STUDY THE FRICTION PROPERTIES OF TREATED ENGINE OIL WITH AN ADDITION OF ZDDP AND NANOPARTICLES

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Faculty of Mechanical Technology and Engineering

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Supervisor Name : Dr. Muhammad Ilman Hakimi Chua Bin Abdullah

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DEDICATION

I dedicate this works to my beloved parents and my supervisor Dr. Muhammad Ilman Hakimi Chua bin Abdullah, who offered unconditional love and support and have always been there for me. Thank you so much for giving me strength to finish my Final Year Project.

ABSTRACT

Globally, there were substantial environmental and economic difficulties linked with the inappropriate treatment and disposal of wasted motor oil. Heavy metals, hazardous chemicals, and other toxins might contaminate soil, water, and air if waste motor oil was not properly treated. The goal of this study was to develop a novel lubricant by incorporating ZDDP and hBN nanoparticles into waste engine oil. The waste engine oil was treated in line with ASTM D-7317 during the procedure. The modified oil was then mixed with 0.2 and 0.5 vol.% ZDDP and hBN nanoparticles, and the samples were homogenized using an ultrasonic homogenizer. A tribological test was performed in accordance with ASTM D-4172 (b), and the CoF and WSD for each sample were calculated. HBN nanoparticle obtain the best result both in WSD and CoF of 0.21 and 1.371(mm) whereas for the worst result it is obvious result obtain for treated used oil with average of WSD and Cof of 0.48 and 1.405(mm). The results obtained from SEM show that the waste engine oil has abrasive and adhesive wear, proving that the oil has the worst results. While hBN nanoparticles show the best SEM results with a cleaner and smoother WSD surface.

ABSTRAK

Pembuangan dan salah urus minyak enjin terpakai menimbulkan ancaman persekitaran dan ekonomi yang ketara di seluruh dunia. Minyak mesin sisa adalah bahan berbahaya yang mengandungi logam berat, bahan kimia toksik, dan bahan cemar lain yang dapat mencemarkan system air, tanah, dan udara jika tidak ditangani dengan cermat. Kajian ini bertujuan untuk merumuskan pelincir baru dari minyak enjin sisa yang dicampur oleh ZDDP dan nanopartikel hBN. Prosesnya melibatkan rawatan minyak sisa buangan mengikut ASTM D-7317; minyak yang dirawat dicampurkan dengan 0.2 dan 0.5 vol.% daripada nanopartikel ZDDP dan hBN; sampel kemudian diselaraskan dengan ultrasonication. Ujian tribologi telah dilakukan mengikut ASTM D-4172 (4-ball testing) di mana CoF dan WSD dinilai untuk setiap sampel. Ujian tribologi telah dilakukan mengikut ASTM D-4172 (b), dan CoF dan WSD untuk setiap sampel telah dikira. Nanopartikel HBN memperoleh hasil terbaik kedua-dua dalam WSD dan CoF sebanyak 0.21 dan 1.371(mm) manakala untuk hasil yang paling teruk adalah jelas hasil diperolehi bagi minyak terpakai yang dirawat dengan purata WSD dan Cof sebanyak 0.48 dan 1.405(mm). Hasil yang diperolehi daripada SEM menunjukkan bahawa minyak engine sisa mempunyai abrasive dan adhesive wear, membuktikan bahawa minyak itu mempunyai keputusan yang paling teruk. Manakala bagi hBN nanopartikel menunjukkan keputusan SEM yang paling baik dengan permukaan WSD yang lebih bersih dan licin.

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LIST OF ABBBREVIATIONS

ASTM	-	American Society of the Internationals Association for Testing and Material
COF	-	Coefficient of Friction
WSD	-	Wear Scar Diameter
ZDDP	-	Zinc dialkyldithiophosphate
Hbn	-	Hexagonal Boron Nitride
SEM	-	Scanning Electron Microscopy
mm	-	Milimeter

CHAPTER 1

INTRODUCTION

1.1 Background

Lubricant is a substance that is used to reduce friction and wear to provide a smooth running in a machine for a satisfactory life of the machine. Most of the lubricants are in a liquid form for example mineral oil, synthetic esters, and silicone fluid but they can also be in a solid form such as polytetrafluoroethylene. An understanding between the lubricant and the tribological surfaces is necessary if the machine elements are to be provided with a satisfactory life. The fluidity of the oil has several advantages over grease because it can enter the loaded conjunction most readily to flush away contaminants such as water and dirt, and other elements (Bernard, 1981).

There are many types of lubricant that can be used in the industry, but the most common use of lubricant is in the automotive industry in Malaysia by 2020. The statistic which is more than 60% are conquered by automobiles in terms of the usage of lubricants in Malaysia by 2020. As for the lubricant to be made from the treated oil is possible by adding a compound for the mixture for example by blending ZDDP to the treated wasted oil making it possible to create a lubricant from wasted oil.

From the extracted wasted oil which was used from the car, by adding ZDDP substance into the filtered waste oil to be created and tested in the lab. Globally, the transportation sector increased by 37% in 1990-2005. This means that it furthers the contamination of the environment by the poisonous gases (Smith, 2008). The purpose of the process is to lower the money spent on making a new lubricant while it can reuse the treated one and still can work the same as the new one. The best blending mixture can be considered by the result of the testing that is being used in the lab. Thus it discussed the aftermath result in the wear involved.

1.2 Problem Statement

There are some issues regarding of waste oil because if all automotive waste oil generated annually were being able to be reused and when untreated waste oil combustion performed it can create hazardous gasses, plus created acidic rain. Alternative fuel technologies have been investigated in recent years to replace fossil fuel due to the reduction of this source and the increase in its demand and cost. The utilization of waste engine oil for diesel production appears to be a viable alternative fuel production method. Waste oil is produced in a range of industries, including industrial, automotive, aviation, and marine. It is estimated that 45 million tonnes of oil are produced worldwide each year (IETC, 2013), with only 40% of this oil being collected and properly disposed of, and only around 8% being recycled into new lubricating oils. Thus resulting the most waste oil that can be reused are automotive lubricants with 56%.

From the worldwide waste oil produced, there are several types of oil that can be treated such as motor oils, metalworking fluids, emulsions, transmission fluids, brake fluids, coolants, heating media, refrigeration oils, electrical oils, and hydraulic fluids. From here, as stated earlier automotive lubricants are the most waste oil that can be treated. Motor oils will be used to be treated in this project the easiest search for waste engine oil which is black engine oil used by a car after 5000 kilometers distance travel. The purpose of the project is to filter the waste oil and treated it as a based oil that it can mix with ZDDP and hBN nanoparticle as a new oil. From this project, the most important thing is learning how the treated process are being handle from scratch. Other than that, the other purpose of the project is the knowledge obtained from the process that shows the world how non-waste lubricating oil can save the world economy from using money on things that can be reused.

Today, waste oil can be reused by treating them and blending it with the ZDDP substance. The degradation of lubricant oil can be decreased by the addition of ZDDP into the base parent oil as an effective anti-wear and antioxidant additive (Canter, 2008). The waste oil can be obtained from the used engine oil in the car and then by using the filtration method to have a treated wasted oil. After obtaining the treated oil, the mixing process with ZDDP to have a mixture. Then see the difference between the mixture results on the wear mechanism test. The result will be recorded and used as a support in the report. The most worrying problem is that expected that, the test is only run in the lab and not in real life. But to confirm our result whether it can be used for the real engine or not by making a few runs for each mixture of the lubricant and testing on ASTM D-4172(4 ball testing) and collecting the wear mechanism. Surface profile measurements are one of the methods to measure the amount of wear (Wen and Huang, 2017).

1.3 Objective

The objective of this project are stated as below;

1. To filter the waste engine oil and treated as a based oil.
2. To formulate treated waste oil blended with ZDDP and hBN nanoparticles.
3. To analyze the tribology properties of the developed oil.

1.4 Scope of the project

The scope of this research are as follows:

1. Filtering the waste engine oil using ASTM D-7317.
2. Formulating a mixture of the ZDDP / hBN nanoparticle as additives in the treated oil.
3. Testing the tribological properties using ASTM D-4172.
4. Analyzing the wear mechanism involved and using SEM.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Lubricant oil

Large amounts of used engine oil from various sources are dumped as hazardous waste into the environment in Pakistan (Shakirullah, 2006), and this causes a number of issues because it contaminates water bodies like the Arabian Sea, rivers, and lakes as well as harming freshwater and marine life. A million gallons of water, along with the fauna and vegetation, would be contaminated by about one gallon of spent engine oil (Moura, 2010).In car engines, lubricant oil is used to lubricate moving parts to reduce friction, protect against wear, remove pollutants, act as a cleaning agent, and act as a cooling and anticorrosive agent.It gathers a variety of contaminants and extra parts from engine wear. Most of these contaminants must be removed in order for the engine oil to be reused. These contaminants include metal particles (iron, steel, copper, lead, zinc, etc.) and other compounds of barium, sulphur, water, dirt, burned carbon, and ash.

Compounds like base oil and additives are used in the production of engine oil, which serves as the equivalent of blood in the arteries of the engine. It is first created from crude oil at the refinery and then delivered to the extraction unit as the lubrication unit's raw material, where the components containing petrol compounds are eliminated. After being transported to a dewaxing unit to separate paraffin and wax, the raffinate (refining material) containing the oil is then sent to a furfural unit to create the petroleum-based oil.

2.1.1 Lubricant oil in engine

A lubricant (engine oil) is an oil-based substance that separates the metal components of an engine, lowers friction, and keeps it clean. Lubricant is used to add oil to machines for lubrication (Jonathan,1993). Oils from animals or plants were once the only sources of lubricants, but petroleum has since replaced them as the primary source of supply for modern requirements in both nature and volume. Lubricating oil can now be produced using modern refining techniques from the majority of crude, and its range extends from thin, easily flowing spindle oils to container cylinder oils (Billet,1999).

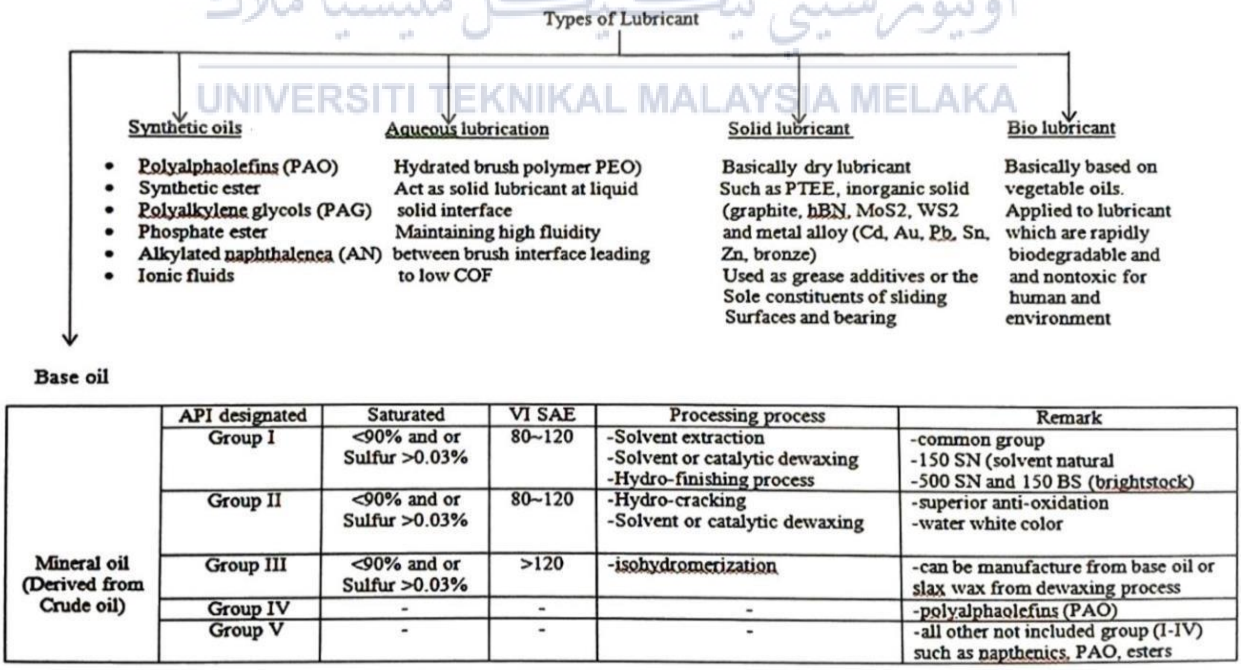
Due to the high operating temperature, lubricant oil experiences a thermal breakdown. When this happens, the oil loses some of its ability to act as a lubricant, and the engine's components rub against one another and eventually wear out. Additionally, lubricant oil contains compounds that can neutralize acids. These additives degrade and lose their effectiveness over time. Finally, oil has the ability to both absorb and suspend combustion byproducts, dust, and water. The oil eventually becomes fully absorbed by this material and can no longer absorb any more. Then, if that material is left in the engine, it may result in corrosion (Einav, 2015).

In order to prevent undesirable qualities, engine oil contains a lot of additives. Oxidation inhibitors, pour point depressants, coloring agents, anti-corrosion agents, and other additives are the most common ones used in engine oil. The ability to recycle used lubricating oils is largely dependent on the type of oil used as the base stock as well as the type and quantity of impurities introduced during use.

2.1.2 Type of lubricant oil in engine

Bio-based lubricants can be defined as oil that is derived from a renewable source and biodegradable. Most will choose vegetable waste or animal fat to extract as a bio-based lubricant. Any source can be extracted as a bio-based lubricant once the material meets the renewable and biodegradable requirements. Research showed that bio-based lubricant are very useful to the mechanical and industrial fields due to their excellent physical properties. It is estimated that up to 60% of synthetic oil will be substituted to bio-based lubricants once biodegradable oil is release in the market. The reason why we choose bio-based lubricant compared to mineral oil is because it has excellent lubricity, is less toxic to the environment, high viscosity index, is renewable and eco-friendly, is spill remediation, and more safer.

There are many types of lubricants that exist in the market based on their function and characteristics. Lubricants can be divided into three types which are solid lubricant semi-solid lubricant and liquid lubricant, but most of them were using liquid lubricant in their vehicle.



	API designated	Saturated	VI SAE	Processing process	Remark
Mineral oil (Derived from Crude oil)	Group I	<90% and or Sulfur >0.03%	80~120	-Solvent extraction -Solvent or catalytic dewaxing -Hydro-finishing process	-common group -150 SN (solvent natural -500 SN and 150 BS (brightstock)
	Group II	<90% and or Sulfur >0.03%	80~120	-Hydro-cracking -Solvent or catalytic dewaxing	-superior anti-oxidation -water white color
	Group III	<90% and or Sulfur >0.03%	>120	-isohydromerization	-can be manufacture from base oil or slax wax from dewaxing process
	Group IV	-	-	-	-polyalphaolefins (PAO)
	Group V	-	-	-	-all other not included group (I-IV) such as napthenics, PAO, esters

Figure 2.1 Type of lubricant (Abdullah, 2015)

2.1.3 Function of lubricant.

In many different fields and applications, lubricants are essential for maintaining smooth functioning, lowering friction, and safeguarding mechanical parts. This paper attempts to give a general overview of the roles played by lubricants, their significance, and the major variables influencing their performance. Reduced friction between moving parts is one of the main purposes of lubricants. Lubricants allow for smooth motion and avoid direct metal-to-metal contact by forming a thin film or boundary layer between surfaces. This lessens frictional forces, cuts down on energy waste, and improves effectiveness.

The engine is the main component of the vehicle. For the machine to operate well, it creates power for the shaft and other spinning components. The engine's lubricant plays a crucial role in preventing wear and corrosion. According to Watson (1955), the pistons, rings, cylinders, bearings, and cam lobes wear down first in an engine. Engine failure is brought on by cylinder bore and piston ring attrition (Jiang, 1998). One method or strategy to reduce wear on both surfaces in close proximity is the use of engine lubricant.

2.2 ZDDP additives

One of the most prevalent additives found in commercially available motor oils is zinc dialkyl dithiophosphate (ZDDP). According to Spikes (2004), ZDDPs function as anti-oxidants, corrosion inhibitors, and wear agents. The ZDDP contents in various motor oils have significantly decreased in recent years. For instance, the maximum concentration of ZDDPs permitted was 1200 ppm in 1995 when the American Petroleum Institute (API) developed the SH service rating for motor oils to be used in petrol engines (American Petroleum Institute, 2010).

2.2.1 ZDDP background

Since they were first utilised as antiwear additives more than 60 years ago, zinc dialkyl- and diaryldithiophosphates (ZDDPs) have been an essential part of nearly all contemporary petrol and diesel engine lubricants (Spikes,2004). However, the 2010-added SN service grade only permits a ZDDP content of up to 800 ppm (American Petroleum Institute, 2010). Concerns regarding ZDDPs' effects on catalytic converters are (mainly) to blame for the declines in ZDDP concentrations. According to certain research (Kaleli, 2001; Huang et al., 2004a), the presence of P in motor oils may cause phosphate deposits on the catalysts, which may lower the conversion efficiencies of catalytic converters. Concerns have also been raised over ZDDPs' impact on the environment. Studies have demonstrated that ZDDPs can cause toxicities when they contaminate soil and ground water because they breakdown into hazardous chemicals that contain S and P (Huang et al., 2004b).

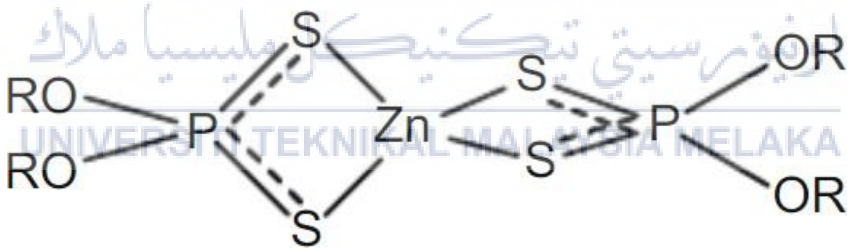


Figure 2.2 Molecular structure of ZDDP

2.3 hBN nanoparticle additives

With today's expanding nanotechnological capabilities, the usage of nanomaterials in various spectrums on living creatures has significantly expanded, raising questions about whether they could be detrimental to human health(Halwa,2007). Numerous studies have shown that distinct nanoparticles (NPs) can have various hazardous effects depending on their functional groups, chemical makeup, and physical characteristics (Hardman, 2006).NPs produce reactive oxygen species that target DNA directly because of their extremely small size and huge surface area, resulting in oxidative damage (DM Brown, 2001). The various nanotoxicity consequences that various nanomaterials may have are yet unknown, and research into the toxic mechanisms is still underway.

Boron nitride (BN) nanoparticles have greatly attracted significant interest due to their superior chemical, physical and thermal properties. With these features, it is used in many engineering applications. Recent research has revealed the potential for use in the biomedical field. Despite numerous studies in engineering applications for industries, studies to evaluate boron nitride for biomedical applications are still limited. There is a growing interest among researchers in the interaction of living systems and boron nitride in terms of biomedical engineering applications.

2.3.1 Definition

The hexagonal ring made of boron and nitrogen atoms placed alternately forms the fundamental component of hBN nanoparticles. A hexagonal lattice structure is created by the bonds between each boron atom and three nitrogen atoms, as well as the bonds between each nitrogen atom and three boron atoms. The hBN nanoparticle's distinctive layered structure is a result of this configuration. In hBN nanoparticles, the layers are kept together by weak van der Waals forces, making it simple for them to slide over one another. Due to this characteristic, hBN nanoparticle is a good lubricant, coating, and filler for composite materials.

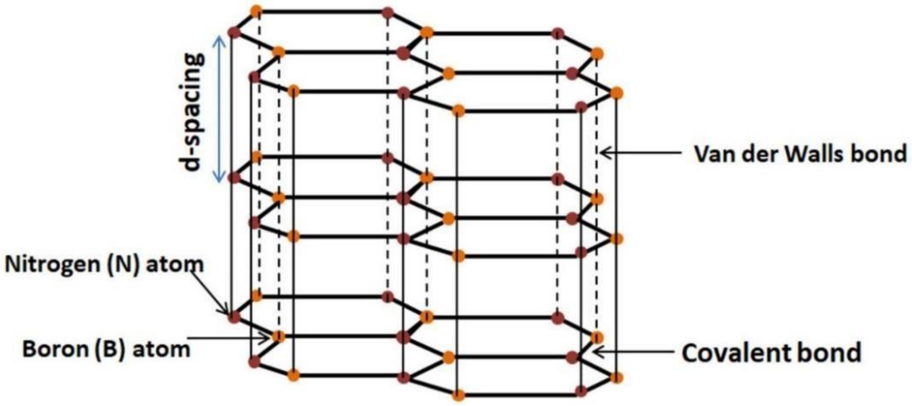


Figure 2.3 hBN nanoparticles molecular structure

2.4 Waste oil

Prior to recent technical advances, coal was the primary fuel used in industry. However, petroleum and natural gas, which are cheaper, easier to mine, process, transport, and utilise than coal, now meet the majority of the world's energy needs. Coal, oil, and natural gas are examples of fossil fuels that are used extensively in the production of energy worldwide. These fuel the industrial, agricultural, and transportation sectors. But in recent years, issues including the depletion of petroleum resources, shifting fuel prices, and environmental concerns have made it possible for researchers to create cheaper, more environmentally friendly alternatives to traditional fuel sources.

Consideration of waste lubricant oil as an alternative or extending fuel has numerous advantages, including the utilisation of waste energy sources thereby protecting the environment from toxic and hazardous chemicals, reducing dependence on fossil fuels, less petroleum imports thus improving on foreign exchange, an infinite source of energy because they lubricate moving parts in machinery, and improvement of regional development and social structure in developing countries. Given that waste engine oil will always be used in engines, it is a significant sort of waste lubricating oil. One gallon of waste oil can contaminate millions of gallons of drinking water and create a film on the water's surface that inhibits oxygen from dissolving, which is bad for all types of aquatic life and the photosynthesis process.

2.4.1 Waste Oil Origin

Lubricating oils are used in services to facilitate the simpler motion of related parts and to protect rubbing surfaces. They act as a medium to dissipate the high-temperature buildup on the moving surfaces during the operation. As the temperature increases, the lubricating oils deteriorate, losing qualities like viscosity and specific gravity. The lubricating oils contain dirt and worn-out metal pieces from the surfaces. The lubricating oil must be drained and replaced with a new one as it loses its lubricating characteristics over time due to the over-reduction of desirable properties (Bowman, 1982)

2.4.2 Statistical Waste Oil

Figure 2.3 shows the general chemical composition of the used engine oils. The basis of contemporary society is the automobile, which cannot function without lubricants. The amount of waste oils has increased along with the population and vehicle counts. Any lubricating oil, mineral or synthetic, that can no longer be used for the intended function is referred to as "waste oil". Additionally, using it helps reduce pollution from the burning of fossil fuels and the preservation of natural resources. In this regard, a number of recycling systems have been developed in recent decades, which aim to solve the ecological, technical and economic problems associated with waste oils.

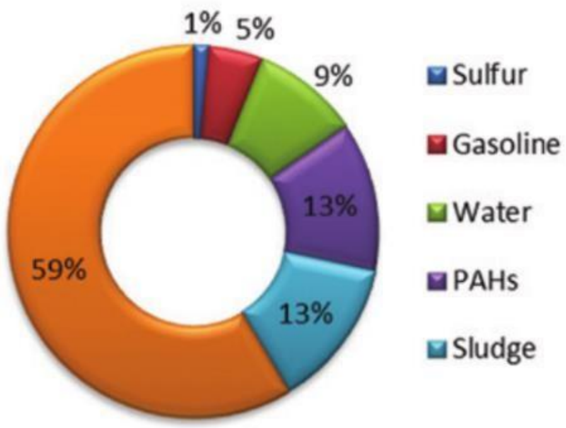


Figure 2.4 Chemical composition of used oil (PurePath Green Technology,)

2.4.3 Environmental Pollution

In general, the buildup of pollutants in soils has the potential to be harmful to the environment and human health; it has the potential to penetrate the food chain and significantly impacts both animal and human health (Khan ,2005). Therefore, appropriate solutions for the management or disposal of used motor oil as well as any other petroleum wastes must be discovered.

2.4.3.1 Type Pollution Occur

One of the worst soil contaminants is thought to be hydrocarbons (Ayotamuno ,2009). Any type of hydrocarbon spill, whether on land or in water, can have a catastrophic impact on the biota of an ecosystem since they contain toxins that pose a risk to both plants and animals. These poisons can permeate a region's food chain and ultimately end up in humans' stomachs. Municipal soils are frequently more contaminated with petroleum derivatives like used motor oil because of the presence of various types of vehicles and machinery, which has led to an increase in the use of lubricants like motor oils. This could lead to spillages, which because of their persistence can be an environmental annoyance. In addition, it can render the soil unsuitable for plant growth for a while, a period of time, or even years (Obire O,2001).

2.5 Friction

Early civilizations were well aware of the principle of friction when they started to utilize tools, erect structures, and create shoes to govern slick terrain. However, understanding of its nature and genesis has been elusive. On the one hand, gravity creates weight and mass, and when the mass must move across gravitational fields, horizontal forces must be applied to overcome the gravitational pull. In tribology, friction is inextricably linked to wearing control and reliability issues for all moving parts in a variety of settings and operating conditions. As a result, the complexity of friction grows along with the quick advancement of designs and machinery. A rigorous evaluation of our knowledge of the fundamentals of friction is necessary.

The literal meaning of friction is the resistance of a mass to motion, frictional force is the force required to overcome this resistance; static frictional force is the force required to overcome this resistance when the mass is at rest; and kinetic frictional force is the force required to keep the mass moving when it is sliding. To permit a comparison of the relative magnitudes of frictional force across a variety of materials and operating situations, the coefficient of friction is a normalized scalar.

2.5.1 Friction in Engine

The engine has a lot of moving parts. Their functionality is maintained, component longevity is increased, and frictional energy losses are reduced with proper lubrication. Numerous concerns with engine durability and reliability, including excessive wear, component seizure, and catastrophic failure, can be linked to issues with insufficient lubrication of crucial parts. Engine integrity and performance, which are factors that matter to the end user are correlated with proper lubrication and minimal friction. Under high speed and low load conditions, the piston ring assembly and bearings are typically operating in the hydrodynamic lubrication regime, and engine oil viscosity plays a crucial role in reducing friction that results from this regime. Speed, load, oil film thickness, oil viscosity, oil temperature, surface topography of engine components, and kind of friction modifiers are the main variables that affect engine friction power.

2.5.1.1 Friction formula

Science has investigated surface contact over time. Scientist Guillaume Amontons developed the principles for analysing the dry sliding of two flat surfaces in the seventeenth century. A block sliding on a plane is first resisted by the friction force. Second, the frictional force is related to the force that the flat normally applies to the block. Third, the apparent contact area has no bearing on the frictional force. Then, the French scientist Coulomb added one more property to the friction force which is the ratio of the Friction force " Ff " to the Normal force "N" which is called the Coefficient of friction, "μ". Then, the equation derived as referred to in Figure 2.5 is shown below.

Equation of Coefficient force:

$$\mu = \frac{F_f}{N}$$

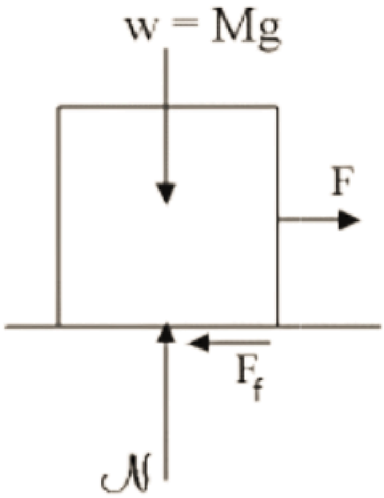


Figure 2.5 Free body diagram

2.5.2 Cause of friction

The piston-ring-liner system, crankshaft and bearing system, and valvetrain system are the three main engine subsystems that contribute to mechanical friction. The precise distribution of friction across these three categories relies on the engine in question, the specifics of component design, and operating circumstances. The main bearing and seals on the crankshaft, however, generate 50% to 100% more friction than the valvetrain system on average, while the friction on the power cylinder is roughly equal. As shown in Figure 2.6.

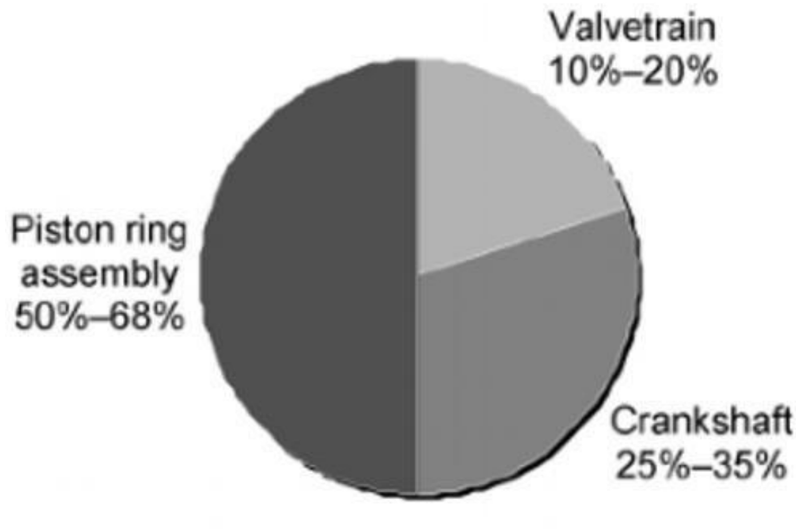


Figure 2.6 Distribution of friction in engine

2.5.3 Type of Wear Occur

Generally, the wear mechanism between two contacts can be divided into four parts, as illustrated in Figure 2.7 first, in (a) when flaws weld together and break apart on a counterface under heavy loads, high temperatures, or high pressures, adhesive wear develops (Hase, 2019). Under pressure, it often occurs during sliding or rubbing motions. Surface finishes can be improved, harder materials can be used, correct lubrication can be used, and operating conditions can be managed to decrease adhesive wear.

Second is (b) When hard particles or hard protuberances are in touch with a surface and travel over it, they cause abrasive wear. When hard protuberances or particles are produced on surfaces during abrasive wear, two-body abrasion occurs, and three-body abrasion occurs when the hard particles roll and slide freely between counterfaces (Todaka, 2022). These specks may be existing in the environment or may be introduced when using machines. On the surfaces, the abrasive action may result in material loss, scratches, and grooves.

Then for (c), when two contacting surfaces are subjected to cyclic loading, fatigue wear results. The cyclic stress will result in crack development and growth, which will finally produce wear particles between contacting surfaces. When the repeating motion and cyclic loading have a small amplitude (typically less than 150 m), fretting wear can develop between the counter-face. Oxide particles, metal-metal adhesive connections, and fatigue cracks are frequently present in conjunction with it (Zhang, 2021).

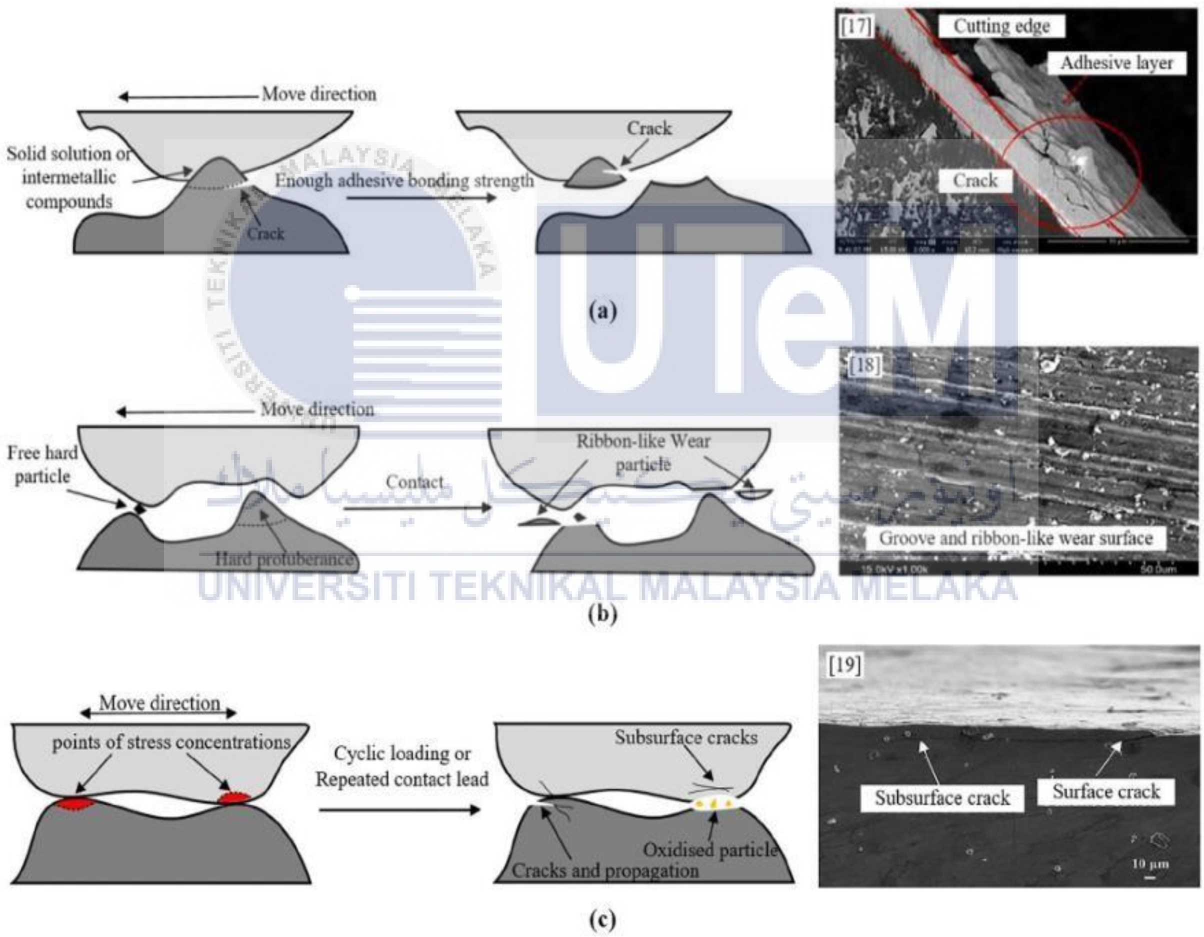


Figure 2.7 Type of wear mechanism (a)Adhesive wear, (b)Abrasive wear, and (c) Fatigue wear

2.5.4 Wear Mechanism

Wear refers to the material's deteriorating, sluggish removal or distortion at solid surfaces. Wear can have mechanical, also known as erosion, or chemical, commonly known as corrosion, causes. Metals are subject to wear through the plastic displacement of surface and near-surface material as well as the separation of wear debris particles. Wear is the erosion of material from a solid surface caused by the action of another solid, according to material science.

Figure 2.8 illustrates how adhesive wear occurs; as one surface slides over another, the interaction between the high areas results in sporadic wear debris particles. Mild adhesion is the slower ejection of coatings, such as oxides. Due to the ripping, shattering, and liquefaction of metallic intersections, severe adhesion results in the evacuation of metal. This results in surface scrubbing, irritation, and sometimes seizures. When surfaces come into frictional contact, adhesive wear can occur between them. It generally refers to the unintentional dislodging and connecting of wear debris and material mixtures from one surface to the next. There are two distinct categories of glue wear.

Fatigue Wear happen when surfaces are subjected to varying stresses, surfaces may tire and begin to wear. High surface tensions induce cracks to propagate deeper into the material, and huge loose particles emerge when two or more of these cracks connect together. When large repetitive stresses are produced by the heating caused by the contact of the two contacting components, thermal surface fatigue occurs. This causes the surface to crack and to lose small pieces of material. Surface fatigue, a type of general material weariness, is a cycle in which cyclic stacking weakens a material's exterior as shown in Figure 2.9. When wear particles are constrained by cyclic split growth of microcracks on the surface, fatigue wear results.

As shown in Figure 3, Abrasives are substances with an angular profile and a hardness greater than the surface being abraded. Examples include the damage to crankshaft journals in reciprocating compressors and sand particles between contact surfaces. Ordinarily, the type of contact and the quality of the contact determine the order of abrasive wear. The technique of abrasive wear is determined by the type of contact. Two-body and three-body abrasive wear are the two types of abrasive wear. When sand or other hard particles remove material from one surface, two-body wear occurs. The fundamental commonality is the removal or displacement of material during a cutting or plow operation. The wear's openness or closure is determined by the contact situation. When the surfaces are sufficiently uprooted to be separated from one another, an open contact state occurs.

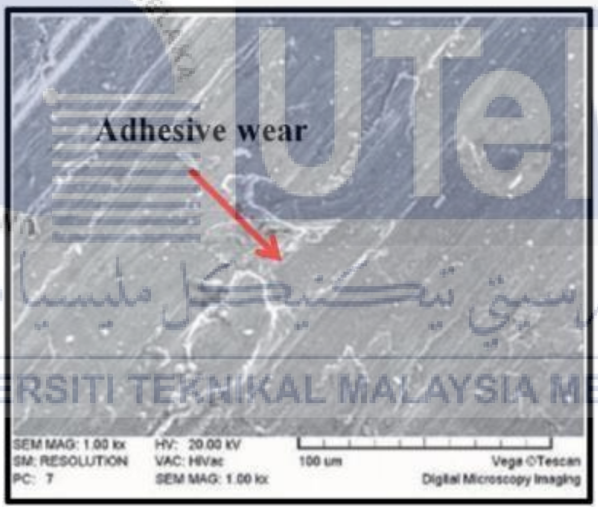


Figure 2.8 Adhesive Wear

Figure 2.9 Fatigue Wear

Figure 3 Abrasive Wear

CHAPTER 3

METHODOLOGY

3.1 Flowchart

This research has several parts of the process. In this project the first step is understanding the objective and problem statement of the project, and continue into finding and collecting the waste engine oil to be filtered. Then filter the waste oil by using ASTM D-7317 which should be done by the end of this semester. Next, are mixing process with additives ZDDP and hBN nanoparticles by using homogenizing ultrasonic tools and preparing 5 samples of treated oil as shown in Table 3.1. After that run the test using ASTM D-4172 which should be done in the next semester. Next, analyze the result to find the wear mechanism involves using SEM. Lastly, conclude and decide the best solution for the mixture.

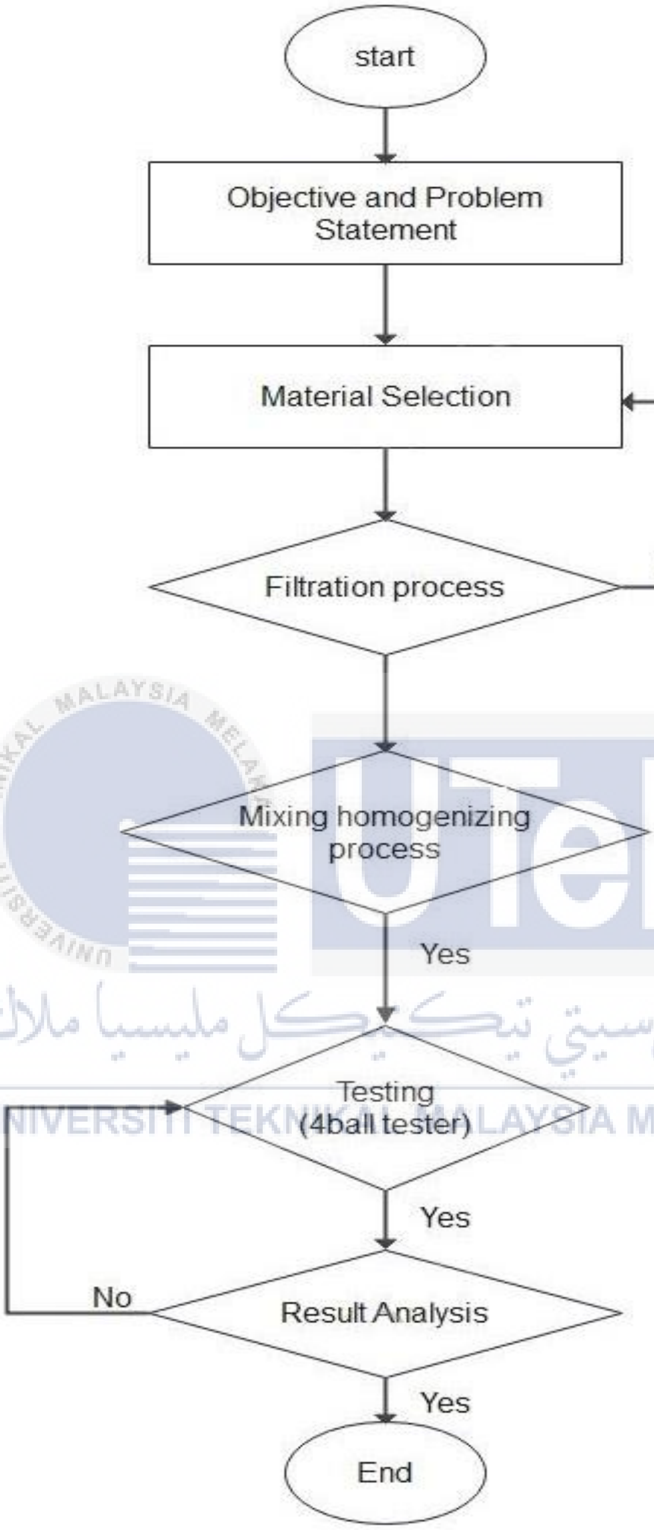


Figure 3.1 Flow Chart

Table 3.1 Table of sample

Sample	Parameter			Average COF	Average WSD
	Sample no.	Oil (%)	Additives (%)		
Treated used oil	1	100	0	-	-
Treated oil + ZDDP 0.25%	2	99.75	0.25	-	-
Treated oil + ZDDP 0.5%	3	99.50	0.5	-	-
Treated oil + hBN nanoparticle 0.25%	4	99.75	0.25	-	-
Treated oil + hBN nanoparticle 0.5%	5	99.50	0.5	-	-

3.2 Material Selection

Major contributors to this market will be motor cars, commercial vehicles, aircraft, railway locomotives and other automotive machinery (2002). The ability of nano-size particles to maintain thermal stability and prevent wear between engine components has made them particularly appropriate as friction modifiers and antiwear additives, which can raise performance and increase engine economy. Referring table 3.1, the most used and easy-finding waste engine oil in machinery which is from a car will be used. As for the additives, ZDDP's and hBN nanoparticles will be use to be mixed with the oil after being treated.

3.2.1 Type Of Waste Oil Used

The waste oil that will be used were as shown in the properties table of waste oil. Waste synthetic are used because of its commonly used in most of the model of the car were using synthetic engine oil since 2019 model. The purpose we use the type of synthetic waste oil is because it is easier to make a comparison between the different types of mixture in the last result. SAE 5W-30 will be used for the project research.

Table 3.2 SAE 5W-30 properties

Properties	Sources	
	Waste Oil	New Oil
Viscosity (cP), 40 °C	-	40.8
Flash Point, °C	-	236
Fire point, °C	-	248
Oil type	-	Synthetic
Viscosity Grade based on Society of Automotive Engineers (SAE)	-	0W/20
Millage usage, km	-	0

3.2.2 ZDDP

ZDDPs, or zinc dialkyldithiophosphates, are oil-soluble compounds used as additives in lubricating lubricants for internal combustion engines and transmissions. ZDDPs are an important component of modern engine oils, and while they make up a small percentage of the overall engine oil, they serve an important function in providing wear protection at key metal-metal contact areas in engines and transmissions. As a result, engine and gearbox life is extended. ZDDPs, because they include sulfur, also provide oxidation protection, extending the life of the engine oil. ZDDPs are sometimes referred to as "multifunctional" additives due to their twofold protective role.

Table 3.2 Table of ZDDP's properties

Properties	ZDDP
Appearance	Yellow powder
Chemical formula	ZDDP
Crystal structure	Hexagonal
Average diameter particle size, nm	7
Density, kgm^{-3}	1.16
Hardness, HRC	65
Maximum use temperature in air, °C	200
Thermal conductivity, $Wm^{-1}K^{-1}$	
Thermal expansion coefficient @25°C–1,000°C	

3.2.3 hBN nanoparticle

Hexagonal boron nitride or known as hBN Because engine oil enhanced with boron-based nanoparticles, particularly hexagonal boron nitride (hBN), works well in preventing wear and lowering the coefficient of friction (COF) (Abdullah et al., 2014), further investigation of the tribological effects of nano-based engine oil diluted with biodiesel fuel was discussed in this study. Recently, nanoparticles have emerged as the most promising additions, with a low concentration of nanoparticles in lubricating oil of 0.2% to 3% vol. adequate to improve tribological qualities.

Table 3.2 Table of hBN nanoparticle's properties

Properties	hBn nanoparticles
Appearance	White powder
Chemical formula	BN
Crystal structure	Hexagonal
Average diameter particle size, nm	70
Density, kgm^{-3}	2.3
Hardness, HRC	40
Maximum use temperature in air, °C	1000
Thermal conductivity, $Wm^{-1}K^{-1}$	27
Thermal expansion coefficient @25°C–1,000°C	$1 \times K^{-1}$/ °C(parallel to press dir.)

3.3 Filtering Waste Oil to Treated oil

There are a few process involved in handling the processes of treating waste oil. By using ASTM D731 to filter the waste oil separate the waste oil into 5 samples with the same properties as shown in table 3.2 earlier.

Figure 3.3 Paper Filtration Apparatus (ASTM D 7317)

3.3.1 Filtration process ASTM D 7317

The vacuum oil filtering method uses a vacuum system to remove impurities, pollutants, and particle matter from oil. It is often used to keep lubricants clean and of high quality in a variety of applications such as industrial machinery, automotive engines, and hydraulic systems. Thus, the vacuum oil filtration method aids in the preservation of oil quality and performance, extending its useful life and preventing damage to machinery or systems. Following manufacturer standards and recommendations for the individual filtering unit and type of oil being treated is critical.

When choosing waste engine oil as a sample for the filtration procedure, ASTM D 7317 must be followed during the experimental phase. The filter membrane will first be cleaned for 15 minutes in a desiccator before being placed in an aluminium weighing dish with a label and weighed to the nearest 0.1 mg. Before tare, the balance will have a 50mL graduated cylinder on it. Oil will then be taken out of the oven and vigorously shaken by hand for at least 30 seconds. 0.25g of the oil sample were dispensed into a graduated cylinder using a medicine dropper. The following step is to add 10 mL of pentane and carefully stir until the oil sample is completely dissolved.

3.4 ZDDP and hBN nanoparticle Blend homogenizing ultrasonic

When ZDDP and nanoparticles are added to oil, they can work together to provide even greater performance benefits. For example, adding nanoparticles to ZDDP-treated oil can help reduce the formation of harmful deposits while still maintaining the protective layer on metal surfaces. Additionally, the nanoparticles can help the oil flow more smoothly and evenly throughout the engine, improving overall performance.

Several types of mixtures are used in this experiment for sample 1, 100% of treated oil will be used to discover the main reference for observation of the result of coefficient of friction(COF) and wear surface diameter(WSD) happen if additives were added to them. As for sample 2, 0.25% of ZDDP will be added to observe the result of the COF and WSD changed the result. To find the difference between the two volumes of the ZDDP was added 0.5% of ZDDP added to the treated oil to show the differences between them. Starting at the fourth sample, 0.25% of hBN nanoparticles are added to treated oil to measure the side effect of COF and WSD changes in the project. Lastly, which are sample five 0.5% were added to make a research of the difference between 0.25% and 0.5% of hBN nanoparticle added in the treated oil. The table shows the sample percentage (volume/volume) of each sample explained earlier.

Table 3.4 Sample Percentage (v/v)

Sample no.	Oil(%)	Additives ZDDP/hBN nanoparticle (%)
1	100	0
2	99.75	0.25
3	99.50	0.5
4	99.75	0.25
5	99.50	0.5

3.4.1 Homogenizing Ultrasonic process

During the homogenizing process, the sample temperature was controlled not to exceed 70°C. Then, using a Sartorius Labsonic P ultrasonic homogenizer for 20 minutes at 50% amplitude and a 0.5 active interval. To stop the nanoparticles from settling, 0.3 vol.% of a surfactant (oleic acid) was added to the samples to stabilize them. The tribological performance of the lubricants was unaffected by the surfactant (Abdullah et al., 2013b).

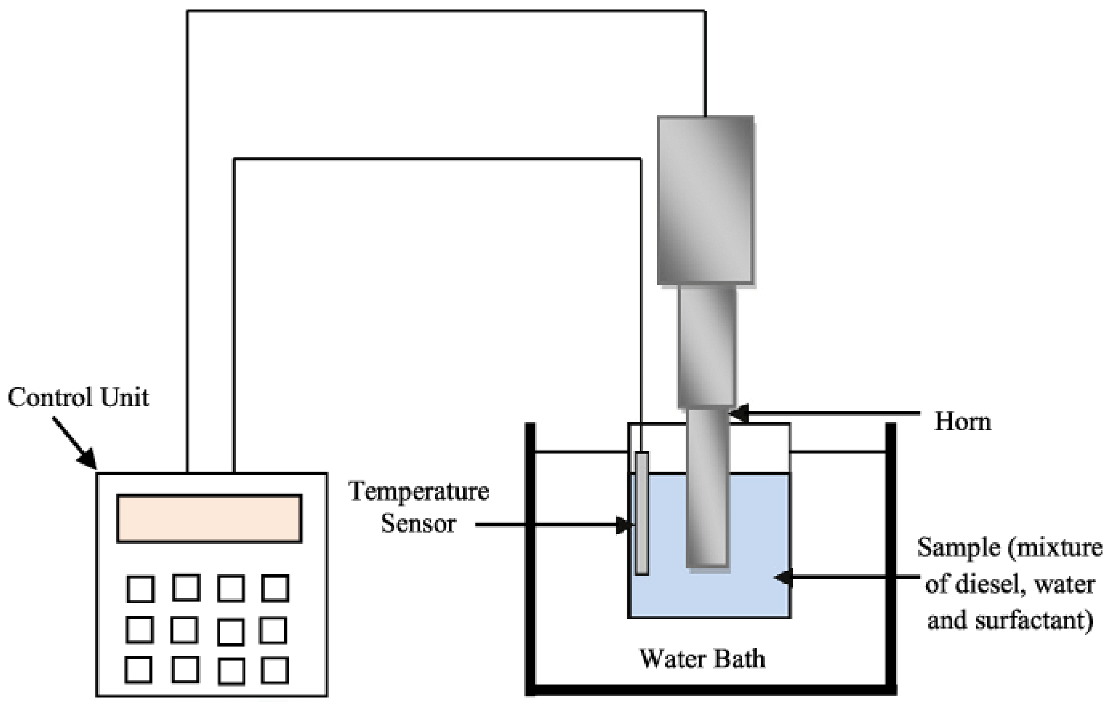


Figure 3.4 Ultrasonic Homogenizer

Begin with a clean, dry container large enough to hold the amount of oil you wish to treat. It is critical to pick a container that is suitable for the chemicals you intend to add. If you are adding ZDDP to the oil, follow the product directions and measure out the necessary amount. ZDDP is normally added in tiny amounts, ranging from 500 to 1200 ppm (parts per million) depending on the application. To guarantee equal distribution of nanoparticles in oil, they may need to be dispersed in a carrier fluid first. The nanoparticles may arrive with their own carrier fluid, or the manufacturer's instructions may need you to add a certain type of carrier fluid.

Once the nanoparticles are disseminated in the carrier fluid, add them to the container containing the treated oil. The number of nanoparticles added will vary depending on the product and application, although they are normally added in modest amounts ranging from 0.1 to 5% by weight. Using a stirrer or other mixing device, completely combine the oil, ZDDP, and nanoparticles. It is critical that the additives are evenly distributed throughout the oil.

Allow the oil to sit for a few minutes to allow the ZDDP and nanoparticles to fully integrate. The manufacturer's instructions should specify how long this procedure should take. Finally, the modified oil can be tested using our ASTM D 4172 equipment. Adding ZDDP and nanoparticles to treated oil should be done carefully and in accordance with the manufacturer's instructions to avoid any negative effects on performance or engine health.

3.5 ASTM D4172

In this project, a four-ball testing machine was utilized to evaluate the lubricant's anti-friction and anti-wear properties. According to ASTM D 4172 - Standard Test Method for Wear Preventive for Wear Preventive feature of Lubricating Fluid, the wear and friction need to be evaluated. The schematic bearings are shown in Figure 3.5. There are 5 different waste engine oils added with additives on the market that will be used as lubricants. Tribological tests were performed using a four-ball tribometer (TR 20) according to the ASTM D4172 and D2783 standards (ASTM, 2010, 2009).

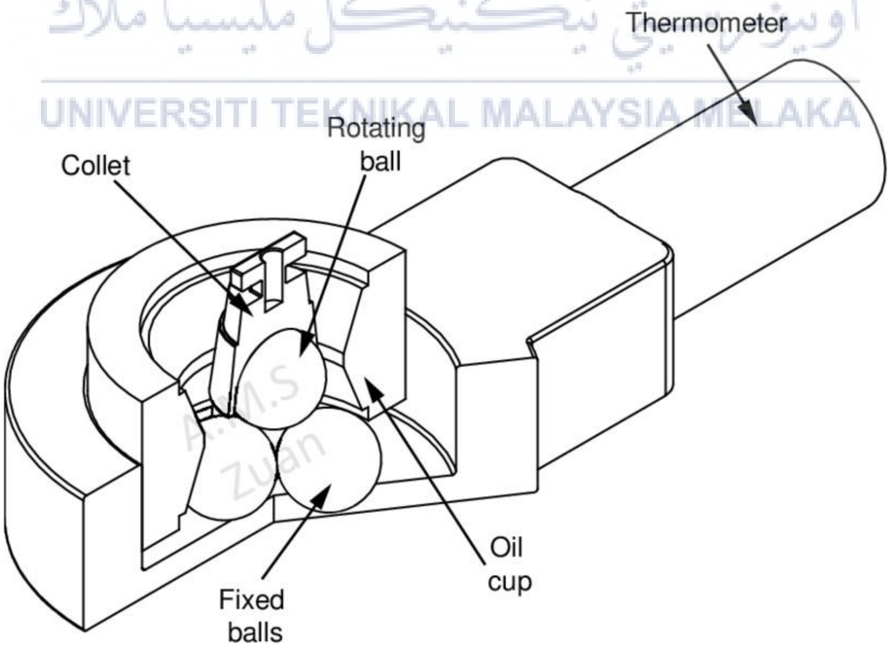


Figure 3.5 ASTM D-4172

Test conditions are a mandatory procedure to make sure the machine does not affect the data during the operation. The test conditions used to develop the precision data were:

Table 3.5 Test Condition range

Parameter	B
Temperature	75 ± 2°C [167 ± 4°C]
Speed	1200 ± 60 rpm
Duration	60 ± 1 min
Load	392 ± 2 N [40 ± 0.2 kgf]

Table 3.6 Result Parameter for obtained COF and WSD

Sample no.	Load (N)	Speed (rpm)	Duration (min)	Coefficient of Friction	Wear Scar Diameter
1	392	1200	35	-	-
2	392	1200	35	-	-
3	392	1200	35	-	-
4	392	1200	35	-	-
5	392	1200	35	-	-

3.5.1 Process

ASTM D4172 is a standard test technique published by ASTM International (previously known as the American Society for Testing and Materials) that uses the Four-Ball Wear Test to determine the wear and friction properties of lubricating oils. In the lubricant industry, this test method is commonly used to evaluate the performance and quality of lubricating oils. Lubricant makers and consumers can gain useful information about the wear and friction properties of lubricating oils by performing the ASTM D4172 Four-Ball Wear Test. This aids in the selection of appropriate lubricants for specific applications, the optimization of equipment performance, and the preservation of machinery and components.

3.6 Surface Roughness by using SEM

SEM is an abbreviation for Scanning Electron Microscopy, a microscopy technique that uses a concentrated electron beam to photograph a sample's surface at high resolution. Surface roughness can be analyzed using SEM, which provides precise information about the topography and morphology of a material's surface.

According to the standard ASTM D4172(USA,2020), the wear scar diameter of steel balls with the 0.01 mm resolution would be evaluated by an optical microscope. To capture the image of the worn scar, the optical microscope utilized the software in the computer. Moreover, the wear scar diameter was calculated using the software, so this procedure was performed for every test of the sample in Table 3.6.

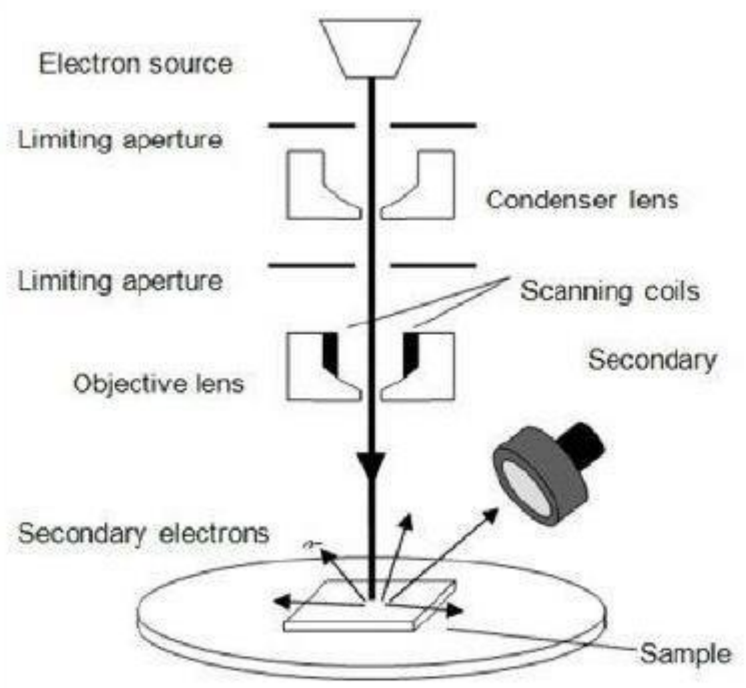


Figure 3.6 SEM diagram

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result and Discussion

The analytical method developed in Chapter 3 will be used in this chapter to examine and analyze the experimental data. A thorough grasp of the outcomes based on empirical evidence will be attained by exploring the causes and identifying contributing factors to the acquired results. Using ASTM D-4172 criteria, the study uses a four-ball testing methodology to evaluate the tribological properties of a new blend that consists of treated oil and two different additives. A thorough analysis of the performance of the tested combination and additives is made possible by this analytical framework, which guarantees a methodical and consistent assessment of the experimental setup. By using this approach, the chapter hopes to shed light on the created formulation's potential benefits and tribological properties, as well as its applicability for a range of uses in the context of ASTM D-4172 requirements.

Table 4.1 COF and WSD result

Sample	Parameter			Average COF	Average WSD (mm)
	Sample no.	Oil (%)	Additives (%)		
Treated used oil	1	100	0	0.48	1.405
Treated oil + ZDDP 0.25%	2	99.75	0.25	0.22	1.381
Treated oil + ZDDP 0.5%	3	99.50	0.5	0.46	1.388
Treated oil + hBN nanoparticle 0.25%	4	99.75	0.25	0.21	1.371
Treated oil + hBN nanoparticle 0.5%	5	99.50	0.5	0.45	1.385

4.1.1 COF differentiation

By using the ASTM D 4172 methodology, the study provides detailed insights into the ideal concentrations of hBN nanoparticles and ZDDP additives for effective lubrication and addressing friction-related engine operating concerns. This interrelationship between engine performance and engine lubricant is an important diagnostic tool to evaluate the engine health and performance (Gautam Yadav, 2014). The results show how different additive concentrations affect the performance of engine oil and can be divided into three categories: low, average, and poor coefficient of friction (COF) outcomes.

The introduction of hexagonal Boron Nitride (hBN) nanoparticles showed a notable performance with a low COF of 0.21 in the low Coefficient of Friction (COF) oil category. This result suggests that a small concentration of hBN nanoparticles improves lubrication considerably, pointing to a possible way to prolong the life of the oil by reducing wear. Similarly, ZDDP at a 0.25% concentration had a favorable influence with a coefficient of determination of 0.22, highlighting the beneficial effect of a small amount of ZDDP in lowering friction. These results highlight the potential advantages of adding ZDDP and hBN nanoparticles to engine oil compositions, demonstrating how they can increase lubrication and reduce wear, which in turn improves engine longevity and performance.

An intermediate value of 0.45 was found when the Coefficient of Friction (COF) for hBN nanoparticles at a concentration of 0.5% was analyzed. This suggests that adding more hBN nanoparticles might not provide any more benefits and might even cause performance to plateau. A similar finding was made with 0.5% ZDDP concentration, where the average COF was likewise 0.45. The idea that going over a specific additive concentration, for both ZDDP and hBN nanoparticles, may not result in any additional improvements and may even jeopardize the oil's lubricating properties, is supported by the similarity in COF values. These results highlight the significance of the ideal additive concentrations in engine oil formulations, since very high concentrations may not provide commensurate advantages and may even negatively impact the overall performance of the lubricant.

The used oil, with an average COF of 0.48, was by far the highest of the examined samples, and it was also the least beneficial in terms of COF results. This result clearly indicates that the base oil alone does not have the best lubricating properties, and that formulations enhanced with additives such as ZDDP or hBN nanoparticles are more successful in reducing friction. The peak COF of the used oil being more than 0.65 is an especially interesting finding, suggesting periods of increased friction and perhaps difficulties in ensuring steady lubrication. This result emphasizes how important it is to include the right additives in engine oil compositions in order to improve lubricating qualities, reduce friction, and guarantee the dependability and lifespan of equipment under a range of operating circumstances.

The importance of additive concentrations in affecting COF in engine oils is highlighted by this study. As demonstrated by the benefits of low concentrations of hBN and

ZDDP, a careful balance is required prove that excessive additive (for oil filling) effect on engine oil dynamic viscosity and performance (Vojtěch, 2014). However, overuse of additives can deteriorate lubrication and result in decreasing returns. Poor performance from the base oil alone highlights the necessity of regularly checking the engine oil to improve engine health overall. For internal combustion engines to operate at their best tribology performance, more tuning of additive concentrations is advised.

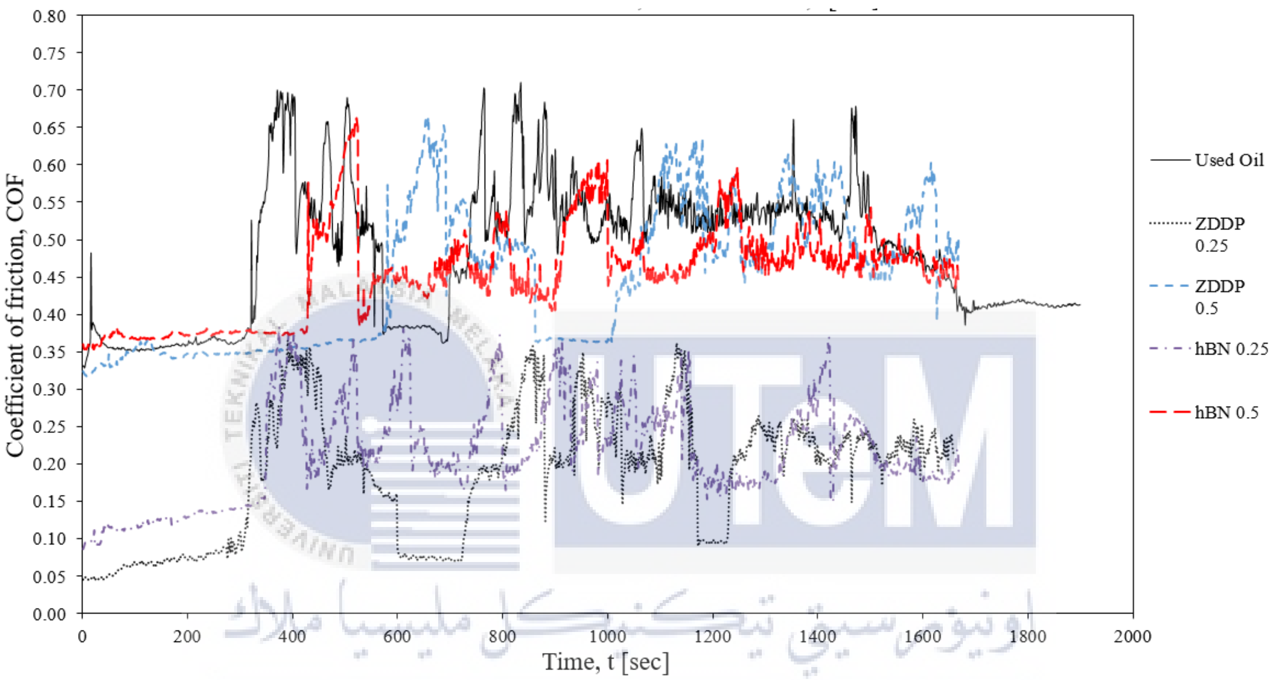


Figure 4.1 Graph of COF vs time results

4.1.2 Average WSD differentiation

The average Wear Scar Diameter (WSD) measurements in the study provide useful information into the efficiency of alternative treatments on waste engine oil. Notably, the WSD for the treated oil was the greatest, measuring 1.405 mm. This shows that the waste engine oil treatment method, which may have included ZDDP and hBN nanoparticles, resulted in a greater wear scar diameter than subsequent treatments. The increased WSD could suggest that the precise formulation or concentration employed to treat the oil caused increased friction and wear, thus jeopardizing the lubricating capabilities.

In comparison, the WSD values for treatments using 0.5% ZDDP and 0.5% hBN nanoparticles were 1.388 mm and 1.385 mm, respectively. These findings imply that both treatments reduced wear, with the ZDDP treatment having a slightly bigger wear scar diameter. The close proximity of these values shows that the effectiveness of ZDDP and hBN nanoparticles in reducing wear is comparable at 0.5% concentration.

Further study demonstrates that as the concentration of ZDDP and hBN nanoparticles lowers to 0.25%, the WSD values decrease. At 0.25% concentration, ZDDP had an average WSD of 1.381 mm, while hBN nanoparticles had the smallest average WSD of 1.371 mm. This implies that, at lower concentrations, both ZDDP and hBN nanoparticles contribute to wear reduction more effectively. The findings highlight the need of tailoring additive concentration levels to obtain the optimum tribological performance in treated waste engine oil.

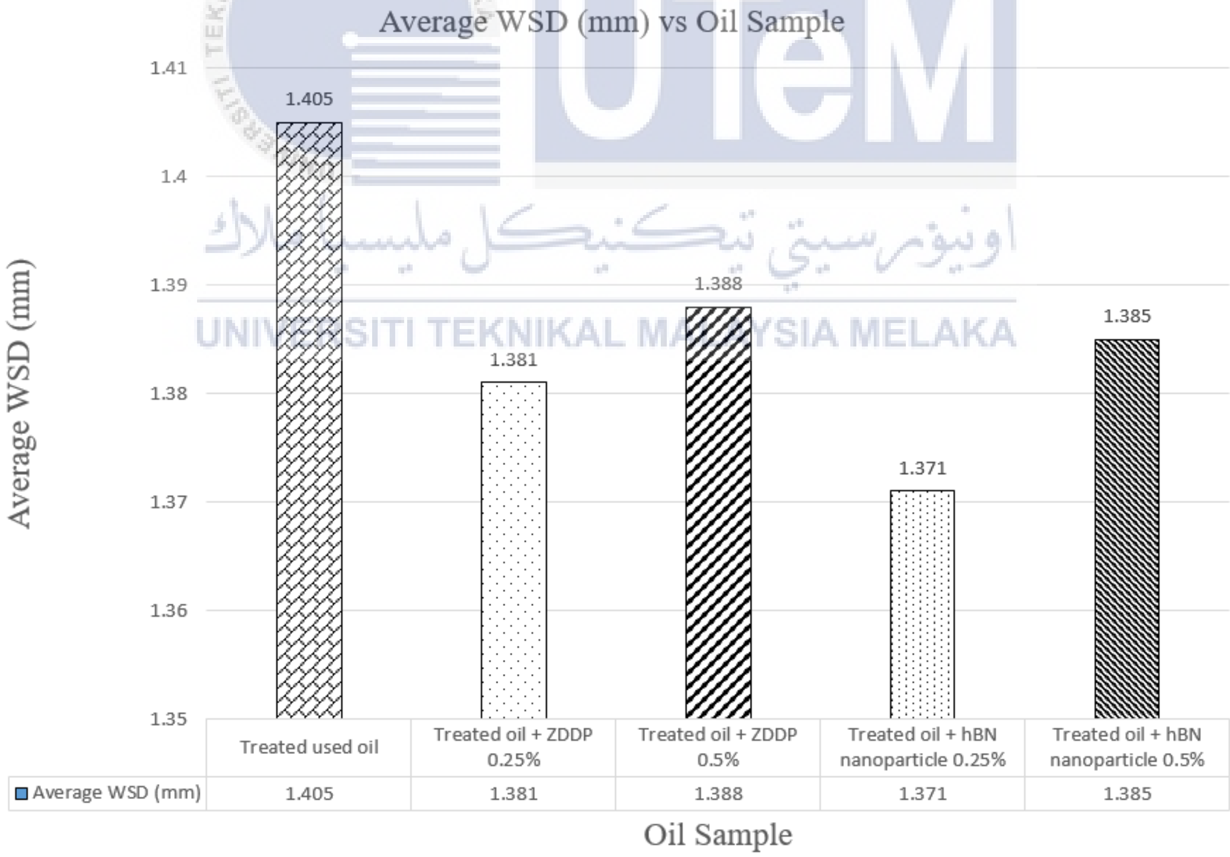


Figure 4.2 Bar Graph of Average WSD (mm) vs Oil Sample

4.2 SEM result

Using four ball testers, compare the attributes of new and varied working life cycle lubricant oils and the depletion of anti-wear and extreme pressure additives. Establish a relationship between the engine's performance and the lubricating oil's working life (Dongare, 2014). Three variables have been determined by thoroughly scrutinizing the SEM results; each condition affects the ball in a unique way. The "best" state, which is defined by little wear and a well-preserved ball surface, shows the best results. Even while it's not ideal, the "intermediate" condition nevertheless manages to significantly lessen fatigue wear. On the other hand, the ball is significantly harmed by the "worst" state, which may result in noticeable wear and surface damage. By giving a thorough understanding of the effects of various variables on the ball, this classification helps to improve and optimize experimental conditions for longer-lasting and more intact balls.

The hBN (hexagonal boron nitride) nanoparticle at a concentration of 0.25% in figure 4.2 (a) stands out as the best. The comparatively smaller and more uniform particle size distribution (WSD) is the first feature that distinguishes this situation. This points to a more regulated and uniform particle size, which has benefits for a number of uses. The WSD in the hBN nanoparticle 0.25% sample is noticeably smaller than in the other circumstances. Where developing certain materials or composites, for example, or where homogeneity in particle size is required, this might be quite important.

Comparing the hBN nanoparticle 0.25% sample's surface morphology to other types of oil SEM results, the SEM results show that it is much smoother. A material's behavior and qualities may change with a smooth surface, making it better suited for some uses. The material's interactions with its environment, including friction, adhesion, and even optical properties, may be impacted by the smoother surface shape. The hBN nanoparticle 0.25% condition sticks out as the most advantageous among the evaluated samples based on the SEM results because of its better surface morphology and smaller, more uniform particle size distribution. These qualities may be essential for maximizing the material's performance in particular applications.

In the intermediate SEM results, the examination of the ball with hBN nanoparticles 0.5% concentration reveals a noteworthy reduction in fatigue wear as shown in figure 4.1(b). This observation is especially significant since it implies that the use of hexagonal boron nitride really reduces wear and tear on the ball surface. The efficiency of hBN nanoparticles in reducing fatigue wear is demonstrated visually by the SEM images, which supports the particles' potential as a protective additive in mechanical systems.

Moreover, it is evident from analyzing the Wear Scar Diameter (WSD) results that the performance falls in between the best and worst cases. It is notable that the wear is not as severe as in the worst-case scenario, despite not reaching the least WSD. With a moderate degree of fatigue wear in the WSD area, this intermediate WSD result shows a balanced performance. The complex results in terms of WSD imply that hBN nanoparticles 0.5% achieves a good balance between wear resistance and possible uses, highlighting the significance of dosage accuracy in getting the best outcomes.

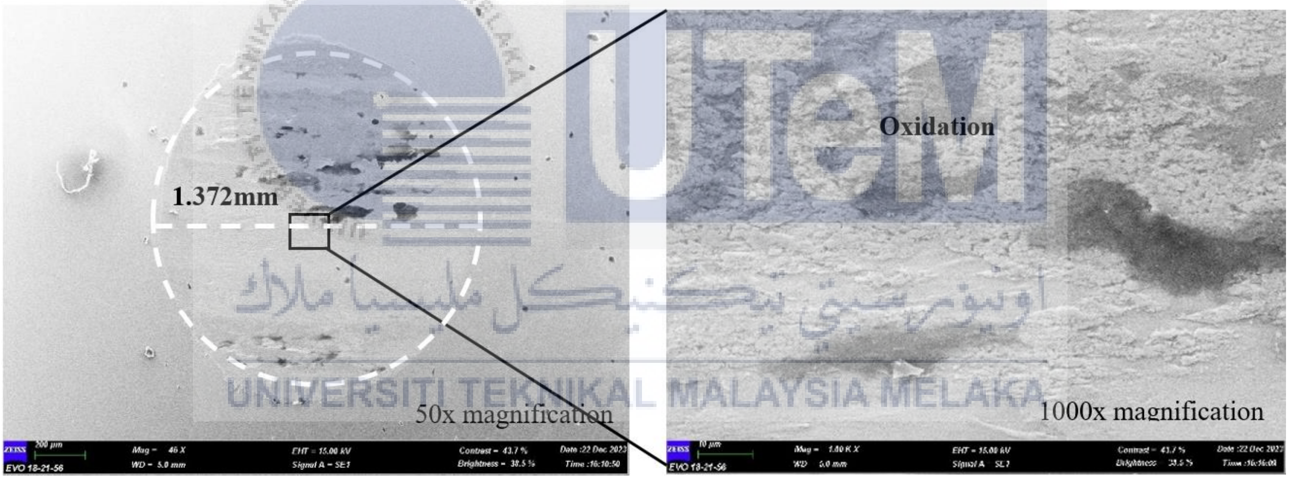
The examination of WSD in conjunction with the intermediate SEM results provide a whole picture of the beneficial impact of a 0.5% concentration of hBN nanoparticles in lowering fatigue wear. This subtle understanding is essential for customizing how hBN is used in different situations, where wear resistance must be balanced with real-world concerns for mechanical systems where a little amount of fatigue wear may be allowed within given bounds. In order to optimize the trade-off between wear reduction and practical implementation, more research and optimization may provide insights into precisely adjusting hBN concentrations for certain applications.

For used oil figure 4.1 (c) the SEM result shown the worst because it contain a bigger WSD than other oil sample, plus adhesive wear and abrasive wear are mostly appear inside the wear scar. The employed oil sample's structural features, notably with regard to wear mechanisms and particle size distribution, have been greatly elucidated by the SEM investigation. When compared to other oil samples, the used oil sample's particle size distribution (WSD) is noticeably bigger and less uniform. This implies that there may have been more wear and tear on the material because the wear debris found in the used oil has a wider variety of particle sizes. The entire condition and functionality of the machinery that depends on this lubricating medium are affected by such distribution.

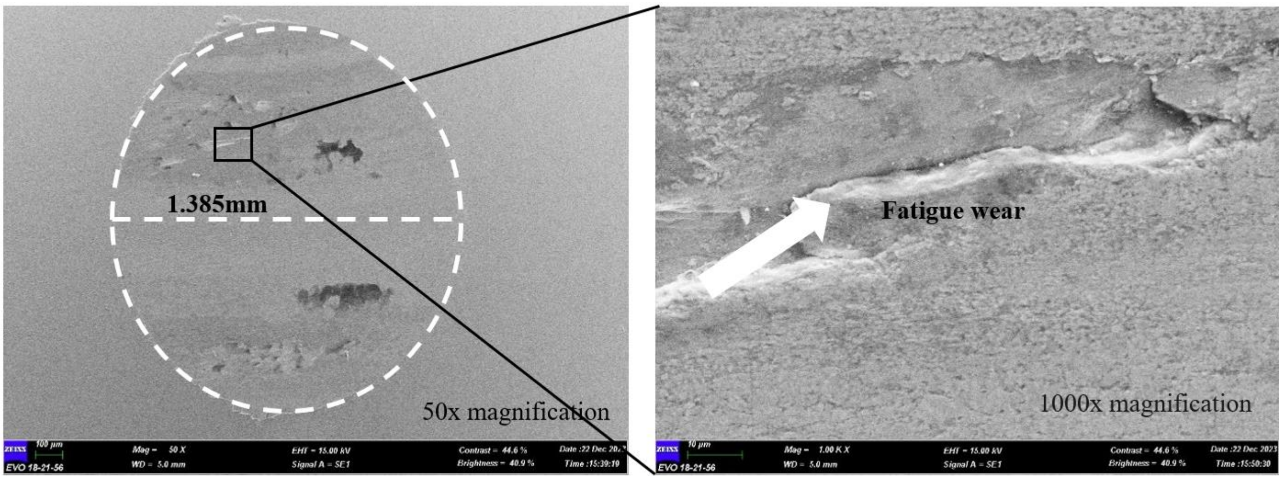
Both adhesive and abrasive wear are present in the used oil sample, according to additional analysis of the wear scar. Material transfer between surfaces, or adhesive wear, is a serious problem. Increased surface contact could be made worse by contaminated or poorly lubricated old oil due to its bigger and less uniform particle content. At the same time, abrasive wear is visible, which is brought on by hard particles or impurities physically abrading material surfaces. Larger particles in the old oil may have abrasive properties due to their irregular forms, which could mean that the lubricating qualities are deteriorating and that abrasive wear is increasing.

It is imperative to investigate the underlying causes of the deterioration of used oil's lubricating properties. A thorough study comprises a careful examination of the oil's composition, a careful check for contamination, and confirmation that the oil is appropriate for the particular operating conditions. The effectiveness of the oil may be jeopardized, and this investigation process is essential for finding and fixing underlying problems. It becomes essential to conduct routine oil analyses and follow maintenance procedures in order to keep an eye on the condition of the lubricating oil, stop excessive wear, and guarantee the longevity and best possible performance of the machinery Wear affects the life of engine; if wear of engine components increases, life of engine decreases (Gautam Yadav, 2014). Through regular examinations and a proactive strategy, enterprises can enhance their sustainability by preventing potential issues and maintaining equipment dependability and efficiency.

In conclusion, The SEM results highlight how crucial it is to keep lubrication conditions at their ideal levels in order to guarantee the dependable operation and long lifespan of machines. The direct relationship between reliable mechanical systems and effective lubrication is highlighted by the observed decrease in fatigue wear, which is especially noticeable upon the addition of hBN nanoparticles at a 0.5% concentration. These results highlight the practical importance of paying close attention to lubrication procedures because they are essential for reducing wear and friction. In order to ensure continuous functionality and prolong the lifespan of machinery, appropriate lubrication is essential and should be carefully considered during the design, maintenance, and operation of mechanical systems.



(a)



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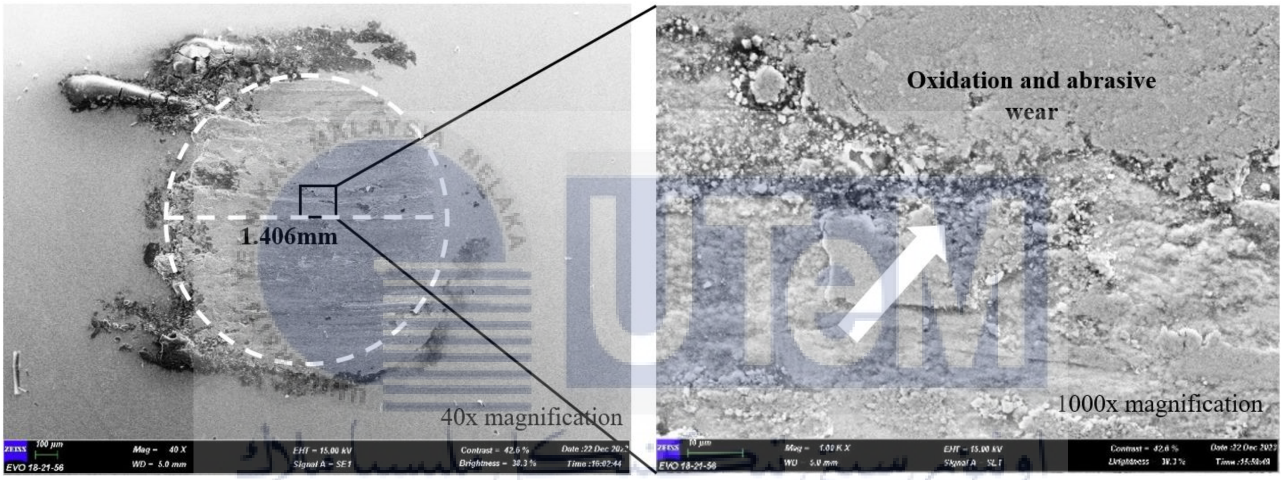

(c)

Figure 4.3 SEM result (a) hBN nanoparticle 0.25%, (b) hBN nanoparticle 0.5%, and (c) used oil

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Taken as a whole, the goals of this project represent a comprehensive approach that includes recycling, formulation, and performance evaluation, supporting environmental sustainability as well as developments in lubrication technology. If these goals are accomplished, it will be a big step forward in tackling waste oil-related environmental issues as well as the search for better lubrication solutions.

As a conclusion for differentiation of COF are that by using the ASTM D 4172 technique, this study offers important new information about the ideal concentrations of ZDDP additives and hBN nanoparticles for efficient lubrication, giving a more complex picture of how these factors affect engine performance. A tripartite classification based on the coefficient of friction (COF) results is shown by analyzing various additive concentrations: low, average, and poor. The outcomes show that adding hBN nanoparticles at a concentration of 0.25% and ZDDP at a concentration of 0.25% can significantly reduce friction, highlighting the potential benefits of these additives in improving engine longevity and performance. The study also emphasizes a threshold effect, which raises the possibility that overly high concentrations could not provide any extra advantages and might even impair the lubricant's overall effectiveness.

It is conclude that thorough examination including tribological evaluations from WSD and SEM analysis of several lubricating oils, those made with hBN nanoparticles highlights the complex interactions between many factors and ball surfaces. The hBN nanoparticle at a 0.25% concentration exhibits excellent performance, highlighting the importance of surface shape and particle size distribution for improved lubrication. The potential of hexagonal boron nitride as a protective additive in mechanical systems is demonstrated by the intermediate SEM results with hBN nanoparticles at a 0.5% concentration, which indicate a significant reduction in fatigue wear. Conversely, bigger and less uniform particle size distributions have a negative effect on wear and the existence of sticky and abrasive wear processes, this is highlighted by the SEM results for used oil.

5.2 Future work and Improvement

From this research, there are a few recommendations that can be made to improve the results received, such as increasing the number of filtration processes on the sample during ASTM D 7317. This procedure aids in the removal of further wear metal and contaminants from the old engine oil. Other than that, utilize a wider variety of additives so that the comparison of types of additives is more pertinent and extensive. This is due to the fact that a wide variety of additives are available and can be utilized to this endeavor. Last but not least, to compare which additive is best to use, utilize samples of different types of old engine oil.

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