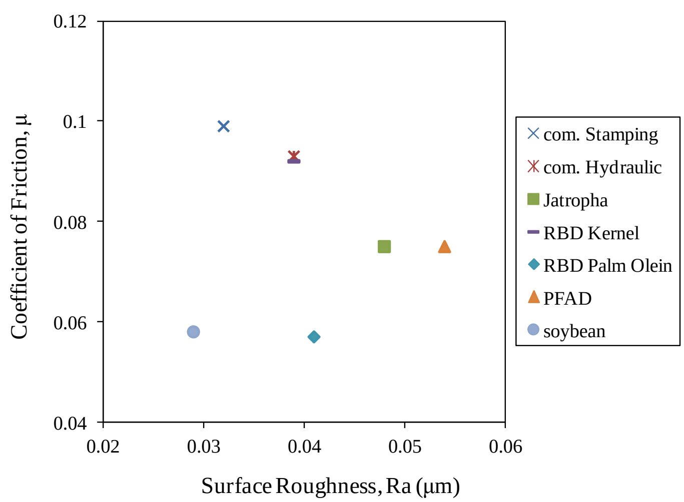



**Figure 5** Coefficient of friction distribution against surface roughness for all experimental conditions

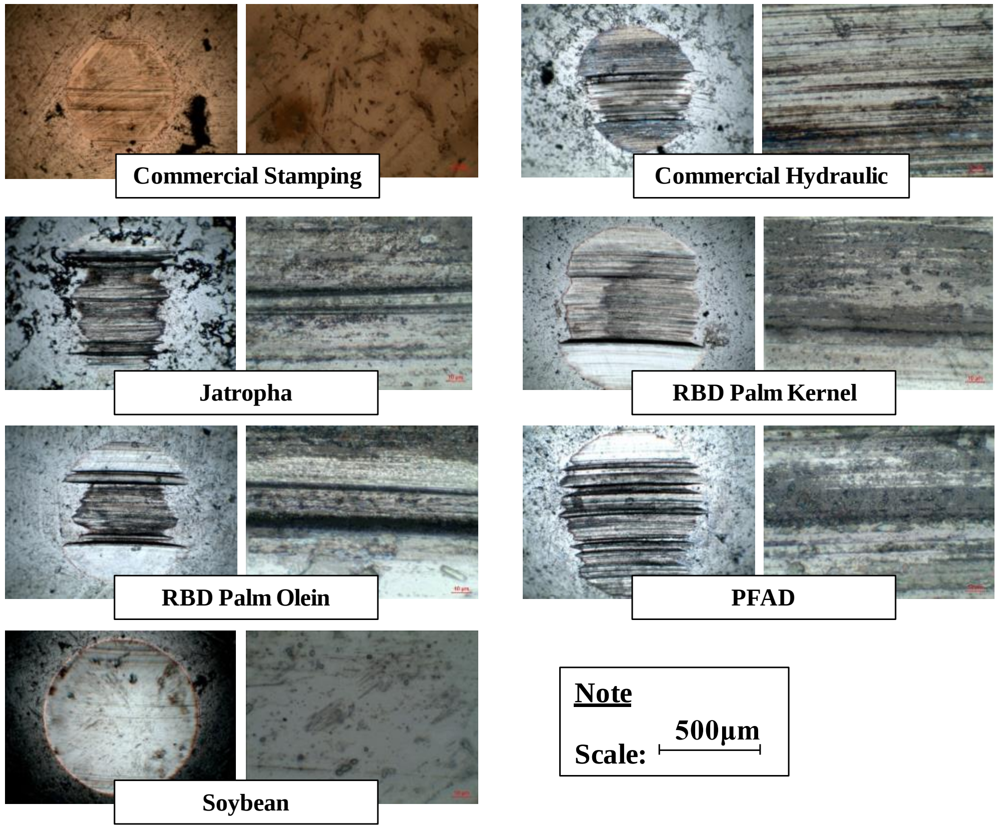



**Figure 6** Worn scar image at 100x and 1000x magnification for ASTM D 4172

Referring to the 100x magnificent row (as shown in Figure 6), it can be seen that when using commercial stamping and soybean oil as lubricant it will produce a complete round shape of wear scar and smooth surface while the other oil produce rough wear surface. It can be see clearly the plough produce on the wear surface. The worst ploughing produce is by using PFAD oil as lubricant where it produces a lot of plough and deep indenting.

The wear scar produce is most likely due to the effect of abrasive wear. Abrasive wear is the situation where the material loss from the surface when sliding across another surface under load. The material of the surface contact that undergoes work hardening during rubbing process is highly potential to experience abrasive wear. The material removal by abrasive action can cause by cutting or wedge forming. It depends on the penetration depth and hardness of material [6, 20].

The result of abrasive wear is different between ductile and brittle material. Ductile material will face three modes of wear which are by micro-cutting, wedge forming and ploughing. Each mode will produce different type of wear particles and strongly depending on the hardness of material. While in brittle material, the wear occur is because of indenting and ploughing effect. It will increase the possible wear volume by presenting the lateral crack during process and it wear rate will be influence by the fracture toughness.

Wear condition that can be seen at 1000x magnificent row (Figure 6) shows that the scar produce at smooth surface is just a small scar with verity directions or can be said as micro-cutting while for the rough surface has produce same direction of ploughing and deep indenting. This shows that the wear effect on metal surface for commercial stamping and soybean lubricant is happen on ductile material while the rest of tested oils are effect on brittle surface. This has proven that the physical properties of the metal surface have change from ductile to brittle.

## 3.2 Extreme Pressure Condition

Figure 7 and Figure 8 represent the value coefficient of friction and wear scar diameter produce respectively. From both graph it can be conclude that when coefficient of friction value increase, the wear scar diameter produce also increase and this is contra to the result gain at anti-wear condition. Extreme pressure test will look for the performance of oil at high load or severe condition. The failure of the oil is not influence of corrosive effect but under factor of strength of the molecule structure itself.

Vegetable oils that been tested have limit to work under high load which about below 160 kg load where the wear scar diameter produce is bigger than 4 mm. It seen that only commercial stamping oil can sustain until load 160kg in it capable to bear more load without fail. Even though commercial hydraulic oil has about same mean value of flash temperature parameter with commercial stamping oil as shown in Figure 3, but their capability to provide thin layer film has limit until 160 kg. Most of vegetable oils have a lot of similar performance as commercial hydraulic oil.

From this experiment, the wear scar surface produce is quite interesting where it can be see that there have smooth surface, shear surface and wedge metal forming. Figure 9 represent the wear scar surface condition at 126kg applying load. This point has been chosen to look for their wear surface because some of tested oil have fail their function, some are about to fail and some of oil still perform well. From this figure, only commercial stamping oil has produce smooth surface and it is suit with the purpose of this oil as stamping lubricant. At this load, the oxidation stability of this commercial oil getting weak and it also causes abrasive wear to occur. These micro-cutting shapes are happened at ductile material and represent hardness of the surface. Wear scar surface for jatropha oil and RBD palm olein oil is similar where there have a lot of shear surface at the middle of scar and also has wedge cutting at the edge or scar. This shear surface is due to adhesive wear while the wedge cutting is due to abrasive wear at brittle surface. The edge of wear scar getting brittle and this happened must be influence by excessive oxygen present during experiment.

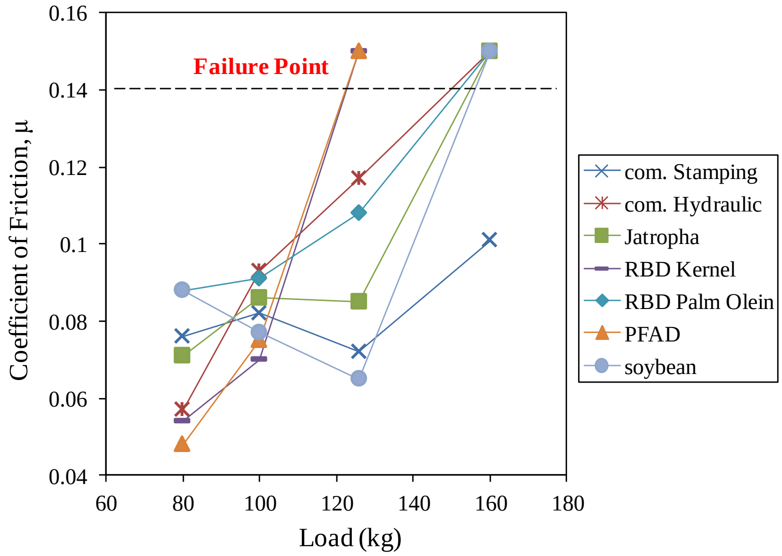



**Figure 7** Coefficient of friction against load

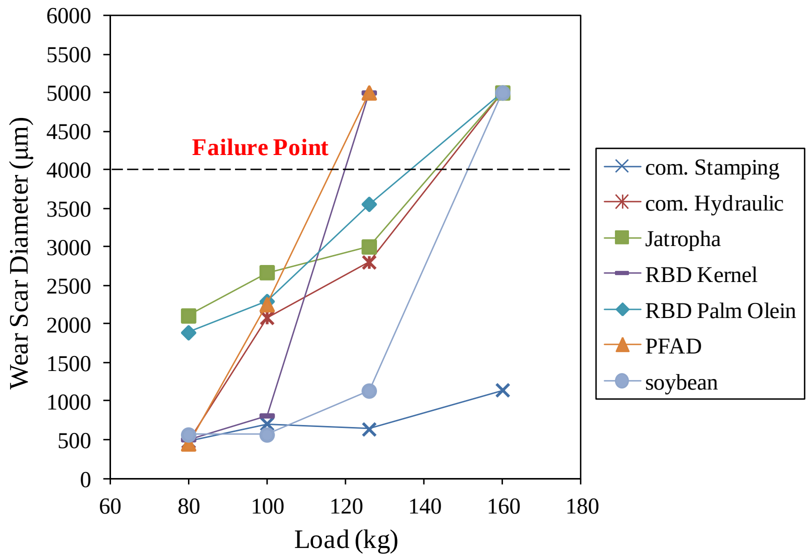



**Figure 8** Wear scar diameter against load

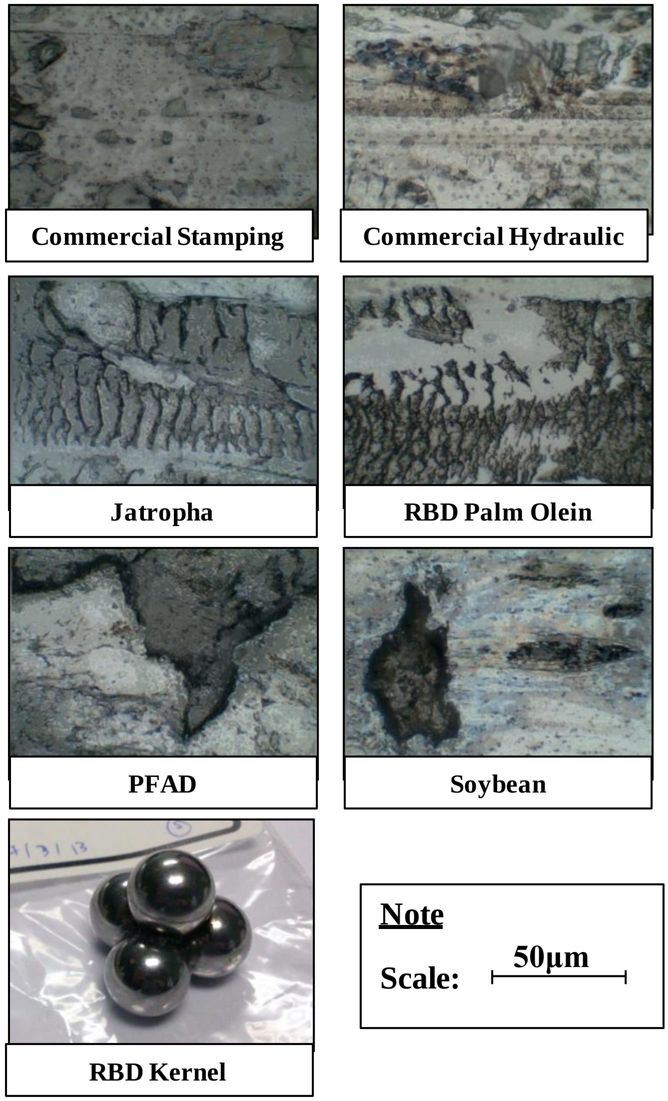



**Figure 9** Worn scar image at 1000x magnificent for ASTM D 2783

## ■4.0 CONCLUSION

Most of vegetable based oil produces lower coefficient of friction compared to the mineral based oil due to fatty acid molecule contained. While free fatty acid molecule that produce through hydrogenation process will promote the propagation of wear scar. Average, pure vegetable oils that been tested have fail functioning as lubricant at 126 kg and 160 kg load. Viscosity value of pure vegetable oil will influence the performance of oil at high temperature and load. Jatropha, RBD palm olein and soybean oil have almost similar performance with commercial hydraulic oil in anti-wear and extreme pressure condition.

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