The Investigation into the Effect of Viscosity to the Friction and Wear Behaviour of Automotive Gear Oils

by

Shahida Shazlin binti Saidin

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

____

(AP. Dr. Mustafar bin Sudin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SHAHIDA SHAZLIN BINTI SAIDIN

ABSTRACT

Improvements in vehicle performance have created additional need for more sophisticated gear oil. Different automotive gear system contains many different components, each having its own requirements for lubrication such as viscosity, power transmission, anti wear, etc. Potential mechanical engineer must be well equipped with the knowledge regarding oil characteristics and performance of an engine system. Unable to exactly identify the tribological problems in the engine and gearbox could seriously affect the performance of the vehicle. The objective of the project is to identify the effect of viscosity of automotive gear oils on friction and wear scar produced. Viscosity is one of the most important properties in automotive gear oil. It is important to investigate the effect of the viscosity on friction and wear behaviour. Thus, the oil properties which affect the friction and wear behaviour can be distinguished and better gear oil can be produce in the future.

Four ball wear test has been conducted to investigate the effect of viscosity on the friction and wear behaviour of automotive gear oil. The Multi-Specimen Tester is used to conduct the four ball wear test and TAMSON-Ubbelohde viscometer is used to conduct the viscosity test. The four ball wear test is done according to the ASTM standard which is ASTM D 4172-94; Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four Ball Method), and the viscosity test is done according to ASTM D 445-09; Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids. The viscosity test is conducted at two temperatures which is 40˚C and 100˚C. Three four ball wear test is conducted on each type of gear oil in order to get more accurate results. From the viscosity test conducted, Gear Oil B has the highest viscosity at both temperatures which is 152.29 cSt at 40˚C and 19.67cSt at 100˚C, while Gear Oil D has the lowest viscosity at both temperatures which is 112.12 cSt at 40˚C and 14.42 cSt at 100˚C. From the four ball test conducted, the wear scar obtained by using Gear Oil D as lubricant is the largest with an average diameter of 443.33μm while the wear scar obtained by using Gear Oil B is the smallest with an average diameter of 409.11μm. This indicates that gear oil with higher viscosity gives better protection from friction and wear.

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First of all, my deepest gratitude to Allah SWT, the Lord of Universe for his blessings and guidance in various aspects for me to accomplish my final year project entitled 'The Investigation into the Effect of Viscosity on the Friction and Wear Behaviour of Automotive Gear Oils'. Special thanks to my parents and family members for their continuous support and encouragement towards me all this while in completing this project.

This Final Year Project has given me lots of useful knowledge and experience n preparing myself to the next stage of life which is career life. First and foremost, I wish to thank my Supervisor, AP Dr Mustafar bin Sudin for his valuable advice, nonstop guidance, motivational support and positive criticism to me which has helped me a lot, right from the start of this project until I am finally able to complete this project. He has driven me beyond my preconceived limits which enabled me to discover my new strengths and capability thus make this project a success.

I also want to thank Mr Munir for his guidance and assistance in conducting the Four Ball Wear Test. He has been a great help during the whole experimental process. A high appreciation to all Mechanical Department technicians especially Mr Faizal, Mr Kamarul, and Mr Irwan for their assistance in all the experiments carried out to complete this project. This project would never been a success without support and technical assistance from all of them.

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Without all of them, I would not have been able to accomplish and meet the objective of this project in total.

Hopefully this project will provide the readers with more knowledge and understanding towards automotive gear oils.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Gears are required in vehicles manufactured today and the past. It is used to transfer the engine power to the driving wheel. All of the gearing needs lubrication. There are wide ranges of gear system in different application requirement. Therefore, there are ranges of performance level required from gear oil to meet mild to severe operating condition of the gears. Gear oil has been commonly considered elementary, but in fact, its development is a dynamic process that requires sophisticated technology. Gear oil has been improved by adding additives to increase its performance. Extreme pressure agents, foam suppressors, anti wear compounds, viscosity index improvers and corrosion inhibitors are examples of additives that have been added into gear oil to enhance its performance. The investigation into the effect of viscosity on the friction and wear behaviour by using automotive gear oil is a must nowadays as the performance requirements of gear oil has increase. Through the study, the effect of viscosity on friction and wear behaviour will be recognized.

1.2 Problem Statement

Most vehicles operate under severe service conditions as defined by vehicle manufacturers, but the majority of vehicles owners are unaware of this. Severe service applications include towing, hauling, off-road use, frequent stop-and-go driving, steep hill driving and temperature extremes. Severe service applications are on the rise. For example, more than 90 percent of Ford Super Duty pickups are used for towing. Severe service increases the need for better gear oil or lubrication [1].

In automotive differentials the ring and pinion are spiral-cut, hypoid gears. It slides more on each other than other types of gears. Although spiral-cut gears allow for quieter operation, under load their extreme sliding action can wipe the oil film from between the gears [1]. High level of extreme-pressure additives are used to protect these gears when the oil film is wiped away or ruptured. High friction and wear in automotive gears will shorten the life of the gears and vehicle. Therefore, it is important to reduce friction and wear between the gears as it will affect the performance of the vehicle. The basic requirement that relates to the function of the automotive gear oil is its influence upon friction and wear characteristics of a system. Viscosity is one of the oil properties that might gives effect to friction and wear of the gears.

1.2.1 Problem Identification

Different types of automotive gear oil give different protection to the friction and wear of an automotive gear. Viscosity is one of the most important properties in gear oil. Different range of viscosity value will leave different effect on the friction and wear of a gear. Therefore, investigation into the effect of viscosity on the friction and wear behaviour by using different type of automotive gear oil is necessary. Other than lubrication, automotive gear oil also functions as a medium to prevent metal to metal contact between the automotive gears. It is used to prevent the friction and wear of the automotive gears. By conducting this project, it can be identify whether viscosity plays a big roles in preventing the friction and wear of the gears. Through appropriate test and analysis, hopefully, it can be known whether the viscosity will leave significant effect to the friction and wear. Furthermore, the investigation into the effect of viscosity on the friction and wear behaviour by using automotive gear oils could help the author as the future mechanical engineer to familiarize with machine and equipment used when conducting the project. The author could also utilize her knowledge gained during the four years of studies and apply it in the project. Other than that, the results obtained could also help other students in their research related to automotive gear oils.

1.2.2 Significant of the Project

This project will help in determining whether the viscosity leaves significant result in the performance of automotive gear oil towards preventing friction and wear between the automotive gears. In the future, this research might provide contribution to the automotive engineers in designing or producing new type of gear oil. Extreme friction and wear in the automotive gears will disturb the performance of a vehicle. A damage gearbox could cause the vehicle owner a lot of money. Prevention is better than cure. Therefore, this project is important to recognize the effect of one of the oil property, which is viscosity to the friction and wear behaviour.

Furthermore, as a future mechanical engineer, it is important to gain experience on how to conduct test on oils as engineer will be dealing with this kind of environment in their work. Experience gained during conducting this project and knowledge utilized will be a valuable lesson to the author in the future. With proper study and proper test conducted, the author will gain extra knowledge regarding automotive gear oil, and the effect of viscosity on the friction and wear behaviour. Hence, it is important to investigate the effect of viscosity on the friction and wear behaviour by using automotive gear oil for future benefits.

1.3 Objectives and Scopes of Study

The objectives of this project are:-

1. To study on automotive gear oils in term of their viscosity, friction and wear properties and perform testing using viscometer and four ball wear test method.
2. To compare and relates the viscosity of the oils to their wear and friction properties in term of wear scars on the balls and its coefficient of friction.

The scopes of study for this project are:-

The scopes of study for this project involve conducting Four Ball Wear Test on four different types of automotive gear oils. By using 12.7mm diameter steel ball to represent the real gears in vehicle. The testing parameter is done according to standard ASTM D 4172-94. Viscosity test are also conducted on the four selected automotive gear oil and the testing parameter is done according to standard ASTM D 445-09. The machine used for the testing purposes are Multi-Specimen Tester to conduct Four Ball Wear Test and TAMSON-Viscometer Unit to conduct viscosity test. While the machine involves for analysis purposes is Optical Microscope single and multi-lenses and Scanning Electron Microscope.

1.4 The Relevancy of the Project

This project is considered as a platform to study further into the automotive gear oil property specifically viscosity. Research in automotive gear oil is relevant as automotive gear oil contributes a lot in the smoothness of gear operation in an engine. Low friction and wear will increase the longevity of the vehicle's gear box and engine. Hence, this project is relevant because by knowing the effect of the viscosity on the friction and wear, improvement can be done to the automotive gear oil to prevent the friction and wear. This project is also relevant to the mechanical engineering student as through this project, the knowledge gained during the four years of studies could be applied and the skills gained can be utilized. Through this project the author will be equipped with necessary skills required to be an excellent engineer.

1.5 Feasibility of the Project within the Scope and Time frame

It is presume that the project is feasible within the scope and time frame if there are no issues with regard to equipment function and material availability. Research work is allocated to be done in this first semester where all the information and knowledge regarding this topic is gathered and studied, the testing machines and analysis equipments needed for testing is reserved, and the material needed for the project, in this case different types of automotive gear oil is purchased. The experimental work starts in second semester where all the testing in the laboratory, data gathering and results analysis of automotive gear oil will be done along with documentation of the whole project. At this point, the experimental work has completed and detail analysis has been carried out. Conclusions and recommendation has been made.

CHAPTER 2
LITERATURE REVIEW/ THEORY

2.1 Property of Gear Oil

Property of Gear Oil is very important as it determines the compatibility of the automotive gear oil with operating condition of the gearbox and differentials. Therefore, understanding on properties of automotive gear oil is essential in conducting this project. For this project, only one property of gear oil will be studied, which is viscosity.

2.1.1 Viscosity

One of the most important parameter which plays a fundamental role in automotive gear oil is oil viscosity. Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or extensional stress. In everyday terms for fluids only, viscosity is "thickness." Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction [2]. Good viscosity is essential to ensure cushioning and quiet operation. An oil viscosity that is too high will result in excess friction and degradation of oil properties associated with high oil operating temperature. In cold climates gear lubricants should flow easily at low temperature [3].

Viscosity of gear oils is a compromise between the gear parameters requiring low viscosity and those requiring high viscosity. Low viscosity is favourable for high speed, low loaded gears with a good tooth surface finish. Low viscosity provides thin oil film, low friction, and good cooling conditions. High viscosity is favourable for low speed, highly loaded gears with a rough tooth surface. High viscosity provides thick oil film, high wear resistance and low galling even at high pressure (EP) [4].

Knowing the temperature at which the oil is expected to operate is critical as oil viscosity is extremely temperature dependent [5]. Therefore oil selected for a particular gear should provide its reliable operation within the expected temperature range. The low temperature limit of gear oil is 9°F (5°C) higher than its pour point. The highest operation temperature in spur gears is about 130°F (54°C). In the worm gears the temperature may reach 200°F (93°C) [4].

It is appear that the more viscous oils would give better performance, as the generated film will be thicker and there would be a better separation of the two surfaces. But, that is not always the case as more viscous oil requires more power to be sheared [5]. Thus, more power losses and more heat generated results in an increase in the temperature of the contacting surfaces. This will lead to the failure of the component.

Kinematic viscosity is defined as the ratio of dynamic viscosity to fluid density [5]:-

$$\mathbf{v = n / \rho} \quad \dashrightarrow \quad \mathbf{1}$$

Whereby:-

v is the kinematic viscosity [m^2 / s];

n is the dynamic viscosity [Pas];

ρ is the fluid density [kg / m^3].

The most common used kinematic viscosity unit is the Stoke [St]. This unit however, is too large for practical application, thus a smaller unit, the centistokes [cSt], is used. The SI unit for kinematic viscosity is [m^2 / s] [5]:-

$$\mathbf{1\ [S] = 100\ [cSt] = 0.0001\ [m^2 / s]} \quad \dashrightarrow \quad \mathbf{2}$$

The Society of Automotive Engineers (SAE) has established a viscosity grading system for gear oils. According to the SAE viscosity grading system, all oils are divided into two classes which are monograde and multigrade [4].

Monograde gear oils are designated by one number (70, 90, 140, 250, etc.). The number indicates a level of the oil viscosity at a particular temperature. The higher the grade number, the higher the oil viscosity. Viscosity of gear oils designated with a number only without the letter "W" (SAE 80, SAE 90, SAE 140 etc.) was specified at the temperature 212°F (100°C). These gear oils are suitable for use at high ambient temperatures. Viscosity of gear oils designated with a number followed by the letter “W” (SAE 70W, SAE 75W, SAE 80W etc.) was specified at the temperature 0°F (-18°C) [4]. The letter “W” means winter. These grades are used at low ambient temperatures.

Multigrade gear oils are designated by two numbers and the letter “W” (SAE 75W-90, SAE 80W-90, SAE 85W-140 etc.). The first number of the designation specify the oil viscosity at cold temperature, the second number specifies the oil viscosity at high temperature. Viscosity of gear oils may be stabilized by polymeric additives (viscosity index improvers). Viscosity of such gear oils is specified at both high and low temperature. That is why these oils are called multigrades. For example: SAE 85W-140 oil has a low temperature viscosity similar to that of SAE 85W, but it has a high temperature viscosity similar to that of SAE 140 [4]. Multigrade gear oils can be used in a wide temperature range [4].

2.2 Gear Oil Classification

2.2.1 SAE Viscosity Classification

SAE Recommended Practice J306 classifies lubricants for use in automotive manual transmissions and drive axles by viscosity measured at 100°C, and by maximum temperature at which they reach a viscosity of 150 000 cP when cooled and measured in accordance with ASTM Standard D 2983 (Method of Test for Apparent Viscosity at Low Temperature Using the Brookfield Viscometer) [6].

This limiting viscosity of 150 000 cP was selected on the basis of test data indication that lubrication failures of pinion bearings of a specific axle design could be experienced when the lubricant viscosity exceeded the value. Since other axle designs, as well as transmissions, may have higher or lower limiting viscosities, it is the responsibility of the gear manufacturer to specify the actual grades that will provide satisfactory service under different ambient conditions [6].

Table 2.1: Axle and Manual Transmission Lubricant Viscosity Classification [6]

SAE J306 Viscosity Classification for Automotive Gear Oils			
SAE Viscosity Grade	Maximum Temperature for a viscosity of 150,000 cP (°C)	Minimum Viscosity at (cSt) a 100°C	Maximum Viscosity at (cSt) a 100°C
	ASTM D 2983	ASTM D 445	ASTM D 445
70W	-55	4.1	--
75W	-40	4.1	--
80W	-26	7.0	--
85W	-12	11.0	--
80	--	7.0	<11.0
85	--	11.0	<13.5
90	--	13.5	<18.5
110	--	18.5	<24.0
140	--	24.0	<32.5
190	--	32.5	<41.0
250	--	41.0	--

2.2.2 AGMA Specifications for Gear Lubricants

The American Gear Manufacturers Association (AGMA) have issued specifications and recommendations for gear lubricants used in various types of gear application. AGMA Standard 250.04 details specifications for rust and oxidation inhibited (R and O) and extreme-pressure (EP) lubricants used in enclosed gear drives. The viscosity brackets correspond to those given in ASTM D 2422 ‘Standard Recommended Practice for Viscosity System for Industrial Fluid Lubricants’ [6].

Table 2.2: AGMA Viscosity Grades for Enclosed Gearing

AGMA Lubricant No.	Viscosity Limits of former AGMA Classifications SUS at 100ºF	Corresponding ISO Viscosity Grade
1	193 – 235	46
2, 2 EP	284 – 347	68
3, 3 EP	417 – 510	100
4, 4 EP	626 – 765	150
5, 5 EP	918 – 1122	220
6, 6 EP	1335 – 1632	320
7 Comp, 7EP	1919 –2346	460
8 Comp, 8EP	2837 – 3467	680
8A Comp	4171 – 5098	1000

Oils marked ‘comp’ are compounded with 3 to 10% fatty material. The AGMA Standard 251.02 details specifications for three types of open gear lubricants – rust and oxidation inhibited (R and O), extreme-pressure (EP) and residual type gear oils. In this case the viscosity brackets for the higher viscosity grades are measured at 100˚ C [6].

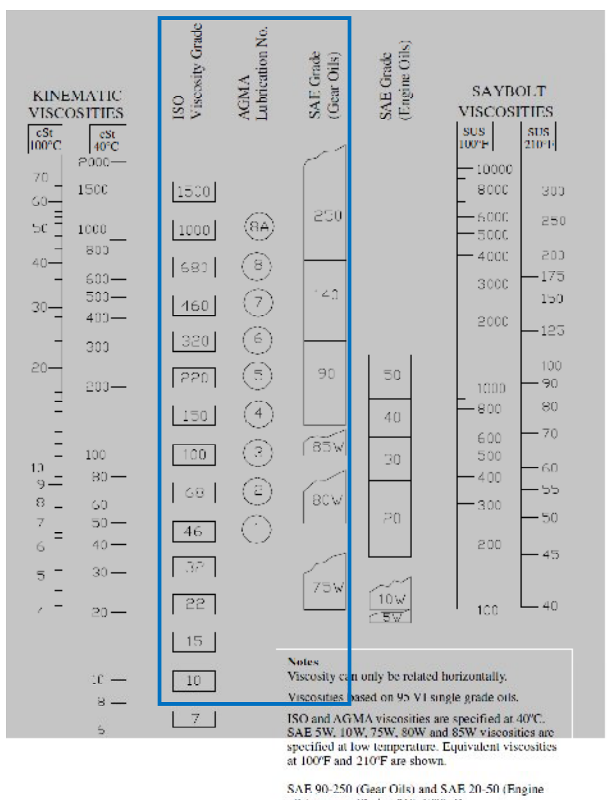


Figure 2.1: Comparison between ISO Viscosity Grade, AGMA Lubrication No. and SAE Viscosity Grade

2.3 Friction and Wear

2.3.1 Friction

Friction is the force resisting the relative lateral (tangential) motion of solid surfaces, fluid layers, or material elements in contact. When contacting surfaces move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy, or heat [7].

Varieties of friction [7]:-

- Dry friction resists relative lateral motion of two solid surfaces in contact. Dry friction is also subdivided into static friction between non-moving surfaces, and kinetic friction (sometimes called sliding friction or dynamic friction) between moving surfaces.
- Lubricated friction or fluid friction resists relative lateral motion of two solid surfaces separated by a layer of gas or liquid.
- Fluid friction is also used to describe the friction between layers within a fluid that are moving relative to each other.
- Skin friction is a component of drag, the force resisting the motion of a solid body through a fluid.
- Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.

Lubrication is a common way to reduce friction such as oil, water, or grease, which is placed between the two surfaces, often lessening the coefficient of friction. The science of friction and lubrication is called tribology. Lubricant technology is when lubricants are mixed with the application of science, especially for industrial or commercial objectives [7].

Factors affecting the friction between surfaces [8]:-

- Well lubricated surfaces
- The friction resistance is almost independent of the specific pressure between the surfaces.

- At low pressures the friction varies directly as the relative surface speed
- The friction is not so dependent of the surface materials
- The friction is related to the temperature which affects the viscosity of the lubricant.

Friction – reducing lubricants have become increasingly important in recent years. Smooth running oils have been formulated for gear lubrication, which require additives for reducing friction in the frictional region [9].

2.3.1.1 Coefficient of Friction

Coefficient of friction is a dimensionless quantity used to calculate the force of friction both static n kinetic [7]. Both static and kinetic coefficients of friction depend on the pair of surfaces in contact. The values are usually determined experimentally. Coefficient of static friction is defined as the ratio of the maximum static friction force between the surfaces in contact to the normal force while the coefficient of kinetic friction is defined as the ratio of the kinetic friction force between the surfaces in contact to the normal force. In the kinetic friction, the direction of the friction force may or may not match the direction of a motion.

Table 2.3: Approximate Coefficient of Friction

Materials		Static friction, μ_s	
		Dry & clean	Lubricated
Aluminum	Steel	0.61	
Copper	Steel	0.53	
Brass	Steel	0.51	
Cast iron	Copper	1.05	
Cast iron	Zinc	0.85	
Concrete (wet)	Rubber	0.30	
Concrete (dry)	Rubber	1.0	
Concrete	Wood	0.62[9]	
Copper	Glass	0.68	
Glass	Glass	0.94	
Metal	Wood	0.2-0.6[9]	0.2 (wet)[9]
Polythene	Steel	0.2[10]	0.2[10]
Steel	Steel	0.80[10]	0.16[10]
Steel	Teflon	0.04[10]	0.04[10]
Teflon	Teflon	0.04[10]	0.04[10]
Wood	Wood	0.25-0.5[9]	0.2 (wet)[9]

Coefficient of Friction between steel during dry condition and lubricated condition

2.3.2 Wear

The process leading to loss of material is known as "wear". Major types of wear include abrasion, adhesion (friction), erosion, and corrosion [10]. In materials science, wear is the erosion of material from a solid surface by the action of another surface. It is related to surface interactions and more specifically the removal of material from a surface as a result of mechanical action [11]. Wear is the major case of material wastage and loss of mechanical performance and any reduction in wear can result in considerable savings [5]. The need for mechanical action, in causing the wear in form of contact due to relative motion, is an important distinction between mechanical wear and other processes with similar outcomes.

Wear can also be defined as a process in which interaction of the surfaces or bounding faces of a solid with its working environment results in dimensional loss of the solid, with or without loss of material [11]. Aspects of the working environment which affect wear include loads (such as unidirectional sliding, reciprocating, rolling, and impact loads), speed, temperature, type of counterbody (solid, liquid, or gas), and type of contact (single phase or multiphase, in which the phases involved can be liquid plus solid particles plus gas bubbles) [11]. Mechanical systems such as bearing and gears are examples of components involving wear [10]. Friction and associated wear between sliding and/or rotating components is a major factor in high energy cost and fluid contamination. Significant reductions in these effects can be achieved by optimising the lubrication film between the components [12].

There is no specific standard for testing or measuring a materials wear resistance. This can be attributed to the complex nature of wear, in particular "industrial wear", and the difficulties associated with accurately simulating wear processes. A number of wear tests have been developed by committees in an attempt to standardise wear testing for specific applications. In the results of standard wear tests (such as those formulated by the respective subcommittees of ASTM Committee G-2), the loss of material during wear is expressed in terms of volume. The volume loss gives a clearer picture than weight loss, particularly when comparing the wear resistance properties of materials with large differences in density [11].

For example, a weight loss of 14 g in a sample of tungsten carbide + cobalt (density = 14000 kg/m^3) and a weight loss of 2.7 g in a similar sample of aluminium alloy (density = 2700 kg/m^3) both result in the same level of wear (1 cm^3) when expressed as a volume loss [11].

The working life of an engineering component is over when dimensional losses exceed the specified tolerance limits. Wear, along with other aging processes such as fatigue, creep, and fracture toughness, causes progressive degradation of materials with time, leading to failure of material at an advanced age. Wear is one of a limited number of manners in which a material object losses its usefulness. The economic implications can be of enormous value to industry [11].

2.4 Boundary Lubrication

When bodies come into closer contact at their asperities; the heat developed by the local pressures causes a condition which is called stick-slip and some asperities break off. At the elevated temperature and pressure conditions chemically reactive constituents of the lubricant react with the contact surface forming a highly resistant tenacious layer, or film on the moving solid surfaces (boundary film) which is capable of supporting the load and major wear or breakdown is avoided. Lubrication is the process, or technique employed to reduce wear of one or both surfaces in relative motion to one another by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces [13].

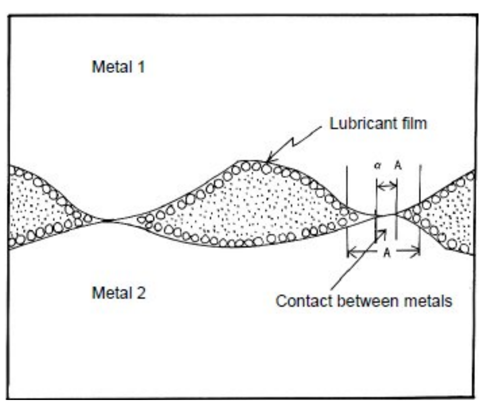


Figure 2.2: Friction surface contact model[13]

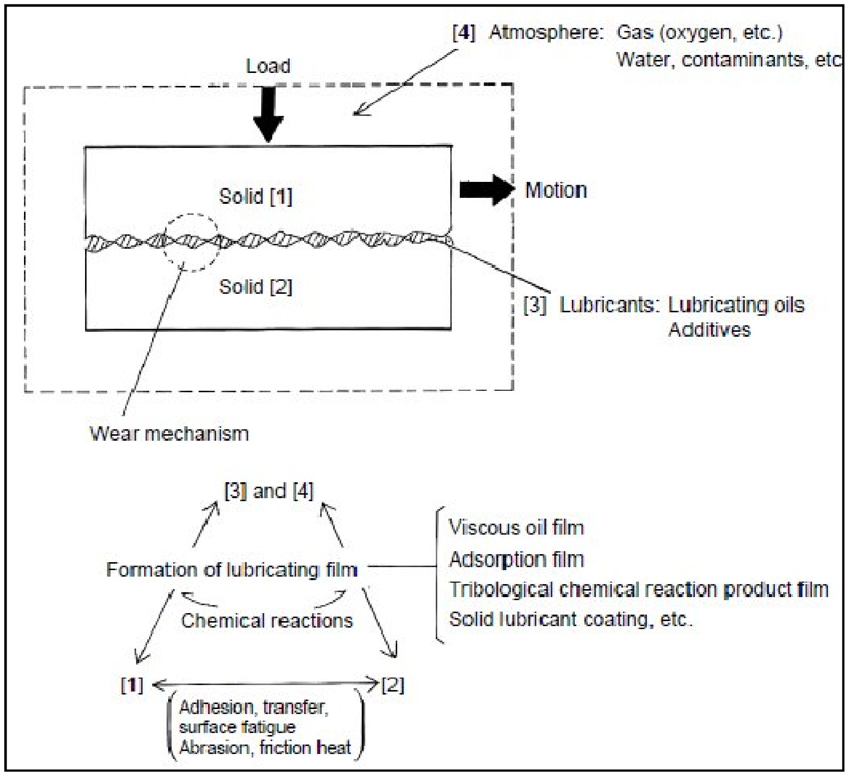


Figure 2.3: Wear under boundary condition[13]

Figure 2.2 shows the function of gear oil which lubricates the metal surface and prevent metal to metal contact thus protecting the metal surface from wear. While figure 2.3 shows the formation of wear under boundary condition. The formation of oil film reduces the friction and wear between the metal surfaces. Listed below are factors that dominate film formation for so-called boundary lubricity, in which lubricant forms lubricating films on friction surfaces, reducing friction and wear and preventing seizures [13].

(i) Formation of viscous oil films

(ii) Formation of physical or chemical adsorption films

(iii) Formation of in situ lubricating films

- (a) Formation of polymer films (for example, friction polymers) on friction surface spots
- (b) Formation of solid lubricant films

(iv) Formation of inorganic reaction product films

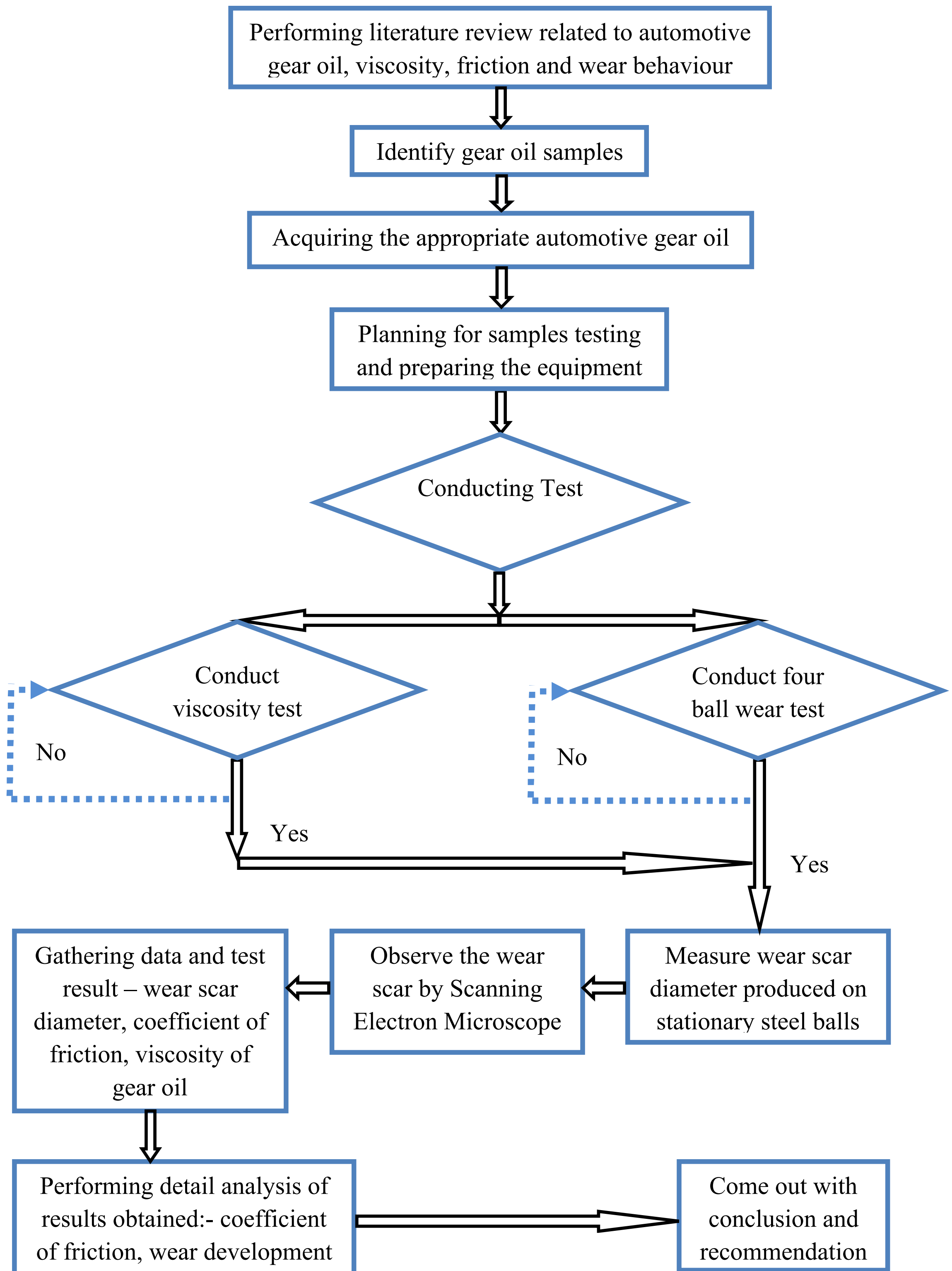
(v) Formation of solid lubricant coatings

If the lubricant contains suitable additives, reactions between the additives and the metal surfaces are released, generating reaction products which form a thin boundary layer with a lubricating effect.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology



3.2 Tools Required

The experimental process will involve the utilization of five main equipments which are:-

3.2.1 Multi-Specimen Tester – to conduct four ball wear test

3.2.2 TAMSON Viscometer unit – to conduct viscosity test

3.2.3 Optical Microscope – to observe the wear scar produced on steel ball

3.2.4 Scanning Electron Microscope – to observe the wear scar produced

3.3 Experimental Procedure

3.3.1 Friction and Wear Test by Four Ball Wear Test

The first step in the experimental process is the four ball wear test. The four ball wear test is conducted to obtain the wear scar on the steel ball by immersing the steel ball into the selected automotive gear oil.

The four ball wear tester is the predominant wear tester used by the oil industry to study lubricant properties. It has been used widely to study the lubricating properties of oils and to study interactions at wearing contacts [14]. The Four Ball Wear Test determines the wear protection properties of a lubricant. Three metal balls are clamped together and covered with the test lubricant, while a rotating fourth ball is pressed against them in sliding contact. The balls are immersed in the oil sample at a specified speed, temperature and load. This contact typically produces a wear scar, which is measured and recorded [15]. At the end of a specified test time, the average diameter of the wear scars on the three lower balls is measured [16]. The smaller the average wear scar, the better the wear protection provided by the lubricant.

According to ASTM D 4172-94; Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four Ball Method), the ball are 12.7mm (0.5in.) diameter. Loads are applied by the way the spinning ball which presses into the center of the triangular formation of the three stationary balls [14]. The load used maybe selected from 147N to 392N, while the rotation speed of the top ball is 1200rpm in 60 minutes. The temperature is 75°C and can be controlled from a heater attached to the ball pot. The ball used is from AISI standard steel ball No.E.52100 grade 25 Extra Polish.

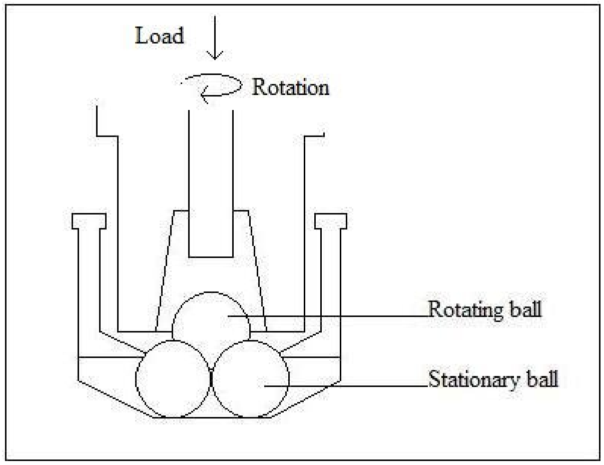


Figure 3.1: Schematic of a four ball wear tester

Figure 3.2: Multi Specimen Tester used to conduct Four Ball Wear Testing

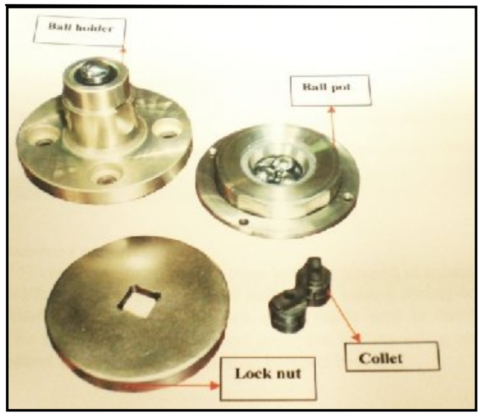


Figure 3.3: Four Ball Tester Attachment [16]

3.3.1.1 Four ball wear test procedure

The arrangement follows the ASTM standard D4172.

Procedure for tightening ball pot [17]:-

1. First clean new test balls, ball pot and collet thoroughly using solvent (hexane).
2. Insert a clean ball in collet by using ball inserter/ extractor mounted on the base plate of the machine and insert it into the spindle.
3. Place the ball pot assembly in the slot on base plate. Remove the lock nut, lift the ball race by about 5mm, insert three clean balls in the cavity, and lower the ball race to retain balls in position. Set torque wrench to the required torque value (68Nm or 50 ft lbs) by pulling out the lever from the arm and rotating in the required direction, push back the lever to lock the torque wrench.
4. Torque wrench is having an arrow mark on both sides of the handle. Make sure that while tightening, torque is applied in clockwise direction and while loosening it is in anti-clockwise direction.
5. Place lock nut over ball pot and rotate by hand till it touches the tip of ball, further tighten it with the torque wrench set at the recommended value.

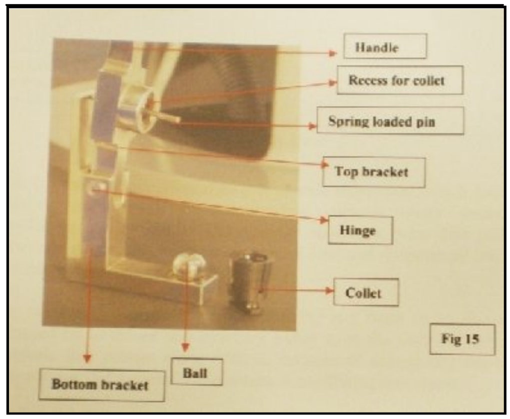


Figure 3.4: Ball inserter [16]

Procedure for inserting the top ball [16]:-

1. Place ball to be inserted at the bottom as shown (Figure 3.4).
2. Insert collet into recess at top.
3. Bring down the lever and press down handle to lock, a click sound will be uttered to indicate ball is locked.

Ball holder is made of a single unit with provision at top to fix firmly onto spindle and at bottom a taper provided to insert collet for holding a ball specimen. After tightening the ball pot and inserting the top ball into the ball holder, both parts are installed in the spindle and ready for the experiment to start [17].

For load under 500N, the machine must be load manually. Operation by manual loading [16]:-

1. Run 'Winducom 2006' software by clicking the icon.
2. Click 'run continuously' icon under the toolbar at the left corner of the screen.
3. Click the 'Power' icon to switch on the machine.
4. Set desired testing time.
5. Set desired speed and speed type.
6. Set desired temperature.
7. Set desired trip value for safety.
8. Enter file name, sample id, etc.
9. Click 'Acquire' icon.

10. Set all parameter to zero.
11. Apply balancing load at the leverage arm by put 5 kg weighting mass to balance the mechanical load.
12. Check whether the wear sensor has touched the ball holder or not.
13. Apply the load by putting the dead weight.
14. Adjust the load icon into the desired value by sliding the weighting mass slowly.
15. Click 'Run' icon to start the test.
16. When the machine has stop running, click the 'Power' icon to switch off the machine.
17. Remove the sample from the holder.

The Calculation of Wear Scar obtained through Four Ball Wear Test:-

The primary measurement from Four Ball Wear Test is wear and friction. The wear scar is produced on the three stationary balls. The wear scar is measured under calibrated optical microscope and recorded as the wear scar diameter or the calculated wear volume [14]. The wear scars resulted from the top ball rotating against each of the bottom three balls under the test load.

In order to calculate the wear scar, few assumptions are made. It is assumed that the wear occurs only on the stationary balls, and the missing material comes from spherical segments of the stationary balls that correspond to the net wear occupied by the rotating spherical ball that fits into the wear scar.

The wear scars are measured for each of the bottom three balls. In general, each of the three bottom balls will have a wear scar that is very similar in size and shape to the other two lower test balls. A measurement is made with a microscope of each wear scar diameter, in horizontal and vertical direction (x-axis and y-axis). A total of six measurements are taken, two for each ball, and then the average of the six readings is considered to be the wear scar diameter for a given test fluid under a specific test method [21].

The load cell is utilized to measure the rotational force acting on the test cup, and to thereby calculate the coefficient of friction. The torsional forces that have been measured with the load cell can be used to calculate the average coefficient of friction for a given test fluid under specific test conditions [21]. Two characteristics of a lubricant can be determined in this way:

1) The coefficient of friction of the fluid
2) The amount of wear that occurred in the presence of the test fluid under given test conditions.

3.3.2 Viscosity Test on the Automotive Gear Oils

The second step in the experimental process is the viscosity test. This test is conducted by using the TAMSON viscosity unit to obtain the kinematic viscosity of all selected automotive gear oils. For this project, viscosity test will be done using the Ubbelohde viscometer. An Ubbelohde type viscometer or suspended-level viscometer is a measuring instrument which uses a capillary based method of measuring viscosity.

Procedure for conducting viscosity test:-

1. A suitable capillary tube size will be chosen.
2. Then, the tested fluid or in this case automotive gear oil is inserted into the capillary tube.
3. After that, the tube is immersed in the synthetic fluid in the TAMSON viscometer unit.
4. Next, after the temperature has stable, the efflux time (s) of the oil is recorded. An average of three reading is taken.
5. Finally, the efflux time (s) is multiplied with the viscosity constant to get the viscosity of the oil.

The advantage of this instrument is that the values obtained are independent of the concentration [18]. Viscosity test is a test to measure a lubricant’s resistance to flow at a specific temperature by using viscometer. The drag caused by relative motion of the fluid and a surface is a measure of the viscosity. The viscosity will be measured in centistokes (cSt). Viscosity is measured at 100°C for engine oil applications.

Figure 3.5: The TAMSON Viscometer unit (Inside it, Ubbelohde viscometer)

3.3.3 Wear Scar Analysis by Optical Microscope

The third step in the experimental process is the beginning of the analysis procedure whereby the wear scar obtained from the four ball wear test will be observed under the optical microscope and the wear diameter is measured.

The optical microscope is an optical instrument containing one or more lenses that produce an enlarged image of an object placed in the focal plane of the lens [19]. Through this optical microscope (Figure 3.6), the scar is clearly seen with in the scale of eye piece, count number of divisions covering the scar along major axis. The eyepiece measurement is up to 10x [17]. Optical microscope with multi lenses is used to view and observe the wear scar in bigger magnification.

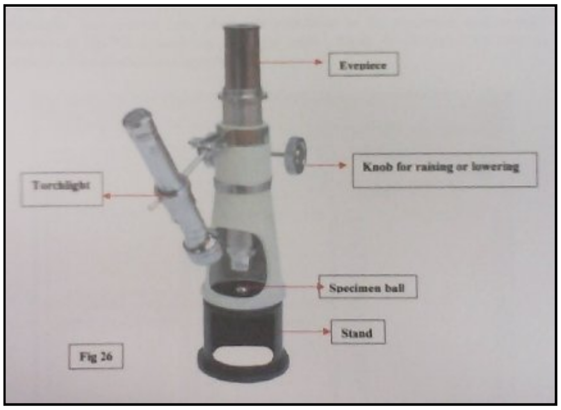


Figure 3.6: Optical Microscope [17]

Figure 3.7: Optical Microscope with multi lenses [19]

3.3.4 Wear Scar Analysis by Scanning Electron Microscope (SEM)

The use of scanning electron microscope is to analyse the wear scar produced on the steel ball in more detailed magnification. This is the forth step from the whole experimental process.

The Scanning Electron Microscope (SEM) is a microscope that uses electrons instead of light to form an image. The scanning electron microscope has many advantages over traditional microscopes. The SEM has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels [20].

The SEM is an instrument that produces a largely magnified image by using electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum. The beam travels through electromagnetic fields and lenses, which focus the beam down toward the sample. Once the beam hits the sample, electrons and X-rays are ejected from the sample. Detectors collect these X-rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen [20].

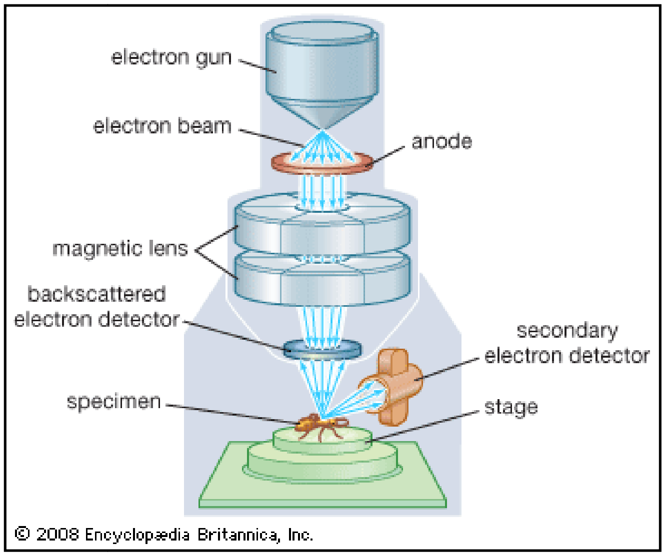


Figure 3.8: Schematic of Scanning Electron Microscope

Figure 3.9: Scanning Electron Microscope

3.3.5 Data Gathering and Full Analysis

After completing all the test and analysis by using all the equipment needed for this project, all the data obtain such as table, graph and chart are gathered so that full analysis and discussion can be carried out to reach the output of this project.

3.4 Gantt Chart

Table 3.1: Gantt Chart of Final Year Project 1

No.	Activities	Week 1	2	3	4	5	6	7	8	9	MID SEM BREAK	10	11	12	13	14
1.	Selection of Project Topic	●														
2.	Topic awarded to students		●													
3.	Preliminary Research Work:- i. Primary research regarding automotive gear oil ii. Identify the gear oil manufacturers and potential automotive gear oil for the project															
4.	Submission of Preliminary Report					●										
4.	Project Work:- i. Identify the standards which need to be followed for conducting the testing. ii. Identify the machine and the equipment in the labs which is going to be used for the project.															
5.	Submission of Progress Report									●						
6.	Seminar											●				
7.	Project work continues:- i. Purchasing the selected automotive gear oil. ii. Reserve the machine and equipment for testing. iii. Run the sample test to familiarize with the machine, equipment and the testing procedure.															
8.	Submission of Interim Report Final Draft															●
9.	Oral Presentation															●

Table 3.2: Gantt Chart of Final Year Project 2

No.	Activities	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Project Work Continues:- iv. Reserve the machine and equipment for testing. v. Experimental work starts:- - Four ball wear test								MID SEM BREAK							
2.	Submission of Progress Report 1					●										
3.	Project Work Continues:- iii. Experimental work continues:- - Four ball wear test - Viscosity test iv. Preparation for analysis of steel ball															
4.	Submission of Progress Report 2									●						
5.	Seminar (Compulsory)									●						
6.	Project Work Continues:- i. Analysis work starts:- - Observe wear using optical microscope, SEM, and surface profiler - Relates the wear observed with the oil viscosity															
7.	Poster Exhibition											●				
8.	Submission of Dissertation Final Draft															●
9.	Oral Presentation									***During study week***						
10.	Submission of Dissertation (Hard Bound)									***7 days after oral presentation***						

Planned Activities ● Key Milestone

Current Progress

CHAPTER 4
RESULT AND DISCUSSION

4.1 Results

4.1.1 Four Ball Wear Test

Twelve four ball wear test has been executed on four selected automotive gear oil. All the testing parameters are according to the standard from ASTM D 4172-94; Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four Ball Method). The test has been carried out four automotive gear oil chosen, which are Gear Oil A, Gear Oil B, Gear Oil C, and Gear Oil D. Three types of results are obtained from the Four Ball Wear Test which are:-

1. Wear scar diameter on the stationary steel balls
2. Coefficient of friction
3. Wear development on the stationary steel balls

The value of coefficient of friction and the wear development on the stationary steel balls are obtained directly from the four ball wear test. While the wear scars formed on the stationary steel balls are examined under optical microscope and the wear scar diameter is measured. The results obtained are as follows:-

4.1.1.1 Wear Scar Diameter

Gear Oil A

Table 4.1: Wear Scar Diameter for Gear Oil A – Test 1a

Ball No.	Diameter (µm) of wear scar		Average diameter (µm)
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	336	336	336
2	448	476	462
3	504	504	504
Total average wear scar diameter (µm)			**434**

Table 4.2: Wear Scar Diameter for Gear Oil A – Test 2a

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	588	476	532
2	532	392	462
3	476	336	406
Total average wear scar diameter (µm)			**467**

Table 4.3: Wear Scar Diameter for Gear Oil A – Test 3a

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	504	504	504
2	448	448	448
3	252	168	210
Total average wear scar diameter (µm)			**387**

Total average of wear scar diameter for three test on Gear Oil A = **429.33 µm**

Gear Oil B

Table 4.4: Wear Scar Diameter for Gear Oil B– Test 1b

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	588	420	504
2	700	504	602
3	616	364	490
Total average wear scar diameter (µm)			**532**

Table 4.5: Wear Scar Diameter for Gear Oil B– Test 2b

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	420	392	406
2	308	252	280
3	280	196	238
Total average wear scar diameter (µm)			**308**

Table 4.6: Wear Scar Diameter for Gear Oil B – Test 3b

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	504	504	504
2	448	448	448
3	252	168	210
Total average wear scar diameter (µm)			**387**

Total average of wear scar diameter for three test on Gear Oil B = **409.11µm**

Gear Oil C

Table 4.7: Wear Scar Diameter for Gear Oil C – Test 1c

Ball No.	**Diameter (µm) of wear scar**		**Average diameter (µm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	420	364	392
2	560	532	546
3	392	448	420
Total average wear scar diameter (µm)			**453**

Table 4.8: Wear Scar Diameter for Gear Oil C – Test 2c

Ball No.	**Diameter (μm) of wear scar**		**Average diameter (μm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	280	252	266
2	448	420	434
3	476	448	462
Total average wear scar diameter (μm)			**387**

Table 4.9: Wear Scar Diameter for Gear Oil C – Test 3c

Ball No.	**Diameter (μm) of wear scar**		**Average diameter (μm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	392	420	406
2	420	392	406
3	476	448	462
Total average wear scar diameter (μm)			**424**

Total average of wear scar diameter for three test on Gear Oil C = **421.56μm**

Gear Oil D

Table 4.10: Wear Scar Diameter for Gear Oil D – Test 1d

Ball No.	**Diameter (μm) of wear scar**		**Average diameter (μm)**
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	308	280	294
2	392	364	378
3	644	560	602
Total average wear scar diameter (μm)			**425**

Table 4.11: Wear Scar Diameter for Gear Oil D – Test 2d

Ball No.	Diameter (µm) of wear scar		Average diameter (µm)
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	420	364	392
2	448	420	434
3	392	336	364
Total average wear scar diameter (µm)			**397**

Table 4.12: Wear Scar Diameter for Gear Oil D – Test 3d

Ball No.	Diameter (µm) of wear scar		Average diameter (µm)
	X-axis (Horizontal axis)	Y-axis (Vertical axis)	
1	336	364	350
2	700	700	700
3	476	476	476
Total average wear scar diameter (µm)			**509**

Total average of wear scar diameter for three test on Gear Oil D = **443.33µm**

Comparison of Wear Scar Diameter

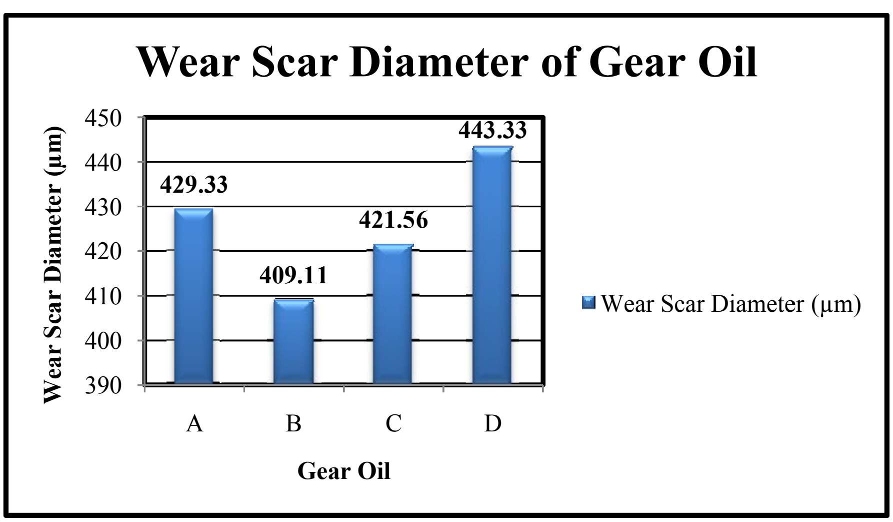


Figure 4.1: Comparison of Wear Scar Diameter between Gear Oil A, B, C, and D

4.1.1.2 Coefficient of Friction

Gear Oil A

Table 4.13: Coefficient of Friction of Gear Oil A

Test No.	Coefficient of Friction
1	0.0044
2	0.0469
3	0.0411
Total average of coefficient of friction	**0.0308**

Gear Oil B

Table 4.14: Coefficient of Friction of Gear Oil B

Test No.	Coefficient of Friction
1	0.0052
2	0.0126
3	0.0179
Total average of coefficient of friction	**0.0119**

Gear Oil C

Table 4.15: Coefficient of Friction of Gear Oil C

Test No.	Coefficient of Friction
1	0.0025
2	0.0251
3	0.0433
Total average of coefficient of friction	**0.0236**

Gear Oil D

Table 4.16: Coefficient of Friction of Gear Oil D

Test No.	Coefficient of Friction
1	0.0705
2	0.0737
3	0.0422
Total average of coefficient of friction	**0.0621**

Comparison of Coefficient of Friction

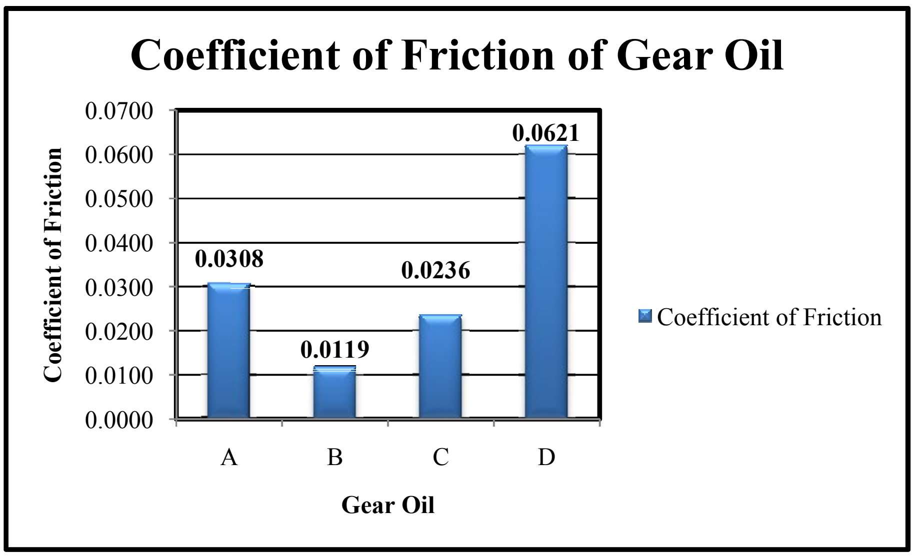


Figure 4.2: Comparison of Coefficient of Friction between Gear Oil A, B, C, and D

4.1.1.3 Wear on Stationary Steel Ball

Gear Oil A

Table 4.17: Wear Depth on Steel Ball by using Gear Oil A as lubricant

Test No.	Wear Depth (µm)
1	-35
2	9.5
3	23
Average	**-0.83**

Gear Oil B

Table 4.18: Wear Depth on Steel Ball by using Gear Oil B as lubricant

Test No.	Wear Depth (μm)
1	-24
2	-29
3	-41
Average	**-31.33**

Gear Oil C

Table 4.19: Wear Depth on Steel Ball by using Gear Oil C as lubricant

Test No.	Wear Depth (μm)
1	1
2	-39
3	2
Average	**-12**

Gear Oil D

Table 4.20: Wear Depth on Steel Ball by using Gear Oil D as lubricant

Test No.	Wear Depth (μm)
1	92
2	-55
3	-23
Average	**4.67**

Comparison of Wear Development

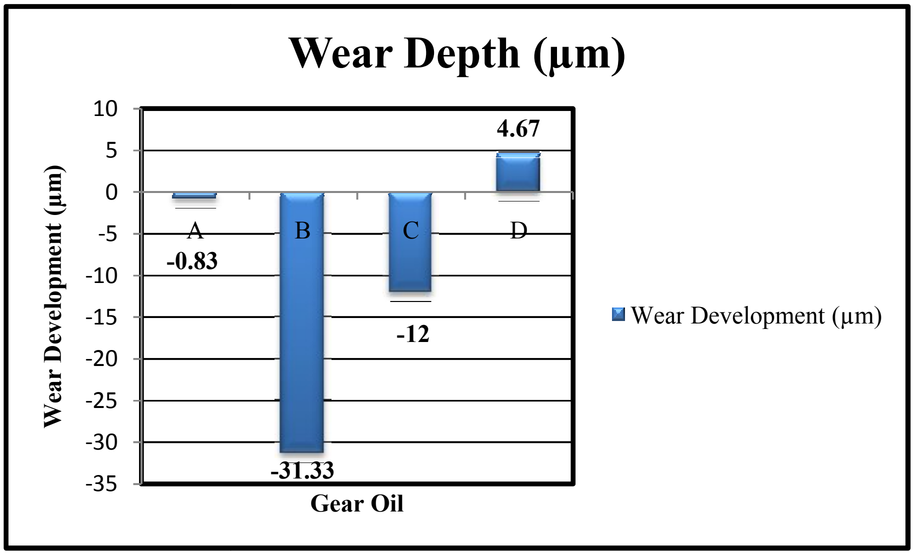


Figure 4.3: Comparison of Wear Depth between Gear Oil A, B, C, and D

4.1.2 Viscosity Test

Viscosity test has been carried out on four selected automotive gear oils. All the testing parameters are done according to standard from ASTM D 445-09; Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids. The test has been conducted at two temperatures which is 40˚C and 100˚C. Three readings are taken for each test at each temperature in order to get accurate results. The results obtained are as follows:-

4.1.2.1 Gear Oil A

Table 4.21: Viscosity of Gear Oil A

Reading No.	Efflux time (s)		Viscosity (cSt)	
	40˚C	100˚C	40˚C	100˚C
1	142.25	17.01		
2	139.37	16.35		
3	140.23	16.20		
Average	140.62	16.52	**147.09**	**17.28**

4.1.2.2 Gear Oil B

Table 4.22: Viscosity of Gear Oil B

Reading No.	Efflux time (s)		Viscosity (cSt)	
	40˚C	100˚C	40˚C	100˚C
1	145.34	18.75		
2	145.42	19.04		
3	146.01	18.63		
Average	145.59	18.81	**152.29**	**19.67**

4.1.2.3 Gear Oil C

Table 4.23: Viscosity of Gear Oil C

Reading No.	**Efflux time (s)**		**Viscosity (cSt)**	
	40˚C	**100˚C**	**40˚C**	**100˚C**
1	141.55	15.14		
2	144.73	15.27		
3	145.11	15.23		
Average	143.80	15.21	**150.41**	**15.91**

4.1.2.4 Gear Oil D

Table 4.24: Viscosity of Gear Oil D

Reading No.	**Efflux time (s)**		**Viscosity (cSt)**	
	40˚C	**100˚C**	**40˚C**	**100˚C**
1	108.12	13.57		
2	106.67	13.71		
3	106.78	14.07		
Average	107.19	13.78	**112.12**	**14.42**

4.1.2.5 Comparison of Viscosity

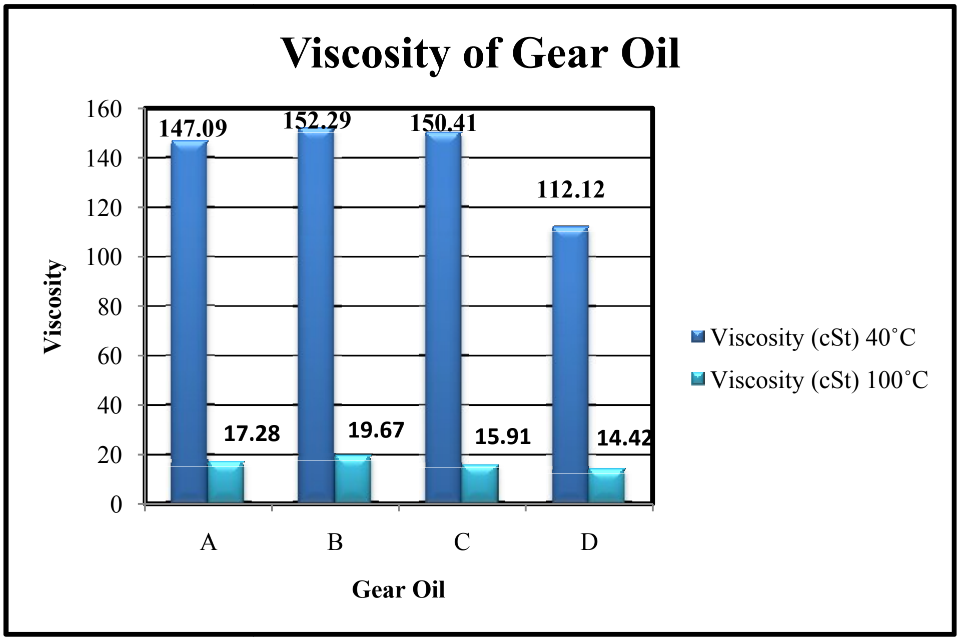
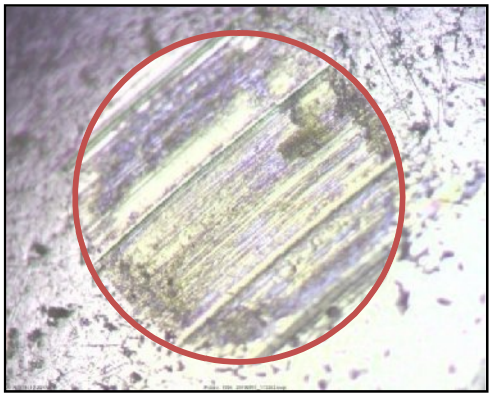


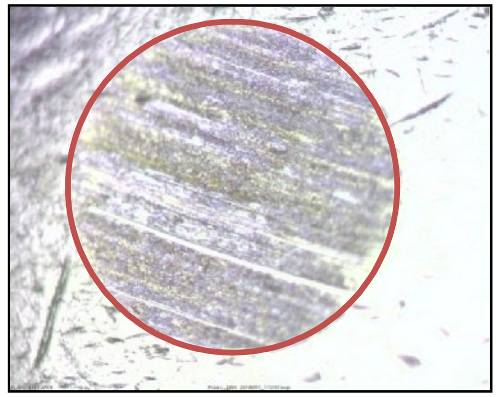
Figure 4.4: Comparison of Viscosity between Gear Oil A, B, C, and D

4.1.3 Analysis of Wear Scar by Optical Microscope

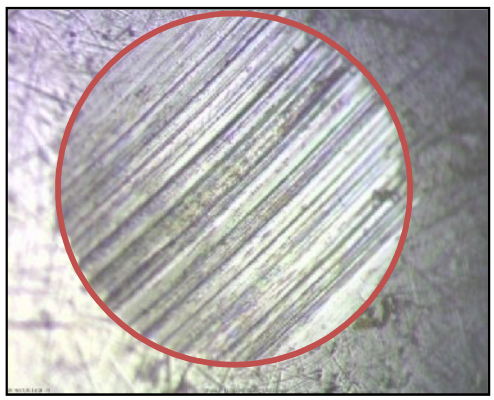
4.1.3.1 Gear Oil A



Test 1



Test 2



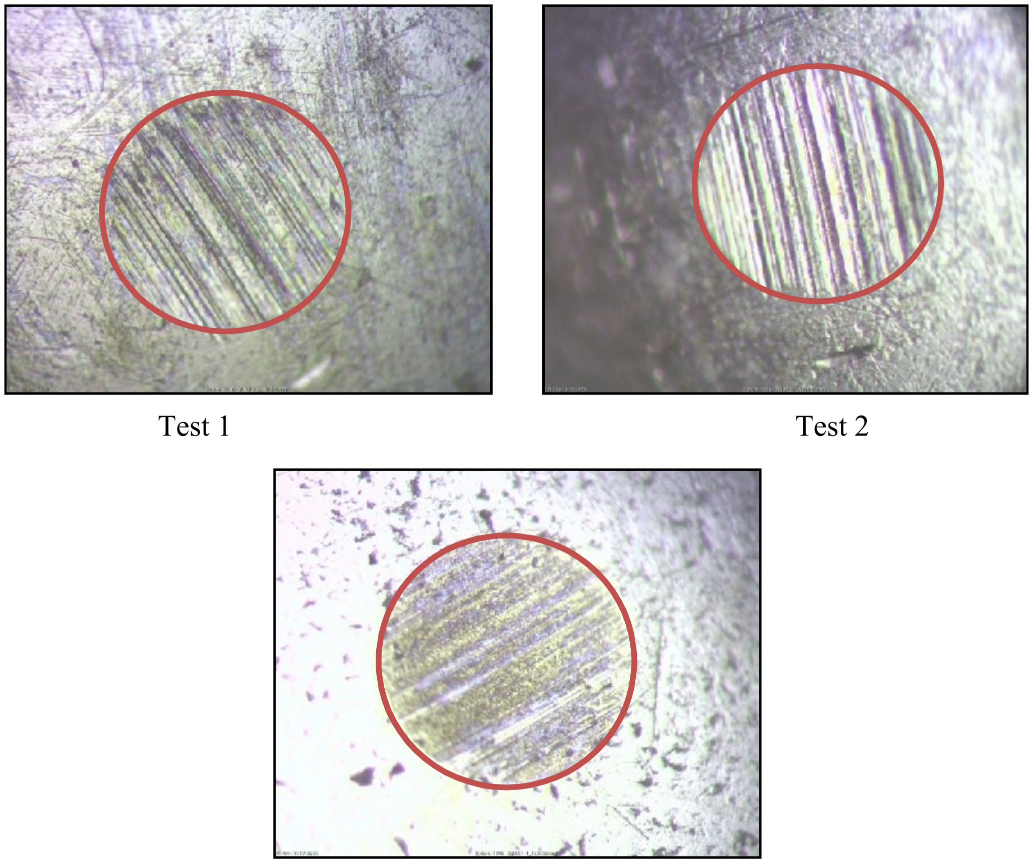
Test 3

Figure 4.5: Wear scar produced on steel ball by using Gear Oil A - observed by Optical Microscope

Table 4.25: Average wear scar diameter of each test for Gear Oil A

Test No.	Average Wear Scar Diameter of each test (µm)
1a	434
2a	467
3a	387
Total Average	**429.33**

4.1.3.2 Gear Oil B



Test 1 Test 2

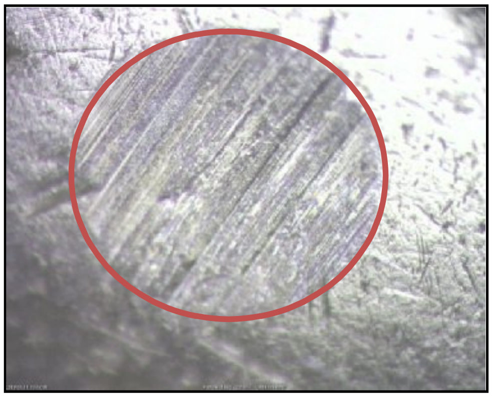
Test 3

Figure 4.6: Wear scar produced on steel ball by using Gear Oil B - observed by Optical Microscope

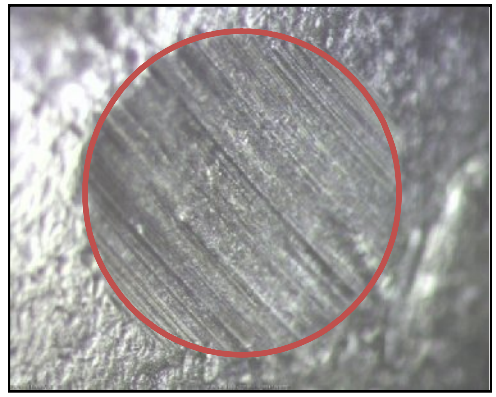
Table 4.26: Average wear scar diameter of each test for Gear Oil B

Test No.	Average Wear Scar Diameter of each test (µm)
1b	532
2b	308
3b	387
Total Average	**409.11**

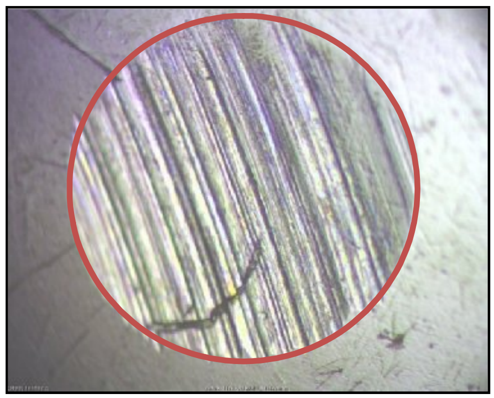
4.1.3.3 Gear Oil C



Test 1



Test 2



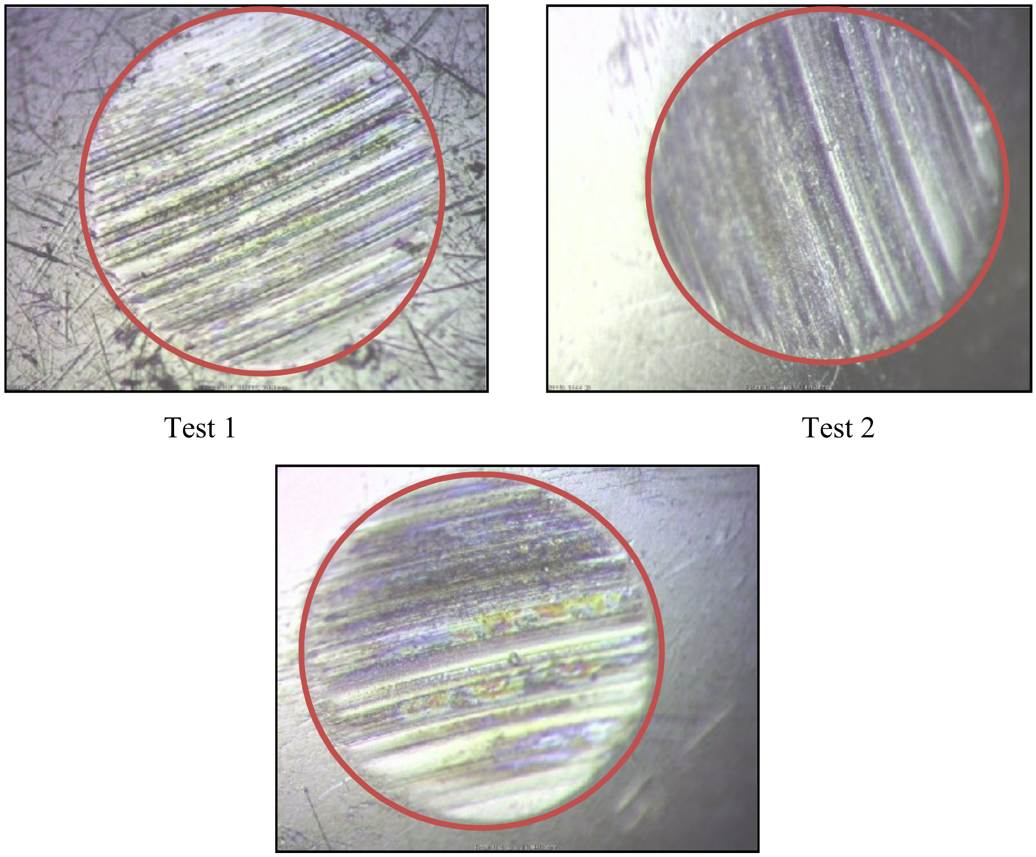
Test 3

Figure 4.7: Wear scar produced on steel ball by using Gear Oil C - observed by Optical Microscope

Table 4.27: Average wear scar diameter of each test for Gear Oil C

Test No.	Average Wear Scar Diameter of each test (µm)
1c	453
2c	387
3c	424
Total Average	**421.56**

4.1.3.4 Gear Oil D



Test 1 Test 2

Test 3

Figure 4.8: Wear scar produced on steel ball by using Gear Oil D - observed by Optical Microscope

Table 4.28: Average wear scar diameter of each test for Gear Oil D

Test No.	Average Wear Scar Diameter of each test (µm)
1d	425
2d	397
3d	509
Total Average	**443.33**

4.1.4 Analysis of Wear Scar by Scanning Electron Microscope

4.1.4.1 Gear Oil A

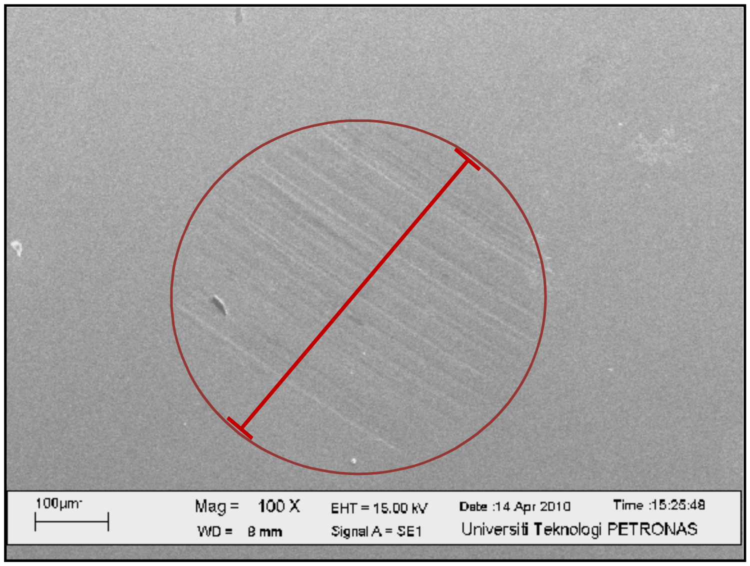


Figure 4.9: Gear Oil A with 100x magnification

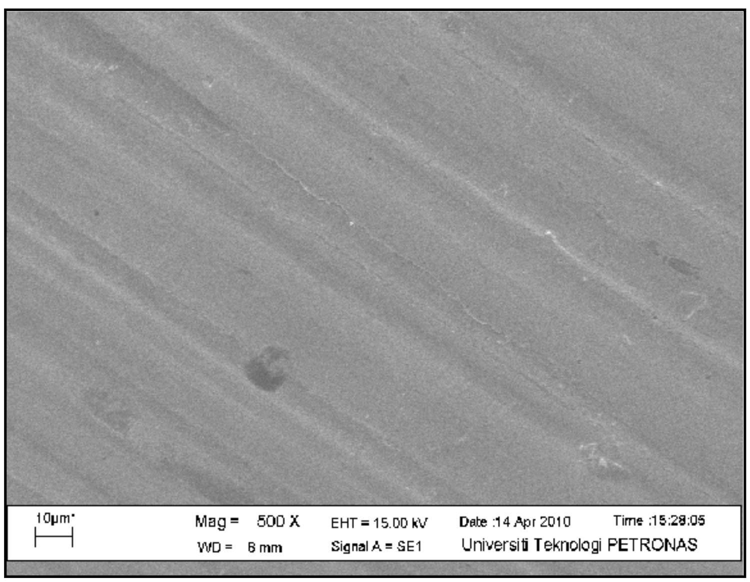


Figure 4.10: Gear Oil A with 500x magnification

4.1.4.2 Gear Oil B

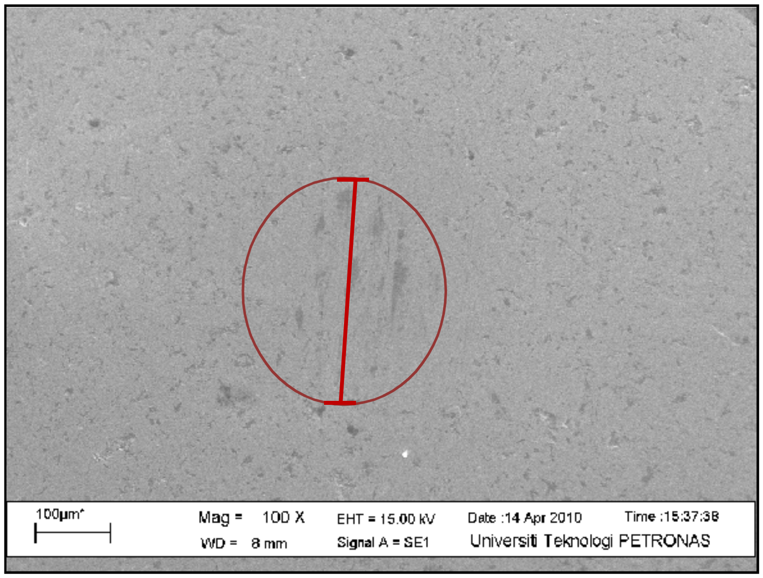


Figure 4.11: Gear Oil B with 100x magnification

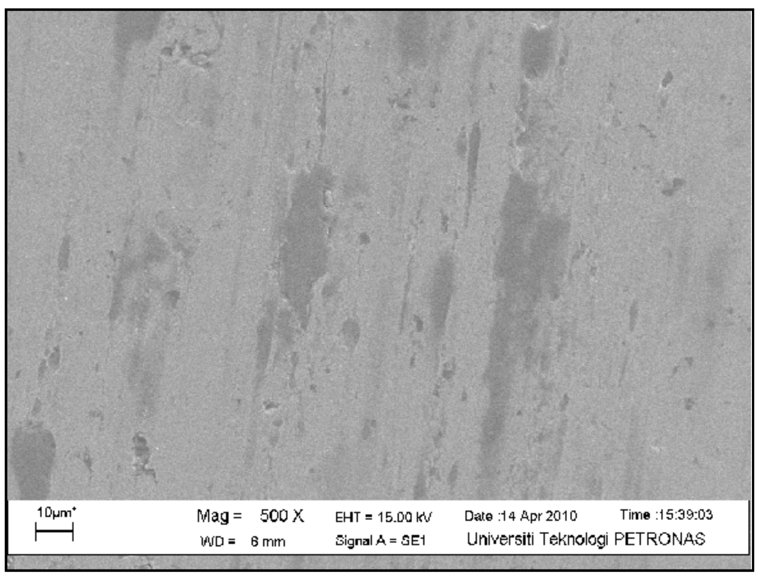


Figure 4.12: Gear Oil B with 500x magnification

4.1.4.3 Gear Oil C

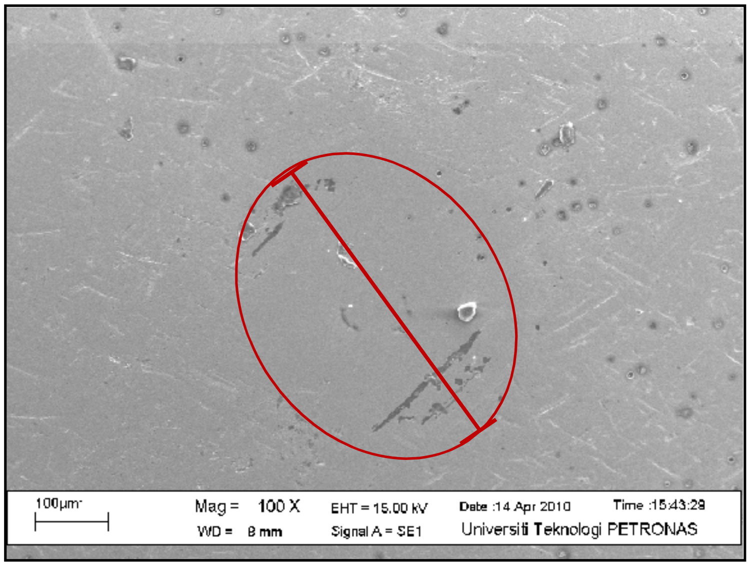


Figure 4.13: Gear Oil C with 100x magnification

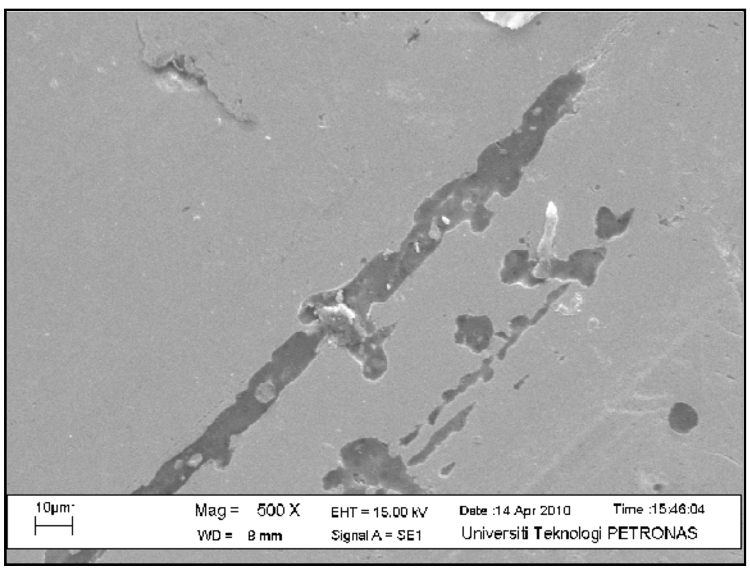


Figure 4.14: Gear Oil C with 500x magnification

4.1.4.4 Gear Oil D

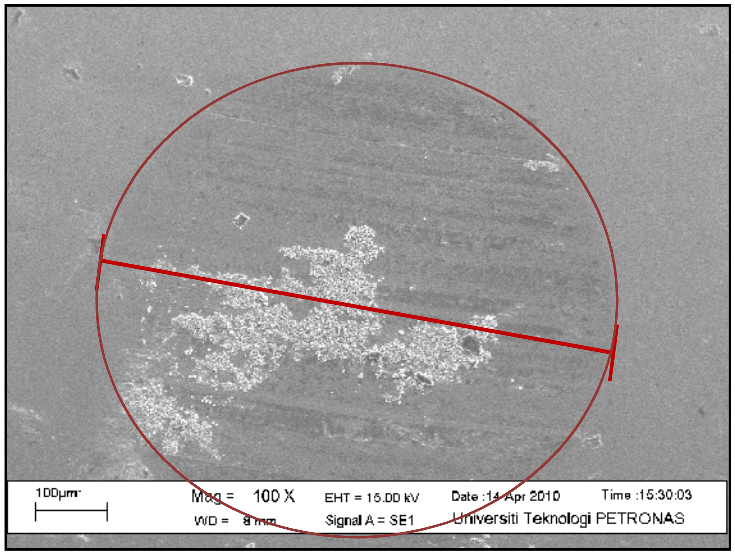


Figure 4.15: Gear Oil D with 100x magnification

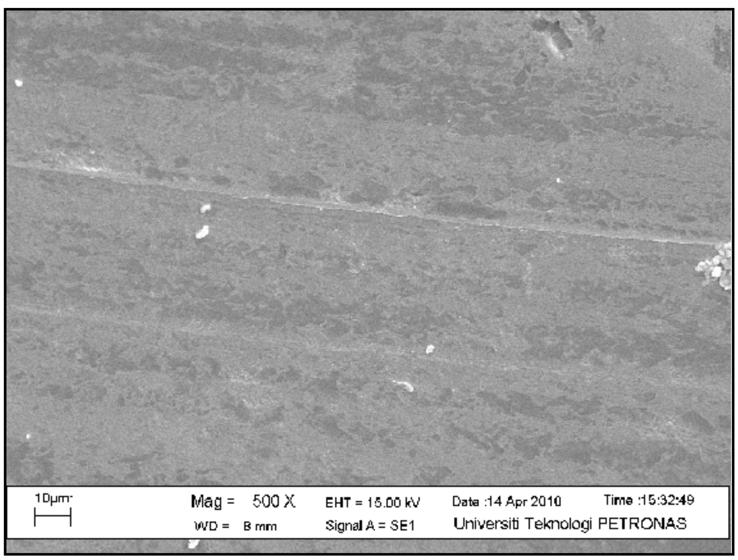


Figure 4.16: Gear Oil D with 500x magnification

4.2 Discussion

4.2.1 Viscosity of Gear Oils

Viscosity test has been conducted on the four selected automotive gear oils. The test is run at two temperatures which is 40˚C and 100˚C. The viscosity of the gear oil is obtained by multiplying the efflux time (s) of the oil with the viscosity constant obtained from the TAMSON-Viscometer Unit catalogue.

Viscosity = Efflux time (s) x Viscosity constant (cSt/s)

The viscosity constant differs according to the tube size used during the test. In this case, the tube size used is 3; given the viscosity constant is 1.046cSt/s.

Table 4.21 shows the average viscosity of Gear Oil A at 40˚C which is 147.09cSt and at 100˚C which is 17.28cSt. Table 4.22 shows the viscosity of Gear Oil B which is 152.29cSt at 40˚C and 19.67cSt at 100˚C. The viscosity of Gear Oil C is shown in Table 4.23 whereby the viscosity of the oil is 150.41cSt at 40˚C and 15.91cSt at 100˚C. Last of all, Table 4.24 shows the viscosity of Gear Oil D that is 112.12cSt at 40˚C and 14.42cSt at 100˚C. Comparing the all the Gear Oil viscosity obtained at 40˚C with the ISO Viscosity Grade, all of the Gear Oil viscosity is in range which is between 135cSt to 165cSt, except for Gear Oil D which has the viscosity of 112.12cSt at 40˚C.

From Figure 4.4; the comparison of viscosity between Gear Oil A, B, C, and D, it is distinguished that Gear Oil D has the lowest viscosity at both temperatures, followed by Gear Oil A, C and lastly Gear Oil B which has the highest viscosity at both temperatures.

4.2.2 Wear Scar Diameter

Wear Scar is one of the results obtained from the Four Ball Wear Test. From the wear scar formed on the stationary steel balls, the ability of the lubricating fluid to prevent friction and wear can be determined. The wear scar diameter on the stationary steel ball is measured and recorded. From the test conducted, the average of wear scar diameter obtained from test 1a, 2a, and 3a (Table 4.1, 4.2 and 4.3) of Gear Oil A is 429.33µm, the average wear scar diameter attained from the test 1b, 2b, and 3b (Table 4.4, 4.5 and 4.6) of Gear Oil B is 409.11µm, while the average wear scar diameter obtained from test 1c, 2c, and 3c (Table 4.7, 4.8 and 4.9) of Gear Oil C is 421.56 µm and lastly, the average wear scar diameter obtained from test 1d, 2d and 3d (Table 4.10, 4.11 and 4.12) of Gear Oil D is 443.33 µm.

From Figure 4.1; the comparison of wear scar diameter between Gear Oil A, B, C, and D, it can be seen that wear scar produced by using Gear Oil B as lubricating oil is the smallest. The wear scar produced by using Gear Oil D as lubricant is the largest, while the wear scar diameter obtained by using Gear Oil A is the second largest, and wear scar diameter obtained by using Gear Oil C is the third largest. This indicates that Gear Oil B has a best ability to prevent wear from occurring on the steel ball. Significantly, it indicates that Gear Oil B gives better protection to the gears in our vehicle. Meaning that Gear Oil D, which causes the largest wear scar on the steel balls has the lowest ability to protect the steel ball from wear. Thus, it indicates that Gear Oil D gives low protection to the gears in the vehicle. Furthermore, during the experiment session, it is observed that the temperature of the steel ball rise up much slower by using Gear Oil B compared to Gear Oil D. By using Gear Oil D, the sample's temperature increased up to 78˚ C quicker as compared to Gear Oil B. This shows that Gear Oil B has the ability to withstand high temperature, thus provides better protection from wear on the steel ball.

By relating back the viscosity of the gear oils with the wear scar diameter formed on the steel balls, the smallest wear scar diameter is formed on the steel balls which use Gear Oil B which has the highest viscosity at both temperatures as lubricant. On the other hand, the largest wear scar diameter is formed on the steel balls which use Gear Oil D which has the smallest viscosity at both temperatures as lubricant. From the relations, it is apparent that Gear Oil with high viscosity gives better protection from wear formation on the steel balls thus resulting in small formation of wear scar, vice versa; Gear Oil with low viscosity gives less protection from wear formation on the steel ball, which then causes large formation of wear. Therefore, it can be said that the Gear Oil B with the highest viscosity gives better protection from wear compared to Gear Oil C, A, and D. From this, we can see the relation of Gear Oil's viscosity to the ability of Gear Oil in resisting wear formation on the steel ball.

4.2.3 Coefficient of Friction

Coefficient of Friction graph shows the ratio of the force of kinetic friction between the steel ball with oil film in between the surfaces, or with little oil film or without the presence of oil film in between the surfaces and the force forcing them together during the Four Ball Wear test. As stated in the literature review, the coefficient of friction between steel with the presence of lubrication between the two steel surfaces should be lower than the coefficient of friction between steel without the presence of lubrication in between the two steel surfaces.

Table 4.13 shows the coefficient of friction of Gear Oil A, with the average mean of 0.0308. Table 4.14 shows the coefficient of friction of Gear Oil B with an average of 0.0119, while table 4.15 shows the coefficient of friction of Gear Oil C with 0.0236 as the average and finally table 4.16 show the coefficient of friction of Gear Oil D with an average of 0.0621. From the Figure 4.2; comparison of coefficient of friction between Gear Oil A, B, C, and D, it is clear that Gear Oil B has the lowest coefficient of friction followed by Gear Oil C, Gear Oil A and lastly Gear Oil D. It is known that the lower the coefficient of friction, the higher the ability of the lubricant to minimize friction from two contact surfaces. As Gear Oil B has the lowest value of coefficient of friction, it signify that Gear Oil B possess the ability to minimize the friction between two steel ball surfaces, thus minimizing the wear formation on the steel ball. Meaning, Gear Oil B is better in reducing friction between gears in automotive differential. Gear Oil D which has the highest value of coefficient of friction can still reduce the friction between the steel ball surfaces, but the protection given to the steel ball is not as good as compared to Gear Oil B. Due to that, the wear formation of the steel ball by using Gear Oil D as lubricant is the largest. This concludes that Gear Oil B is better in reducing the friction between the steel balls surfaces compared to Gear Oil A, C and D.

Relating back the viscosity of the Gear Oils to the coefficient of friction of the Gear Oils, Gear Oil D which has the lowest viscosity has the highest value of coefficient of friction, contrary to Gear Oil B which has the highest viscosity, has the lowest value of coefficient of friction. This signifies the relation of Gear Oil's viscosity to the ability of Gear Oil's in preventing or minimizing the friction between the steel ball's surfaces.

4.2.4 Wear Depth

Wear depth is the development of wear on the three stationary balls from the four ball wear test. Linear Voltage Resistance Transducer (LVRT) used in the Multi-Specimen Tester functions to measure the wear development on the three stationary balls. Negative reading is desired as the negative reading shows that the LVRT moves upwards which is away from the stationary balls. This indicates that there are fluid films formed between the steel balls and thus preventing metal to metal contact (rotating steel ball and stationary steel balls). The oil film formed protects the stationary balls from wear. The positive value is undesired in the graph as positive values indicate that the LVRT moves downwards which is nearer to the stationary balls. This indicates that no fluid film is formed between the rotating steel ball and stationary steel ball. The oil film might have slipped away due to high rotating speed. Result in the formation of wear at the surface of the three stationary balls as the effect of metal to metal contact. Scanning Electron Microscope is very sensitive to depth, as the depth of the wear formed on the steel balls are not so deep plus the steel ball is round, the wear scar image captured by Scanning Electron Microscope are not so clear compared to the wear scar image captured by Optical Microscope.

Table 4.17 shows the wear depth produced by using Gear Oil A as lubricant with an average of -0.83. Table 4.18 shows the wear development produced on the steel balls by using Gear Oil B as lubricant with an average of -31.33. The wear development produced by using Gear Oil C as lubricating oil is shown in Table 4.19 with an average of -12. Lastly, Table 4.20 shows the wear development on the steel balls by using Gear Oil D as lubricating oil with an average of 4.67. Only Gear Oil D causes the positive value in wear development. This point out that there is no oil film or too little oil present between the rotating and stationary ball during the test, thus causing the formation of wear on the surface of the stationary balls. Gear Oil B has the lowest value of wear development. This indicates that sufficient amount of oil film is present in between the surface of rotating and stationary steel balls. Comparing the wear development by using Gear Oil D as lubricant with the respective wear scar diameter measured and wear development by using Gear Oil B as lubricant with the respective wear scar diameter measured, it shows that the positive (large) value of wear development results in larger wear scar diameter and negative (small) value of wear development yields in smaller wear scar diameter.

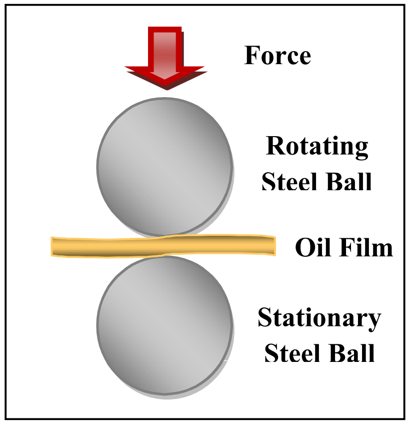


Figure 4.17: Sufficient amount of oil film lubricates the steel ball

It can also be concluded that, Gear Oil B with higher viscosity lubricates the steel ball's surface better by the formation of oil film; as shown in Figure 4.17. Thus minimizing the friction and wear on the steel ball. Gear Oil D with smallest viscosity, did not lubricates the steel surface very well. The formation of oil film maybe too little, or the oil film slipped away during the test due to the low viscosity of the oil resulting in high friction on the steel ball which then causes wear; as shown in Figure 4.18.

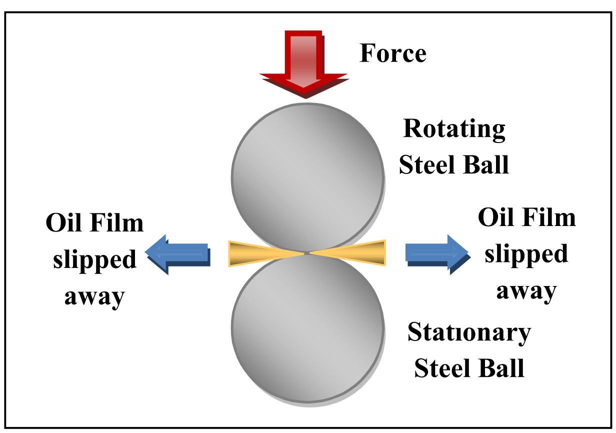


Figure 4.18: Insufficient amount of oil film lubricates the steel ball

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As the conclusion, a well-balanced gear lubrication formulation is critical in all types of vehicles; either it is a standard or a high performance vehicle. With more horsepower, more towing capacity, higher hauling limits and changes in vehicle design, more stress is placed on automotive gear oil.

All in all, this project has met its objective, which is:-

1. To study on automotive gear oils in term of their viscosity, friction and wear properties and perform testing using viscometer and four ball wear test method.

Four ball wear test and viscosity test has been successfully conducted. All the results obtained such as viscosity of gear oil, wear scar diameter formed on stationary steel balls, coefficient of friction, and wear development on the steel ball has been used to study automotive gear oils in terms of viscosity, friction and wear.

2. To compare and relates the viscosity of the oils to their wear and friction properties in term of wear scars on the balls and its coefficient of friction.

The viscosity of the oils has been compared and relates to the wear and friction properties in terms of the wear scars formed on the stationary steel balls and the coefficient of friction. Detail analysis has been done and discussions based the results and analysis attained has been carried out to relate the effects of viscosity on the friction and wear behaviour of automotive gear oils.

From the entire test conducted, the effects of viscosity on the friction and wear behaviour of automotive gear oil can be seen clearly. By relating back to the steel balls used in the test with the real automotive gears in the vehicle, the relationship between the viscosity of the automotive gear oil and the friction is obvious. Automotive Gear Oil with higher viscosity has smaller value of coefficient of friction. As example, Gear Oil B with viscosity of 152.29cSt at 40˚ C has small value of coefficient of friction which is 0.0119. Lower coefficient of friction means the friction between two contact surfaces is lower. Thus, it signifies that more viscous the automotive gear oil is, the higher the ability of the oil to prevent or at least minimize the friction between the automotive gears. Automotive Gear Oil with high viscosity gives better protection on the automotive gears. As the oil is more viscous, it lubricates the gear surfaces better, thus reduce friction between the automotive gears. On the contrary, automotive gear oil with lower viscosity has higher coefficient of friction value. As example, Gear Oil D with viscosity of 112.12cSt at 40˚ C has high value of coefficient of friction which is 0.0621. This means that the friction between metal surfaces is higher. With low viscosity, the automotive gear oil could not form oil film which is thick enough to protect the gears from friction. The oil film is too thin; therefore it tends to slipped away from the gear surfaces causing high friction between the gears. This could damage the gears and the vehicle.

Another point is the relationship between viscosity and wear. The relationship between viscosity and wear can also be seen clearly. Automotive Gear Oil with higher viscosity has the ability to prevent wear formation efficiently. As example, Gear Oil B which has the viscosity of 152.29cSt at 40˚ C produced small size of wear scar with diameter of 409.11µm. This means, more viscous the automotive gear oil is, the better its protection from wear towards the automotive gears. With high viscosity, the boundary lubrication between the metal surfaces is improved. Metal to metal contact between the gears is reduced as sufficient amount of oil film has lubricates the metal surface. This reduced the wear formation on the automotive gears, thus increase the life of the gears and also the vehicle itself. Vice versa, automotive gear oil with low viscosity provides low protection in the automotive gears. Taking Gear Oil D as example, with viscosity of 112.12cSt at 40˚ C, the wear scar formed is larger with diameter of 443.33µm. The oil film between the gear surfaces tends to slip away during operation due to low viscosity of the oil. This increased the metal to metal contact of the gear surfaces, thus the wear formation is bigger and finally the life of the gears and the vehicle itself is shortened.

5.2 Recommendation

For future development, it is recommended that this research is continued and expanded further. The full potential of automotive gear oil has not been discovered yet. Further study can be conducted on other properties of automotive gear oil in order to improve its performance.

It is suggested this time to focus on the effect of the additives present in automotive gear oil on the performance of the automotive gear oil itself. As basically, additives are one of the automotive gear oil's properties that influence the performance of the automotive gear oil. Perhaps through that research, the real potential of automotive gear oil can be discovered. Thus, the ability of automotive gear oil can be fully utilized. Hopefully this research will contribute to the automotive industry as well. As for now, the effect of viscosity on friction and wear behaviour of automotive gear oil is known, based on this research, it is hope that further studies is carried out to improve the quality and performance of the automotive gear oil. Other test such as the effect of temperature, pressure and environment to the performance of the automotive gear oil should be conducted for future benefits.

It is also recommended that further study is carried out to produce organic or bio-based automotive gear oils. With this kind of study, country's natural resources such as palm oil can be utilized to developed more environmental friendly automotive gear oil.

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APPENDICCES

APPENDIX I

7.1 Four Ball Wear Test Graphs

7.1.1 Coefficient of Friction

7.1.1.1 Gear Oil A

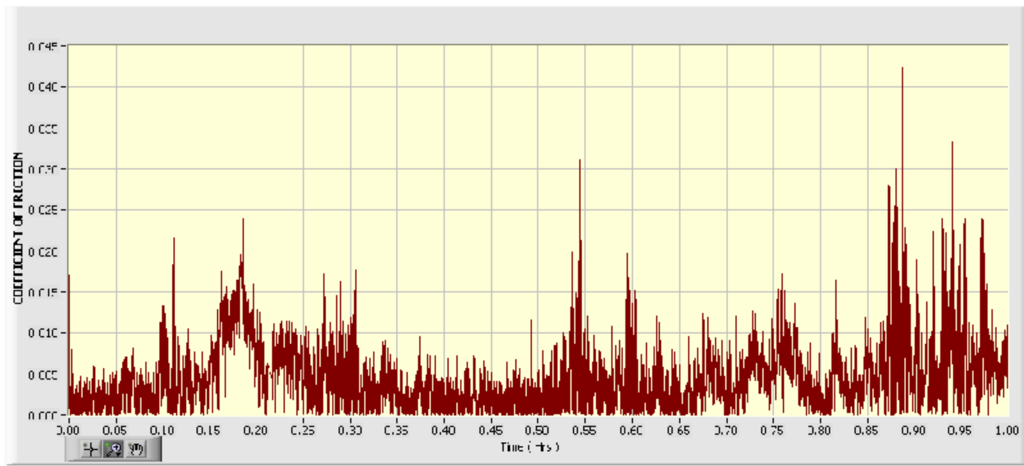

Figure 7.1: Test 1a

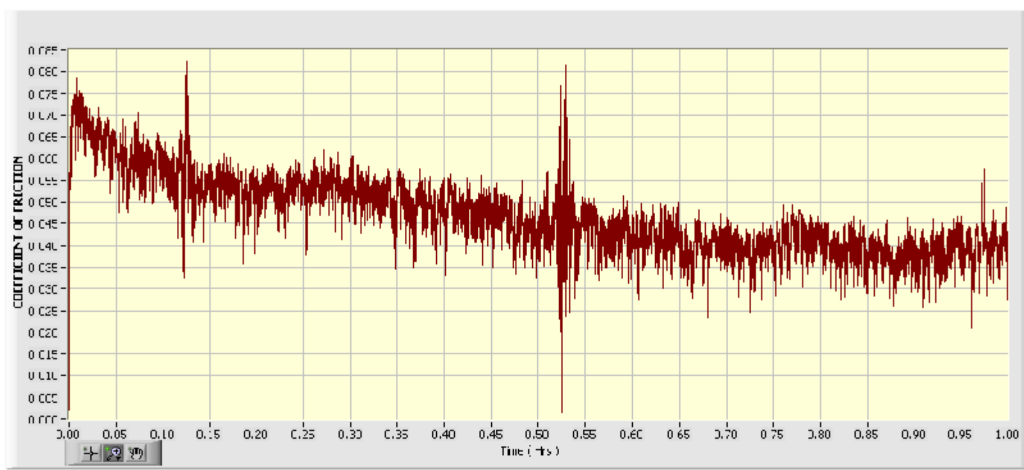

Figure 7.2: Test 2a

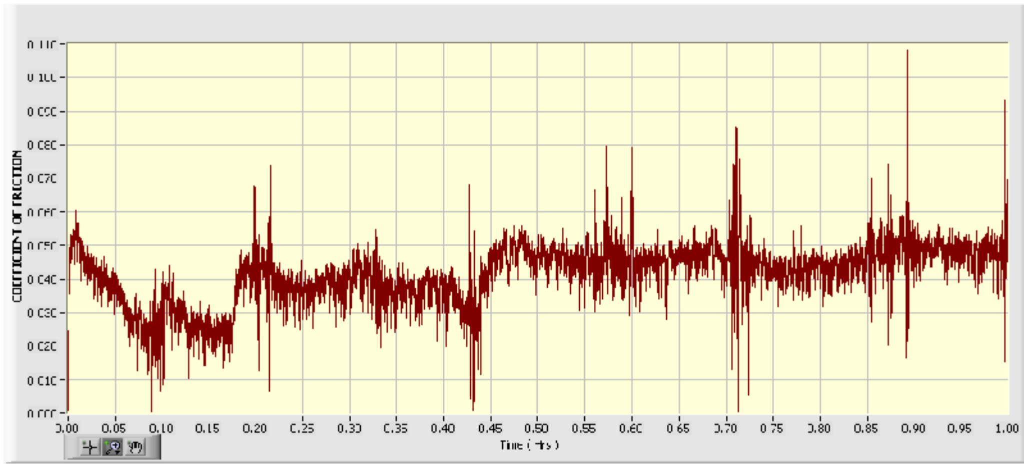

Figure 7.3: Test 3a

7.1.1.2 Gear Oil B

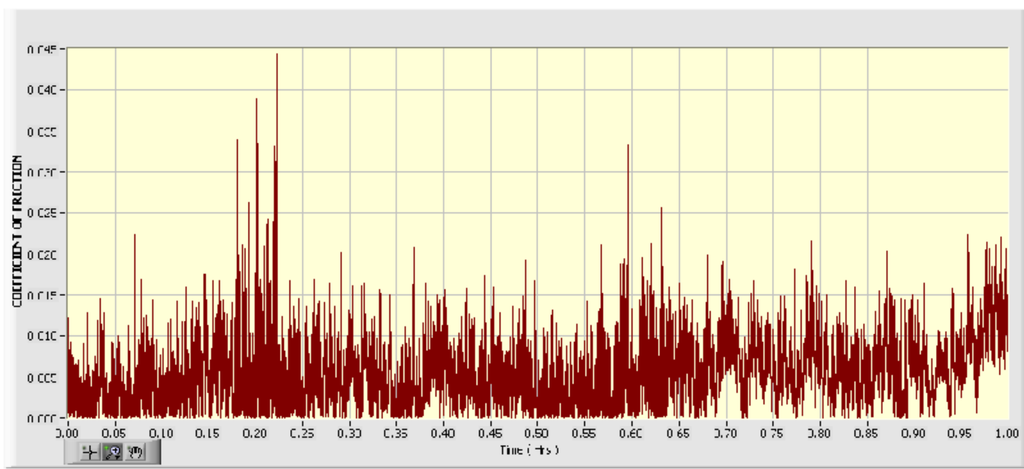

Figure 7.4: Test 1b

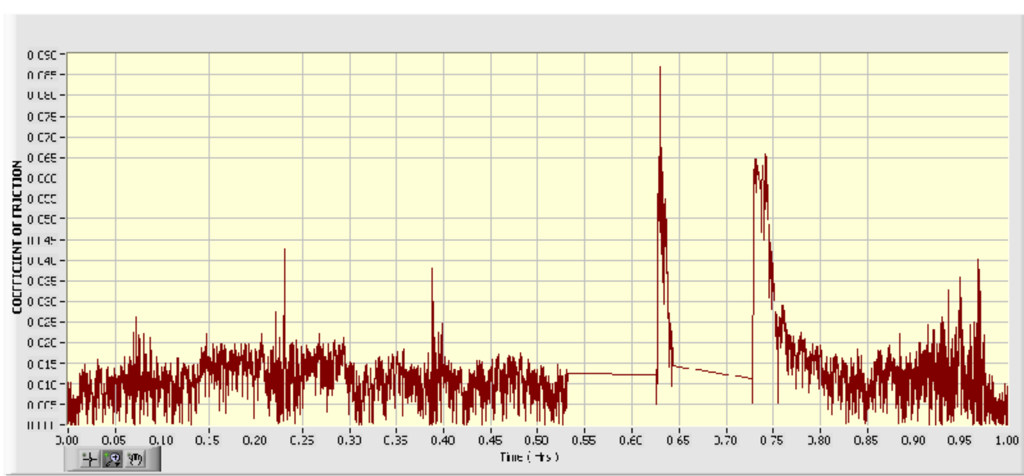

Figure 7.5: Test 2b

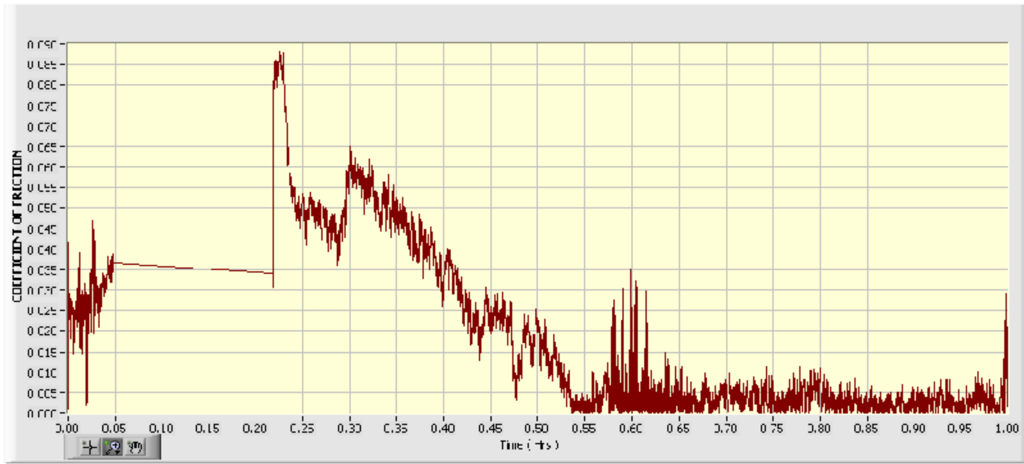

Figure 7.6: Test 3b

7.1.1.3 Gear Oil C

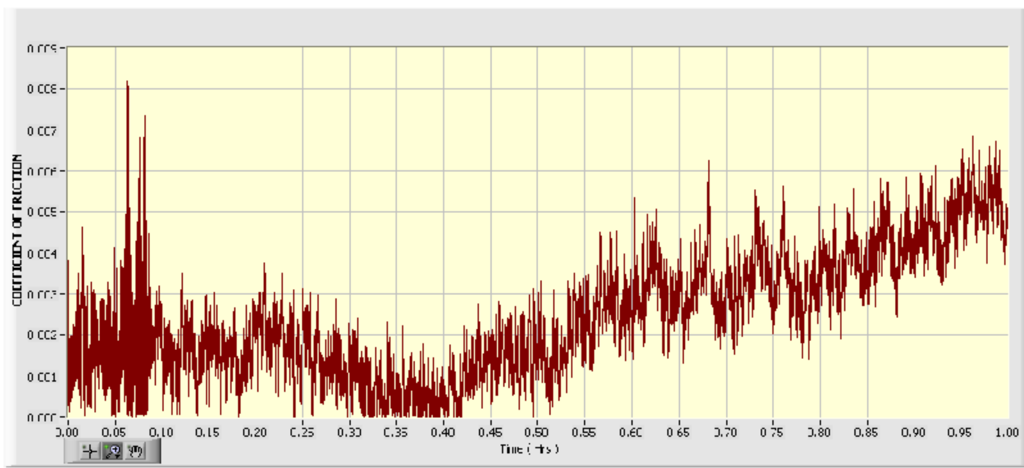

Figure 7.7: Test 1c

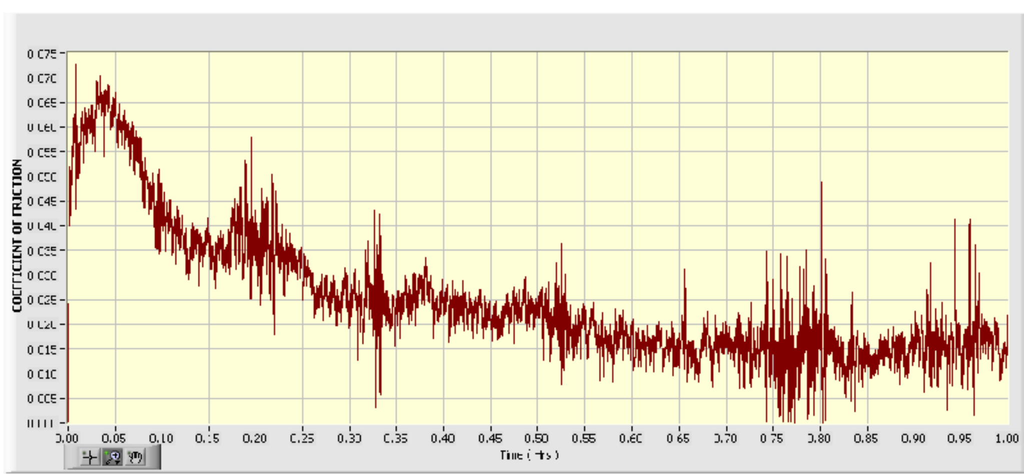

Figure 7.8: Test 2c

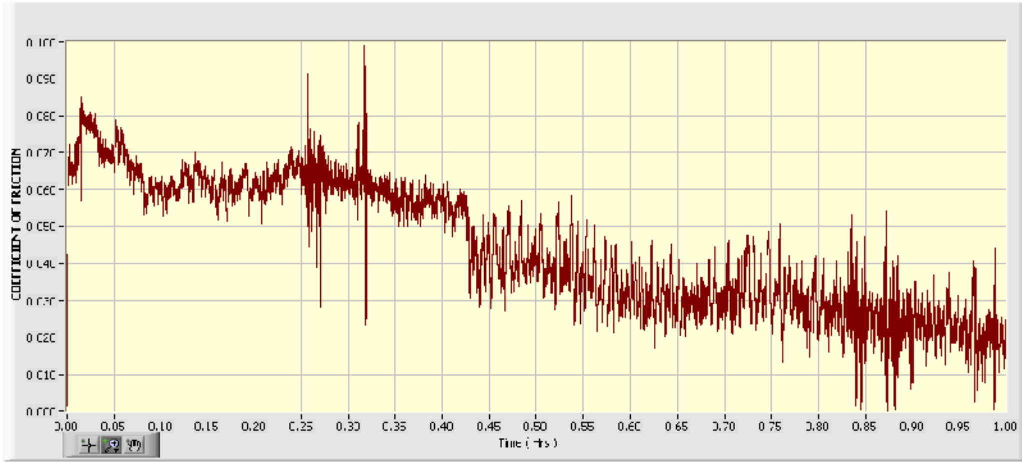

Figure 7.9: Test 3c

7.1.1.4 Gear Oil D

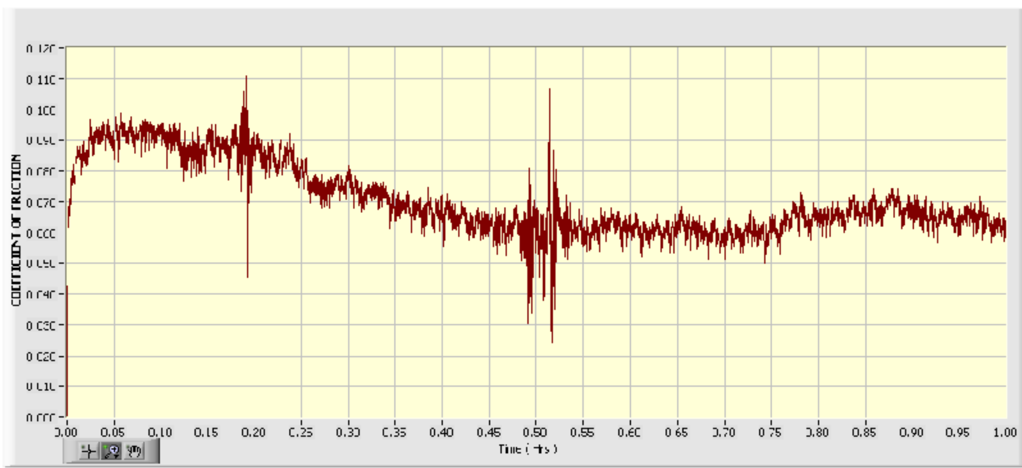

Figure 7.10: Test 1d

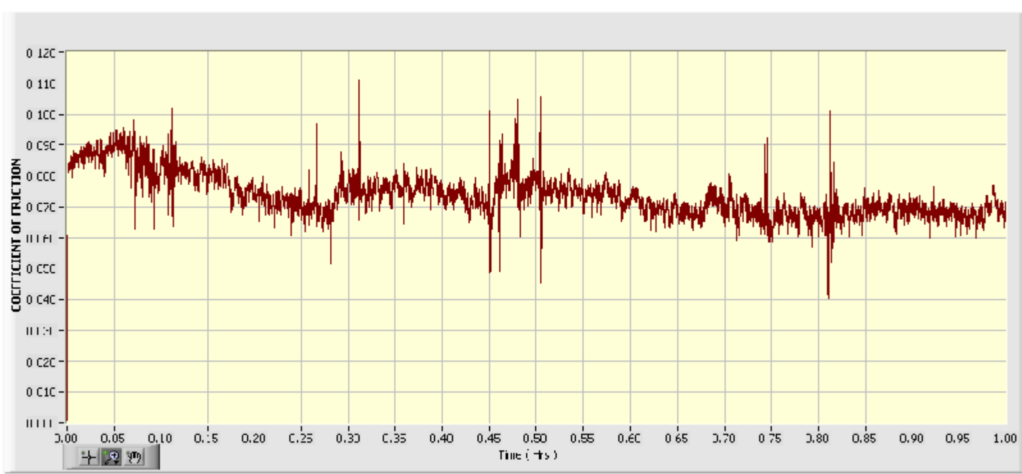

Figure 7.11: Test 2d

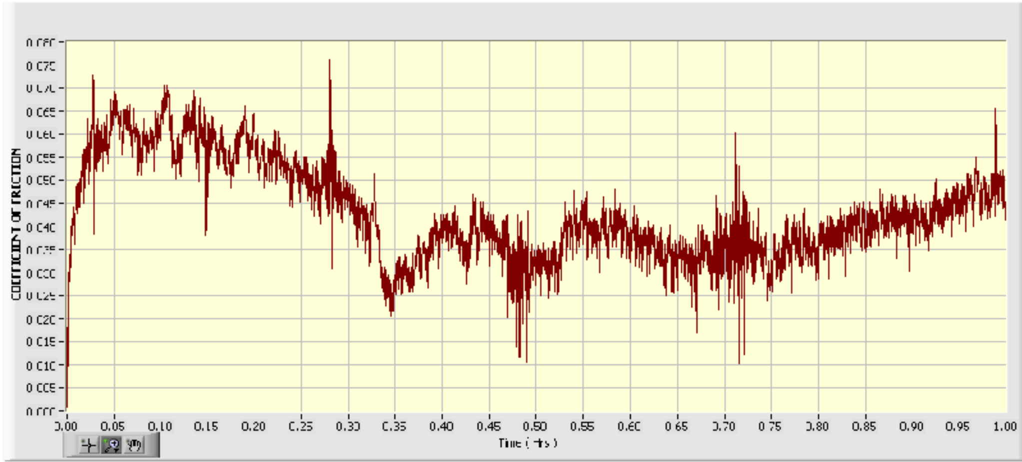

Figure 7.12: Test 3d

7.1.2 Wear Development

7.1.2.1 Gear Oil A

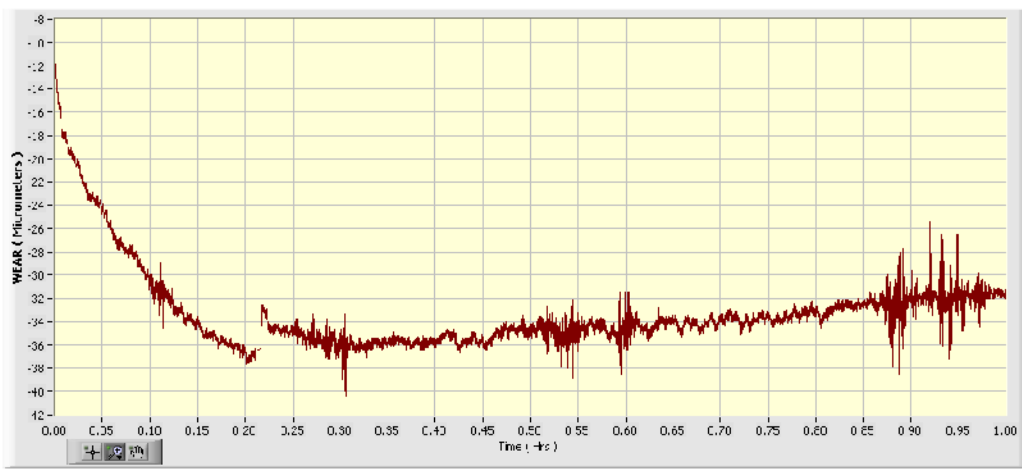

Figure 13: Test 1a

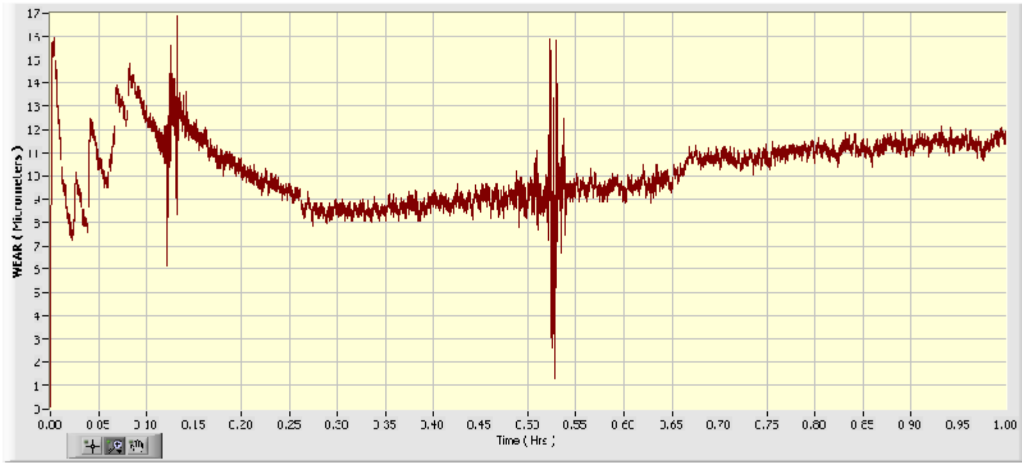

Figure 14: Test 2a

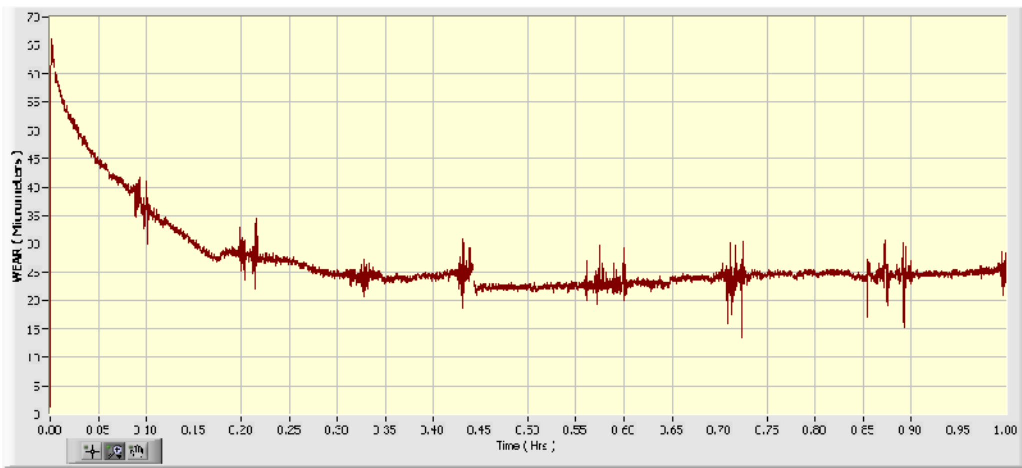

Figure 15: Test 3a

7.1.2.2 Gear Oil B

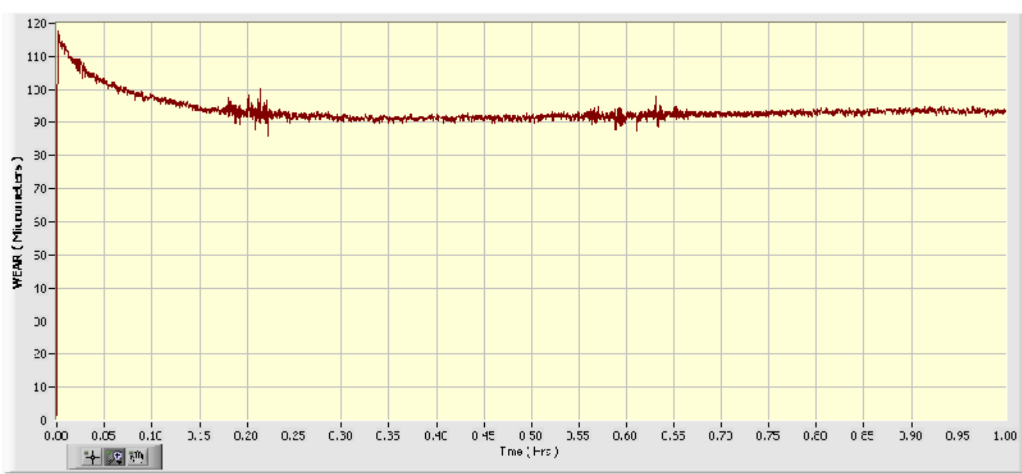

Figure 16: Test 1b

Figure 17: Test 2b

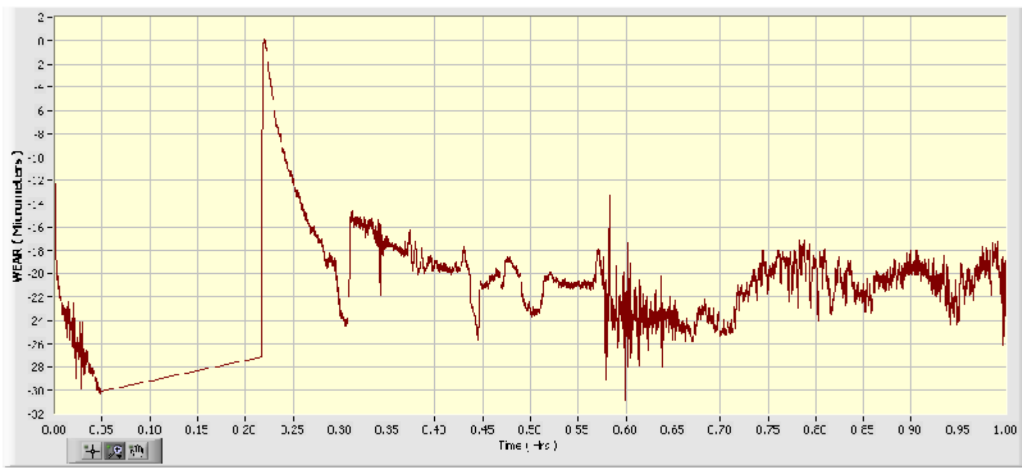

Figure 18: Test 3b

7.1.2.3 Gear Oil C

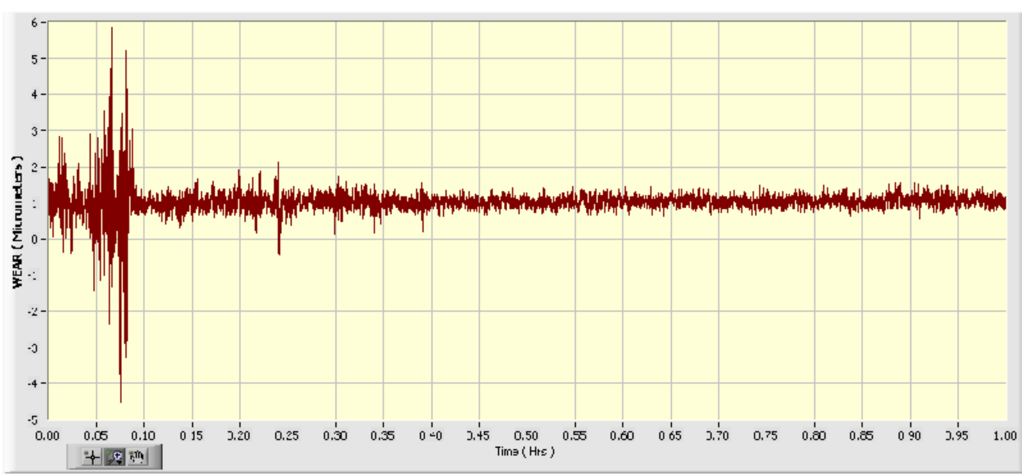

Figure 19: Test 1c

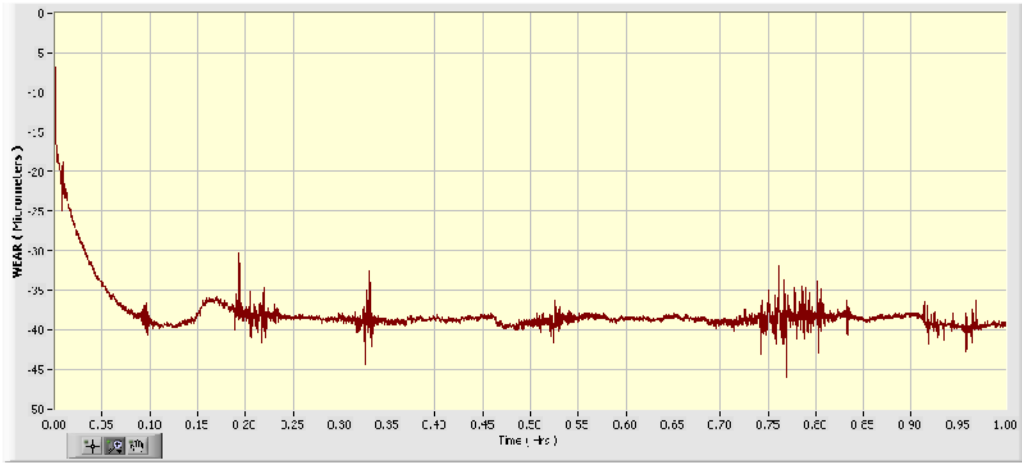

Figure 20: Test 2c

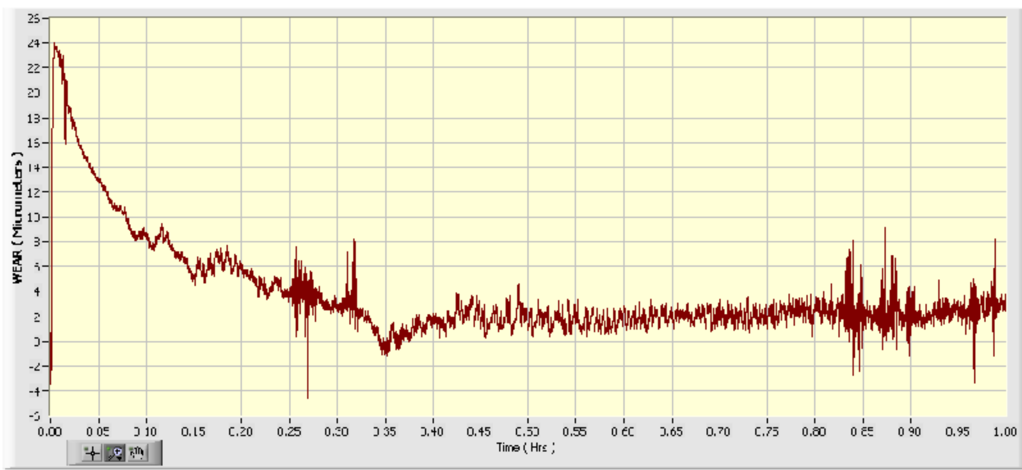

Figure 21: Test 3c

7.1.2.4 Gear Oil D

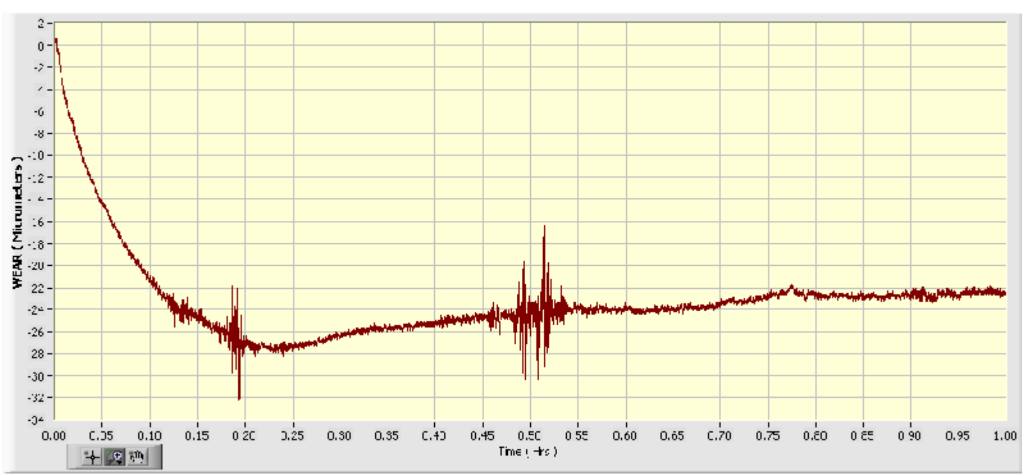

Figure 22: Test 1d

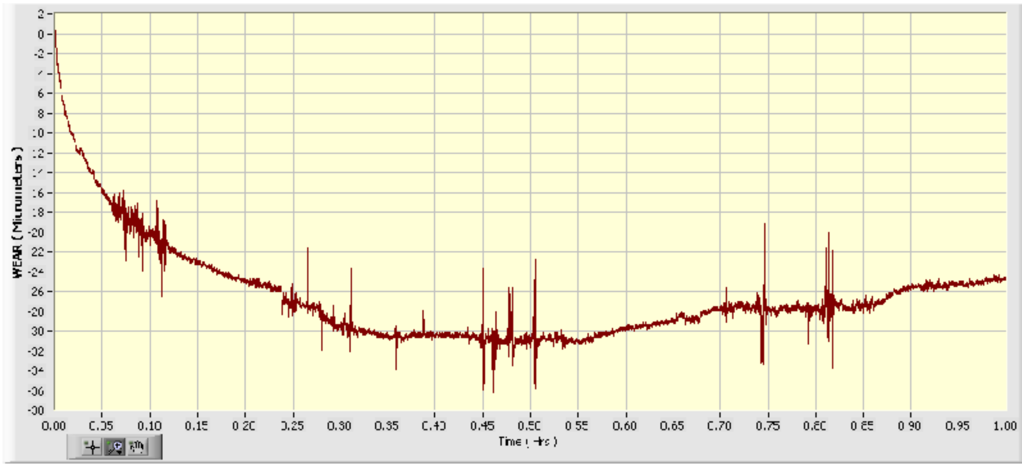

Figure 23: Test 2d

Figure 24: Test 3d

APPENDIX II –

ASTM D 4172 – 94; STANDARD TEST METHOD FOR WEAR PREVENTIVE CHARACTERISTICS OF LUBRICATING FLUID (FOUR BALL METHOD)

APPENDIX III –

ASTM D 445 – 97; STANDARD TEST METHOD FOR KINEMATIC VISCOSITY OF TRANSPARENT AND OPAQUE LIQUIDS