Jurnal Tribologi

MYTRIBOS Malaysian Tribology Society

Received 13 Dec 2014; received in revised form 21 Feb 2015; accepted 2 Mac 2015.
To cite this article: Farhanah and Bahak (2015). Engine oil wear resistance. Jurnal Tribologi 4, pp.10-20.

Engine oil wear resistance

A.N. Farhanah*, M.Z. Bahak

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
*Corresponding author: nurulfarhanahazman@gmail.com

HIGHLIGHTS

- *Engine oil from three different manufacturers with the same SAE viscosity grade available in market does not mean it will have the same lubricity for an engine.*
- *The best lubricant performance would have minimum friction and wear at the same time able to operate at any temperature.*

ABSTRACT

Lubricants play a vital role in an internal combustion engine to lubricate parts and help to protect and prolong the engine life. Lubricant also will help to reduce wear by creating lubricating film between the moving parts hence reduce metal-to-metal contacts. Engine oil from three different manufacturers with the same SAE viscosity grade available in market does not mean it will have the same lubricity for an engine. In this study, commercial mineral lubrication oil (SAE 10W-30) from three manufacturers was investigated to compare the lubrication performance at three different temperatures (40˚C, 70˚C and 100˚C) in 60 minutes time duration by using four ball wear tester. The speed will be varied from 1000 rpm to 2500 rpm. Results show that all three lubricants have different lubricity performance; the smaller the wear scar, the better the lubricant since the lubricant can protect the moving surfaces from direct metal-to-metal contact occur.

Keywords:
| Four-ball tribotester | Wear | Friction | Lubrication | SAE 10W-30 |

1.0 INTRODUCTION

Lubrication is very important in industrial world where it's widely used in transportation, and all machinery. Lubricant is used in order to reduce the friction between two moving surfaces or reduce metal to metal contact. It also can improve the efficiency of machine or engine where it protects them against wear and corrosion hence maximizes their life (Duzcukoglu and Sahin, 2010; Imran et al., 2013; Quinchia et al., 2014). The use of lubricant is very important in an internal combustion engine to lubricate parts and help to protect and prolong the engine life. The quality of the lubricating oil used in the engine plays an important role in prolong the engine life and improve the performance of an engine.

Wear may affect engine life; increase in wear rate will decrease the engine life. Wear is depending on the thickness of the oil or viscosity. It is because in order to minimize wear, thick oil film will have separated the surfaces of the rubbing components (Gangopadhyay et al., 2007). Wear will give a big impact on economic since wear is the main factor of failure in lubricated machinery (Shizhu and Ping, 2012). Furthermore, Kunc et al., mentioned that friction and abrasion between rubbing surfaces are the main factors that affect the wear in engine. Basic wear that can be found in lubricated machinery are surface fatigue, abrasive wear, adhesive wear, corrosion wear, fretting wear, electrical wear, erosion wear and cavitation wear. All this type of wear may come from either contact or noncontact wear. Contact wear occurs when two surfaces have metal-to-metal contact, while noncontact wear occurs although there is no direct contact between the surfaces. A lubricant should provide stable lubrication film between two moving surfaces in order to minimize friction. It's because reduction in friction is one of the functions of a lubricant. Friction and abrasion between rubbing surfaces are the main factors that affect the wear in engine (Kunc et al, 1952). High friction will cause wear and surface damage because friction has a strong correlation with wear. But, high friction does not always have high wear and it's not always direct (Fawzy, 1993).

According to Watson et al. wear in engine usually occurs in pistons rings, cylinders, bearings and cam lobes. But, wear occurs frequently in pistons rings of an engine. Simon and Huang mentioned that the performance of piston ring/engine cylinder bore system in an internal combustion engine will affect the efficiency and durability of engines. This statement has been supported by Jiang and Wang where it stated that failure of an engine usually caused by wear that occurs at the cylinder bore and piston rings. The components that usually affects by abrasive wear are piston/cylinders, swash plates, journal bearings, gears, cams and rolling element bearings (Shizhu and Ping, 2012). Contaminations seem to be the factor that affects engine bearings, camsvalve train, piston rings and cylinder liners. Contaminations were abrasive based on observed scars and debris generated between metallic test surfaces (Enzhu et al., 2013).

The author was used four-ball tribotester to conduct the experiment because many researchers used four ball wear tester to measure friction and wear in their experiment. Previous research has used four-ball tribotester to study the effect of load on the tribological performance of refined, bleached and deodorized (RBD) palm olein (Syahrullail et al., 2013). Other research also used four-ball wear tribotester to investigate the wear prevention characteristics of Palm oil-based TMP (trimethylolpropane) ester as an engine lubricant (Zulkifli et al. 2013). Another researcher was conducting an experiment to study the role of soot particles in the tribological behavior of engine lubricating oils by using a four-ball-tester (Enzhu et al., 2013). Besides that, wear rate of lubricated surfaces were determined by using four-ball wear (Wright et al.,1989). In other research, four-ball tester was used to investigate Jatropha oil as lubricant oil and was compared with hydraulic mineral oil (Golshokouh et al., 2013).

Viscosity of oil plays a vital role in selecting a lubricant because correct lubricant will help to maximize engine life. Society of Automotive Engineers (SAE) has developed viscosity classification to engine oils to describe the kinematic viscosity. For example, in a SAE 10W-30 engine oil, the ‘W’ signifies winter and the first number in the description of SAE 10W-30 indicates the flow of the oil at cold temperatures where the lower the number, the better the flow at cold temperatures. While, the second number indicates the minimum viscosity requirement at 100 to ensure satisfactory lubrication at the final operating temperature. Increased in temperature will increased the viscosity where it will prevent the oil from thinning (Pereira et al. 2007). Temperature has a big effect on viscosity and oil film thickness; viscosity will decrease when the temperature is high where the oils molecules are crack into smaller molecules (Syahrullail et al., 2013). Hence, it will encourage additive and base oil failure. Viscosity of engine oil will influence the wear resistance characteristics of an engine. Engine oil from three different manufacturers with the same SAE viscosity grade available in market not necessarily has the same lubricity performance in an engine. So, the purpose of this article is to determine the anti-wear ability of three different engine oils with the same SAE viscosity.

2.0 METHODOLOGY

Four-ball tribotester machine were used in this experiment to determine the anti-friction and anti-wear ability of the test lubricant. Figure 1 shows the schematic diagram of four-ball tribotester which contain oil cup assembly, collet and ball bearings. These experiments were carried out in different temperatures and speeds by following American Standard Testing Material ASTM D4172. The lubricants that will be used are three different fresh SAE 10W-30 engine oils available in the market. Conditions in this experiment were as follows: temperature: (40˚C, 70˚C and 100˚C) and speed: (1000, 1500, 2000 and 2500 rpm). Moreover, the load will be kept constant at 392N when different speeds are applied. The duration of this experiment was 60 minutes for each test.

Viscosity plays an important role in lubricant ability where it's a criterion need to be looking before the selection of the lubricant. Different oil will have different viscosities. Oil film thickness depends on the viscosity and it can affect wear between two moving surfaces. There are two types of viscosity: kinematic and dynamic. Equation (1) shows the dynamic viscosity correspond to kinematic viscosity (ASTM D445-10):

$$\eta = \upsilon\rho \times 10^{-3} \quad (1)$$

where η is the dynamic viscosity (mPa.s), υ is the kinematic viscosity (mm^2/s) and ρ is the density (kg/m^3).

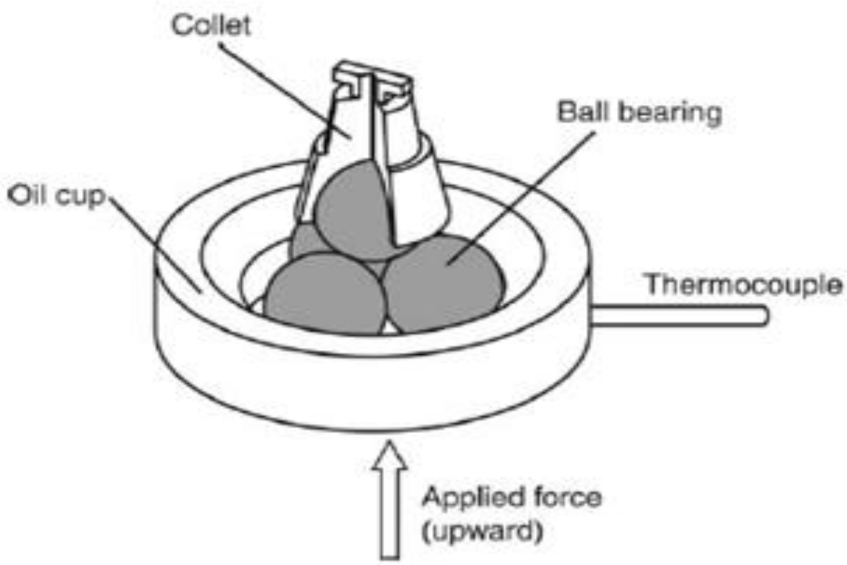


Figure 1: Main part of the four-ball tester [18]

Equation (2) shows the correlation between coefficient of friction with temperature and frictional torque [12]. Coefficient of friction has a direct relationship with frictional torque and has an inverse relationship with temperature.

$$\mu = 0.22248 \times \frac{T}{W} \quad (2)$$

where μ is the coefficient of friction, T is the frictional torque (kg.mm) and W is the applied load (kg). The wear scar diameter on the three stationary balls was measured to compare the lubricant. The test oil on the three stationery balls shall be drain and wipe using fly paper. The wear scar diameter was measured by using high resolution microscope which can be viewed on the computer by using 100× magnifications. The wear scar and wear worn on ball specimens were compared between different oil manufacturer at different temperature and speed in order to evaluate the quality of the lubricant.

3.0 RESULTS AND DISCUSSION

3.1 Kinematic Viscosity

Lubricants wear performance depends on the working temperature. So, the viscosity was taken at three temperatures (40°C, 70°C and 100°C) by using rotating viscometer in accordance with ASTM D445 to compare the lubricant performance under different temperature. The relationship between temperature and kinematic viscosity is shown in Figure 2. In general, it shows that viscosity have an inverse relationship with temperature where increased in temperature will decreased the viscosity. Viscosity of the Oil A at 40˚C is the lowest (only 27%) compared to Oil B and Oil C, while Oil B and Oil C having almost the same viscosity at the same temperature. At both temperatures 70˚C and 100˚C; both Oil A and Oil C having the same viscosity, while for Oil B viscosity was slightly higher. It shows that the viscosity of a lubricant will be influences by the temperature. Study shows that thinner oil will move more easily compare to thicker oil. In this finding increase in temperature will increase the fluidity and dilution of lubricant [18]. In addition, higher viscosity usually has high anti-friction and anti-wear ability so from this graph Oil B has the best lubricity performance followed by Oil C and Oil A.

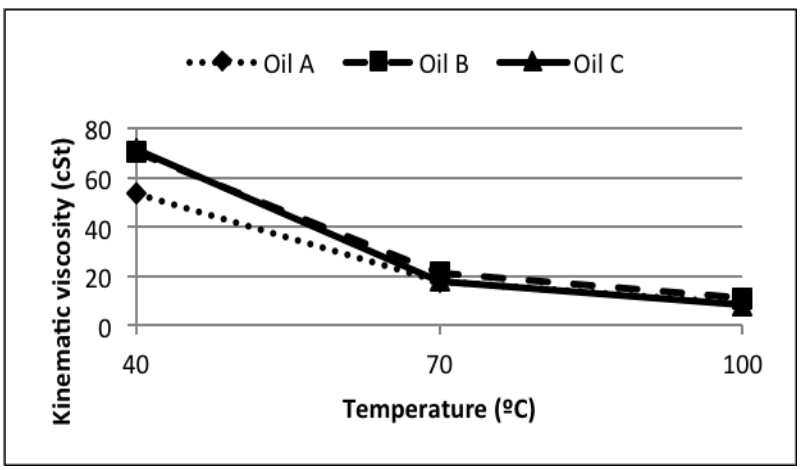


Figure 2: The relationship between temperature and kinematic viscosity for SAE 10W-30

3.2 Friction

Figure 3 shows that friction coefficient for Oil A increased as the speed increased. But, Oil B and Oil C shows different trends where friction coefficient obtained reduced to the increment of speed. In this case Oil B and Oil C were more viscous than Oil A. So, at the same speed and load, both lubricants were able to increase the fluid film thickness and create high separation distance between the two surfaces compared with Oil A. That's why both lubricants have lower coefficient of friction. Furthermore, high speed will generate high pressure. Increase in pressure will help the surface apart and prevent surface contact hence reduced the friction coefficient. On contrary, the reduction in pressure or at low speed, the pressure will act in all directions and squeeze all the oil outs hence direct metal-metal contacts will occur.

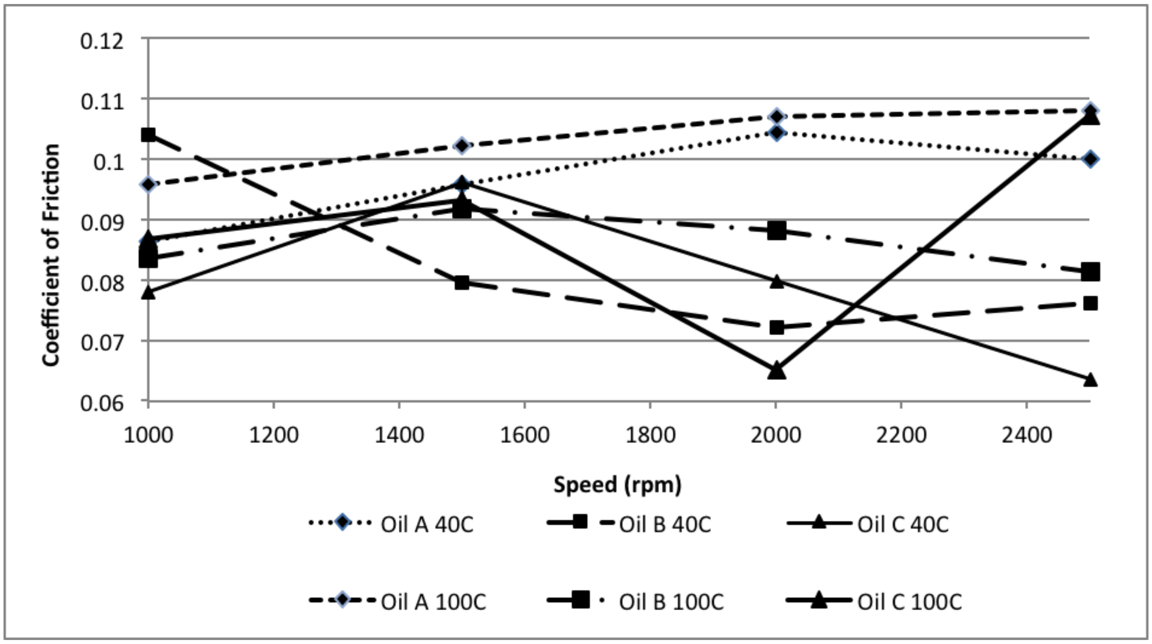


Figure 3: Relation of friction coefficient with speed under 40°C and 100°C temperature

The friction coefficient decreased with increasing in speed due to a change in lubrication conditions from more boundary to more hydrodynamic (Gangopadhyay et al., 2007). When the lubricant has fall into hydrodynamic lubrication, increase in speed will increase in fluid film thickness. Consequently, friction coefficient will fall as the film thickness rise (Kovalchenko et al., 2005). These findings support previous research by Serrato et al. which found that friction decrease as the speed increase because of better separation between two moving surfaces since increase in speed will increase in oil film thickness. In addition, Hsu et al. stated that under boundary lubrication, fluid film between the contact surfaces will be form when the lubricant molecules react with the surface where it was influence by the oxidation of the lubricant.

While, for Oil A as the sliding speed increase, viscosity of the oil will influence the coefficient of friction to increase because it might be under hydrodynamic lubrication. In hydrodynamic lubrication, the oil's viscosity should be maintained under all conditions but when the viscosity reduced too much direct metal-to-metal contact will occur. Moreover, increase in speed will increase the temperature of the rubbing surfaces which will creates much thinner oil film thickness. So, it is difficult to separate the two moving parts and to lower the temperature. Moreover, it is possible that Oil A did not have enough additive that will help to increase the oxidation of lubricant. These findings similar to other researcher result which states that the increase in friction with sliding distance or speed for fresh oil seem to be due to the low formation of a surface film by zinc dialkyldithiophosphate (ZDDP) additive (Moon and Yoshitsugu, 1990).

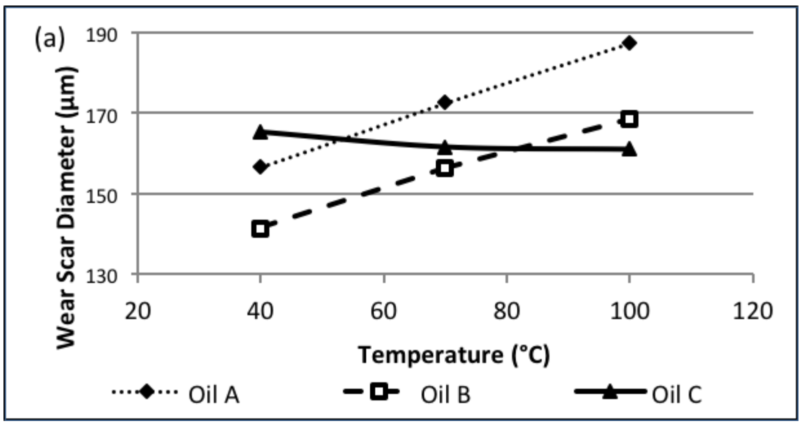
Besides that, Figure 3 also shows that the raised in temperature give a significant effect on friction coefficient for all three lubricants. At low speed (1000 rpm), it clearly shows that Oil A has the lowest anti-friction ability since it has greatest instability during the change of temperature. While at high speed (2500 rpm), Oil C have the best anti-friction ability below 100. But, at 100 Oil B has a decrease in coefficient of friction which it shows that Oil B was the best lubricants compared to others at high speed and temperature. The significant reason for the increase in friction coefficient is because friction is really depending on the lubricant viscosity where the viscosity is affected by the temperature. The possible reason of reduction in friction coefficient with an increase in temperature was due to the change in viscosity and the formation of the oxide film at the rubbing surfaces (Al-Araji and Hussein, 2011).

3.3 Wear Scar Diameter

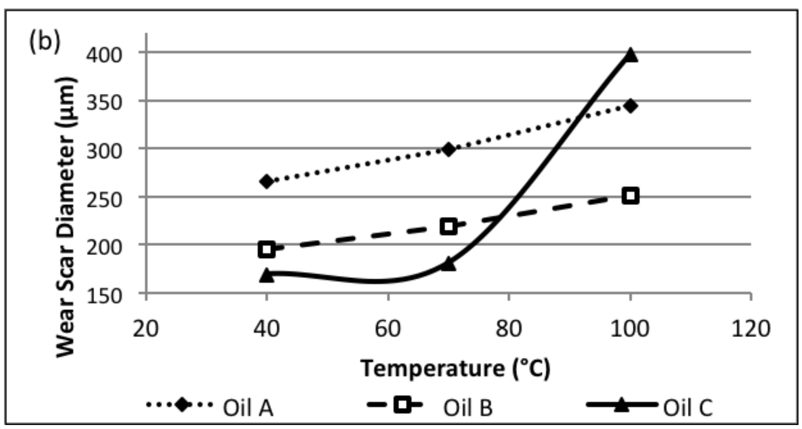
In Figure 4(a) shows wear scar diameter (WSD) increases gradually with an increase in temperature except for Oil C lubricant where increase in temperature will only slightly reduces the wear scar diameter. While, Figure 4(b) shows a proportional increase in WSD at elevated temperature for fresh oil SAE 10W-30 of Oil A, Oil B and Oil C.

The reason for this findings is because increased in temperature will influence the anti-wear films form faster because the interaction between surfaces and additives become more chemically and physically active due to more energy input [24]. Other researcher also stated that the thickness of the oil film will influence the anti-wear capability of the lubricating oils (Fawzy, 1993). In addition, at high temperature thin oil film layer were created so the gap between the upper and lower balls were reduced where it increased the interaction between the lubricants and the metal surfaces hence raised the WSD.

The wear scar diameter for fresh oil SAE 10W-30 of Oil A, Oil B and Oil C under different speed at different temperature was plotted in Figure 5(a) to (c). It’s obvious from the three figures WSD was depends on the rotational speed where WSD increase gradually with increase in speed. Figure 5(a) shows that WSD of both lubricants Oil B and Oil C were increase slightly as the speed increase, however for Oil A (Figure 5(a) to (c)) increases in speed will increase the WSD dramatically. The first significant reason for the rapid increase in WSD for Oil A might be because the oil may contain less antioxidant additive where antioxidant additive will help to form a surface film to reduce metal-to-metal contact and hence reduce wear. Antioxidant additives were added into the engine oil formulations to slow down the rate of oxidation where it plays their role for stabilization purpose and enhances other performance of lubricant (Rudnick, 2009). Oxidation stability of oil must be maximized to prevent from oxidation of the oil. This is because oxidation of the oil may lead to an increase in wear. The addition of correct amount of antioxidant additive to a lubricant will help in preventing direct oxidation of metal surface and surface layer formations, thus, reduces friction and wear (Gangopadhyay, 2007).



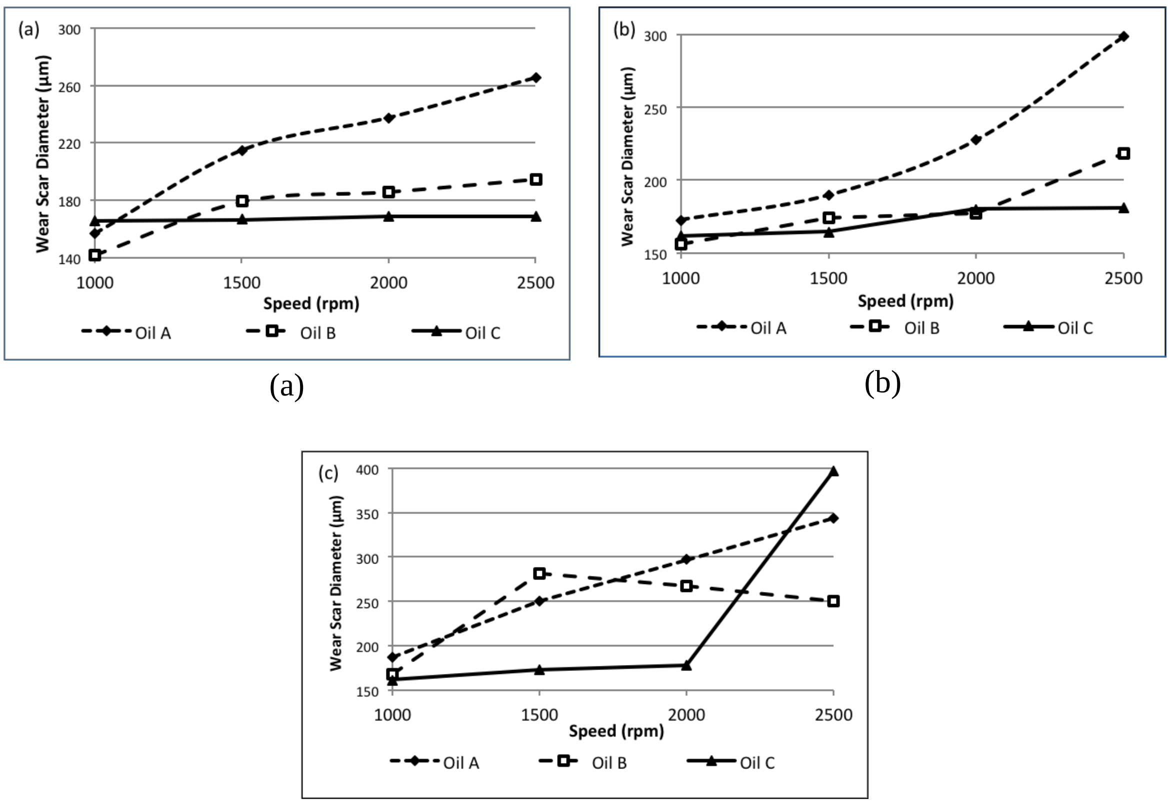
(a)



(b)

Figure 4: The effect of temperature on the wear scar diameter measured at (a) 1000 rpm; (b) 2500 rpm speed for fresh oil SAE 10W-30

In addition, Oil C maintains stability versus speed change for both temperature 40˚C and 70˚C. But, at 100˚C Oil C only maintain its stability below 2000 rpm. Oil C has good anti-wear ability compared to others lubricants only at low temperature. On the other hand, Oil B maintains its stability at elevated speed for both temperature 40˚C and 70˚C. It also has a good anti-wear ability at high speed and high temperature (Figure 5(c)). It might be that Oil B have active additive where it keeps the oil film uniform in order to avoid metal-to-metal contacts. On top of that, increase in speed will support low load hence create high pressure. At high speed thick oil film will be generated which makes the interaction between the lubricant and the metal surfaces minimal. This evidence shows that the lower the wear scar diameter, the better the lubricant is. As a consequence, Oil C has the better anti-wear ability for all three temperatures except at high speed of 100˚C, while Oil B has good anti-wear ability at the high speed engine and at high temperature. This study indicates that although the oils have the same SAE viscosity grade (SAE 10W-30), it does not mean that the oil will have the same lubricity performance because the lubricant for different manufacturer may contain different additive composition and the additive only active at certain temperature.



(a) (b)

(c)

Figure 5: Wear Scar Diameter versus Speed at (a) 40˚C, (b) 70˚C and (c) 100˚C for fresh oil SAE 10W-3

CONCLUSION

This experiment was conducted to determine and compare the anti-wear ability of three different engine oils of the same SAE viscosity available in market at three different temperatures and at different speeds. The following conclusions can be drawn based on the findings of the study:

1. Increased in temperature will reduced the viscosity.

2. The temperature and speed also have a significant influence on the wear scar diameter.
3. Lubricant will have a good anti-wear ability when the wear scar diameter is lower.
4. Oil C provided the best anti-wear and anti-friction ability at low temperature while Oil B has the good lubricity performance at high temperature and high speed.

ACKNOWLEDGEMENT

The author acknowledges Faculty of Mechanical Engineering, Universiti Teknologi Malaysia for their support during this study.

REFERENCES

Al-Araji, N. and Hussein, S., 2011. Effect of temperature on sliding wear mechanism under lubrication conditions. International Journal of Engineering, 5, 176-184.

ASTM D445-10. Standard test method for kinematic viscosity of transparent and opaque liquids (and calculation of dynamic viscosity).

Duzcukoglu, H. and Şahin, O.S., 2010. Investigation of wear performance of canola oil containing boric acid under boundary friction. Tribology Transactions, 54, 57-61.

Enzhu, H., Xianguo, H., Tianxia, L., Ling, F., Karl, D.D. and Hongming, X., 2013. The role of soot particles in the tribological behavior of engine lubricating oils. Wear, 304, 152-161.

Fawzy, M.H.E, 1993. The friction and wear of fresh and used engine oils during reciprocating sliding. Wear, 169, 167-172.

Gabi, N., 2013. The importance of variable speeds under extreme pressure loading in molybdenum disulfide greases using four-ball wear tests. Tribology Transactions, 56, 977-985.

Gangopadhyay, A.K., Carter III, R.O. and Simko, S., 2007. Valvetrain friction and wear performance with fresh and used low-phosphorous engine oils. Tribology Transactions, 50, 350-360.

Golshokouh, I., Syahrullail, S., Farid, N.A. and Mohamadali, G., 2013. Jatropha oil as alternative source of lubricant oil. Life Science Journal, 10, 268-276.

Hsu, S.M., Munro, R. and Shen, M.C., 2002. Wear in boundary lubrication. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 216, 427-441.

Imran, A., Masjuki, H.H., Kalam, M.A., Varman, M., Hasmelidin, M., Al Mahmud, K.A.H., Shahir, S.A. and Habibullah, M., 2013. Study of friction and wear characteristic of jatropha oil blended lube oil. Procedia Engineering, 68, 178-185.

Ing, T.C., Rafiq, A.K.M., Azli, Y. and Syahrullail, S., 2012. Tribological behaviour of refined bleached and deodorized palm olein in different loads using a four-ball tribotester. Scientia Iranica B, 19, 1487-1492.

Jiang, Q.Y. and Wang, S.N., 1998. Abrasive wear of locomotive diesel engines and contaminant control. Tribology Transactions, 41, 605-609.

Kovalchenko, A., Ajayi, O., Erdemir, A., Fenskea, G. and Etsion, I., 2005. The effect of laser surface texturing on transitions in lubrication regimes during unidirectional sliding contact. Tribology International, 38, 219-225.

Kunc, J., McArthur, D., and Moody, L., 1952. How engines wear. SAE Transactions, 61, 221-223.

Moon, W.S. and Yoshitsugu, K., 1990. Wear-preventing property of used gasoline engine oils. Wear, 139, 351-365.

Pereira, G., Lachenwitzer, A., Kasrai, M., Bancroft, G.M., Norton, P.R., Abrecht, M., Gilbert, P.U.P.A., Regier, T., Blyth, R.I.R. and Thompson, J., 2007. Chemical and mechanical analysis of tribofilms from fully formulated oils Part 1 – Films on 52100 steel. Tribology, 1(1), 48-61.

Quinchia, L.A., Delgado, M.A., Reddyhoff, T., Gallegos, C. and Spikes, H.A., 2014. Tribological studies of potential vegetable oil – based lubricants containing environmentally friendly viscosity modifiers. Tribology International, 69, 110–117.

Rudnick, L.R., 2009. *Lubricant Additives Chemistry and Application*. 2nd Ed. United State of America: Taylor & Francis, 3-50.

Serrato, R., Maru, M.M. and Padovese, L.R., 2007. Effect of lubricant viscosity grade on mechanical vibration of roller bearings. Tribology International, 40, 1270–1275.

Shizhu, W. and Ping, H., 2012. *Principles of Tribology*. Singapore: John Wiley & Sons (Asia) Pte Ltd.

Simon, C.T. and Huang, Y., 2004. Modeling of abrasive wear in a piston ring and engine cylinder bore system. Tribology Transactions, 47, 17-22.

Syahrullail, S., Wira, Y.J., Wan Nik, Y.B. and Fawwaz W.N., 2013. Friction characteristics of RBD palm olein using four-ball tribotester. Applied Mechanics and Materials, 315, 936-940.

Watson, C.E., Hanly, F.J., and Burchell, R.W., 1955. Abrasive wear of piston rings. SAE Transactions, 63, 717-728.

Wright, M.S., Jain, V.K. and Saba, C.S., 1989. Wear rate calculation in the four-ball wear test. Wear, 134, 321-334.

Zulkifli, N.W.M., Kalam, M.A., Masjuki, H.H., Shahabuddin, M. and Yunus, R., 2013. Wear prevention characteristics of a palm oil-based TMP (trimethylolpropane) ester as an engine lubricant. Energy, 54, 167-173.