TRIBOLOGICAL PROPERTIES OF PALM OIL MIXED WITH HEXAGONAL BORON NITRIDE (HBN) NANOPARTICLES

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TRIBOLOGICAL PROPERTIES OF PALM OIL MIXED WITH HEXAGONAL BORON NITRIDE (HBN) NANOPARTICLES

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This report is submitted in fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering with Honours

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ABSTRACT

Friction and wear are unavoidable in engineering applications. One of the common solutions to overcome these problems is by using a lubricant. Vegetable oils have been considered as potential candidates in recent years of lubrication development to improve overall tribological performance compared to mineral oils. The purpose of this study is to investigate the effect of different hexagonal boron nitride nanoparticles compositions on the tribological properties of palm oil. These palm oil were blended with various concentrations of hBN nanoparticles, ranging from 0.1 vol.% to 0.5 vol.%. Tribological testing was performed using a four-ball tester according to the standard of ASTM D4172 procedures. It was observed that addition of nanoparticle additives in palm oil showed better lubricating characteristics than pure oil. A further improvement on the addition of nanoparticles was also obtained, wherein it was observed that 0.5 vol.% concentration of nanoparticles exhibit minimum wear rate. The wear rate value of concentration 0.1 vol.% hBN reduced by approximately 10%, in comparison to the pure oil. However, increase percentage concentration of hBN resulted in higher coefficient of friction due to the agglomeration effect of hBN nanoparticles in palm oil. SEM analysis of the worn out samples was carried out to examine the topography of worn surface and EDX elemental mapping shows the elements distribution of boron and nitrogen on the worn surface. 0.5 vol.% hBN has higher distribution for both main element in boron nitride compared to 0.3 vol.% hBN, thus exhibit agglomeration effect.

ABSTRAK

Geseran dan haus tidak dapat dielakkan dalam aplikasi kejuruteraan. Salah satu penyelesaian umum untuk mengatasi masalah ini adalah dengan menggunakan pelincir. Minyak sayuran telah dianggap sebagai calon berpotensi dalam pembangunan pelinciran tahun-tahun kebelakangan untuk meningkatkan prestasi tribologi secara keseluruhan berbanding dengan minyak mineral. Tujuan kajian ini adalah untuk mengkaji kesan komposisi nanopartikel boron nitrida yang berbeza pada sifat-sifat tribologi minyak kelapa sawit. Minyak kelapa sawit ini dicampur dengan pelbagai kepekatan nanopartikel hBN, dari 0.1 vol.% hingga 0.5 vol.%. Ujian tribologi dilakukan dengan menggunakan penguji empat bola mengikut piawaian prosedur ASTM D4172. Telah diperhatikan bahawa penambahan nanopartikel aditif pada minyak kelapa sawit menunjukkan ciri pelincir yang lebih baik daripada minyak tulen. Penambahbaikan lanjut terhadap penambahan nanopartikel juga diperolehi, di mana ia mendapati bahawa kepekatan nanopartikel 0.5vol.% mempamerkan kadar haus minimum. Nilai kadar haus kepekatan 0.1 vol.% HBN dikurangkan dengan kira-kira 10%, berbanding dengan minyak tulen. Walau bagaimanapun, peningkatan kepekatan peratus hBN menghasilkan koefisien geseran yang lebih tinggi disebabkan oleh kesan aglomerasi nanopartikel hBN dalam minyak kelapa sawit. Analisis SEM sampel yang telah dipakai dilakukan untuk memeriksa topografi permukaan yang haus dan pemetaan unsur EDX menunjukkan pengagihan unsur-unsur boron dan nitrogen pada permukaan yang haus. 0.5 vol.% hBN mempunyai pengagihan yang lebih tinggi untuk kedua-dua elemen utama dalam boron nitride berbanding dengan 0.3 vol.% hBN, dengan itu mempamerkan kesan aglomerasi.

DEDICATION

This project and thesis are wholeheartedly dedicated to our beloved parents, who have been our source of inspiration and gave us strength who continually provide their moral, spiritual, emotional, and financial support. To my siblings and supervisor who shared their words of advice and encouragement to finish this study. And lastly, we dedicated this study to ALLAH SWT, thank you for the guidance, strength, power of mind, protection and skills and for giving us a healthy life.

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TABLE OF CONTENTS

		PAGE
	DECLARATION	v
	APPROVAL	vi
	ABSTRACT	vii
	ABSTRAK	viii
	DEDICATION	ix
	ACKNOWLEDGEMENT	x
	TABLE OF CONTENTS	xi
	LIST OF TABLES	xiv
	LIST OF FIGURES	xv
	LIST OF APPENDICES	xvii
	LIST OF ABBREVIATIONS	xviii
CHAPTER 1	**INTRODUCTION**	**19**
1.1	Background	19
1.2	Problem Statement	20
1.3	Objective	21
1.4	Scope of Project	21
CHAPTER 2	**LITERATURE REVIEW**	**22**
2.1	Introduction	22
2.2	Lubricant	23
	2.2.1 Classification of Lubricants	25

2.3 Mineral Oil Based Lubricant 26

2.3.1 Limitations of Mineral Oil Based Lubricant (Boyde S, 2002) 27

2.4 Vegetable Oil as Green Lubricant 27

2.4.1 Palm Oil 29

2.4.2 Overview of Malaysia's Palm Oil Plantation and Utilization 30

2.4.3 History of Palm Oil in Malaysia 31

2.4.4 Types of Palm Oil 32

2.4.5 Benefit of Palm Oil 33

2.4.6 Disadvantage of Palm Oil 34

2.5 Hexagonal Boron Nitride Nanoparticles 35

CHAPTER 3 METHODOLOGY 39

3.1 Introduction 39

3.2 Gannt Chart 40

3.3 Flow Chart 41

3.4 Sample Preparation 42

3.5 Four-ball Tester 44

3.5.1 The Coefficient of Friction (COF) 47

3.5.2 Material of Ball 48

3.6 Friction and Wear Characterization 48

3.6.1 Wear Scar Diameter 49

CHAPTER 4 RESULT & DISCUSSION 50

4.1 Effect of Coefficient of Friction (COF) 50

4.2 Effect of Wear 54

4.3 Relationship between COF and Wear 56

4.4 Wear Characterization 58
4.4.1 Introduction 58
4.4.2 Scanning Electron Microscopy 58
4.4.3 Energy-dispersive X-ray Spectroscopy 60

CHAPTER 5 CONCLUSIONS AND RECOMMENDATION FOR FUTURE RESEARCH 63
5.1 Conclusions 63
5.2 Recommendation for Future Research 64
5.2.1 Determining the viscosity index of each sample solution 64
5.2.2 Modified hBN 65
5.2.3 Conduct repeated experiment 65

REFERENCES 66

APPENDIX 73

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1:	Advantages of palm oil as lubricant (Arif & Syahrullail, 2017)	34
Table 3.1:	Gannt Chart of Final Year Project	40
Table 3.2:	Type of sample solution with different volume percent of hBN and palm oil	43
Table 3.3:	Test parameters according to ASTM 4172	45
Table 4.1:	Measurement of wear scar	54
Table 4.2:	Testing parameters	57

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1:	Palm fruit cross section diagram (Arif & Syahrullail, 2017)	32
Figure 2.2:	The structure of hBN (Kopeliovich, D., 2012)	37
Figure 3.1:	Flow Chart	41
Figure 3.2:	Ultrasonic Homogenizer	42
Figure 3.3:	Schematic diagram of sample preparation by using ultrasonic homogenizer	42
Figure 3.4:	100 vol.% palm oil sample solution	43
Figure 3.5:	Sample solution of (a) 0.1 vol.% hBN, (b) 0.3 vol.% hBN and (c) 0.5 vol.%	44
Figure 3.6:	Four-ball tester machine	44
Figure 3.7:	Assembly of four ball	46
Figure 3.8:	Schematic diagram of a four-ball tester	46
Figure 3.9:	Inverted microscope	48
Figure 4.1:	COF variation of palm oil with hBN nanoparticles and engine oil	51
Figure 4.2:	Graph of average steady state COF against % hBN	52
Figure 4.3:	Schematic diagram of lubrication film in palm oil (a) direct contact, (b) low vol.% hBN and (c) high vol.% hBN	53
Figure 4.4:	Wear rate of palm oil with hBN nanoparticles	55

Figure 4.5: Wear rate of ball materials lubricated under convenctional diesel engine oil and 0.1 vol.% hBN 56

Figure 4.6: Graph of COF and wear rate 57

Figure 4.7: SEM images of wear corresponding to the palm oil mixed with (a) 0 vol.% hBN, (b) 0.3 vol.% hBN and (c) 0.5 vol.% hBN 59

Figure 4.8: EDS image for wear scar lubricated with palm oil 60

Figure 4.9: EDS image for wear scar lubricated with palm oil and 0.3 vol.% hBN60

Figure 4.10: EDS image for wear scar lubricated with palm oil and 0.5 vol.% hBN61

Figure 4.11: Elemental mapping for (a) 0.3 vol.% hBN and (b) 0.5 vol.% hBN 62

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Graph of COF against time for all samples	74
Appendix B	Wear scar diameter (WSD)	77
Appendix C	EDX Elemental mapping	79

LIST OF ABBREVIATIONS

HC	Hydrocarbon
CO	Carbon Monoxide
AW	Anti-wear
hBN	Hexagonal Boron Nitride
COF	Coefficient of Friction
WSD	Wear Scar Diameter
SEM	Scanning Electron Microscopy
EDX	Energy-dispersive X-ray Spectroscopy

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, wear and friction are inevitable in engineering applications. One among the common solutions to beat these problems is by using lubricant which may scale back this friction and wear to a minimum level for promising a far better efficiency. Vegetable oil lubricants provide a renewable supply of environmentally friendly lubricants, regarding to the lubricant's capability to biodegrade into harmless products. Recently there has been an augmented concern in enhancing the utilization of biodegradable vegetable oils in lubricants, especially by environmental likewise as health and issues of safety, emerging due to changes in economic and provide factors. The use of vegetable oils and their derivatives as lubricant base oils are systematically increasing owing to sustainability issues and with regards to preservation of nature as they are biodegradable and environmentally friendly. Moreover, vegetable oil such as palm oil are sometimes a great deal more cost-effective than ester-based oils and thus offer additional potential for the flourishing implementation as lubricants in base oil (Krishna et al., 2014).

However, there was a systematic study showed that absence of additives caused an increase in wear once vegetable oil alone was used as lubricant; subsequent addition of antiwear agent reduced the wear substantially (Jayadas et al., 2006). Stachowiak et al. (2014) reported that to boost the wear resistance characteristic of contacting surfaces is by adding antiwear agents in lubricants. Antiwear agents form a protecting layer to prevent the contact of metal-to-metal by adsorption of their molecules on the substrate surface by physical adsorption or chemical adsorption processes.

In this study, nanoparticle additive, hexagonal boron nitride (hBN) was added and mixed with the palm oil so as to enhance the lubrication properties. The hBN are safe to handle, non-toxic and don't have any limitations on their operational use due to the particles that formed extraordinarily stable compounds (Reeves et al., 2013). These compounds showed an effective lubricating substance additive property with their anti- wear ability. Notably, Talib and Rahim (2018) reported that hBN offered good anti-wear and anti-friction ability that resulted in low coefficient of friction, reduced wear and improved surface roughness. Four-ball tester machine was used and the experiment was conducted by following the ASTM D4172 standard. The result analysis was focusing on coefficient of friction and also the wear scar diameter.

1.2 Problem Statement

Nowadays, environmental concerns have increased interest in lubricants that are biodegradable. As we aware, most of lubricating oils used these days are primarily based on mineral oil that being extracted from petroleum oil. Since vegetable oils such as palm oil are a lot biodegradable than mineral oils, it caused numerous lubricating substance makers reconsider vegetable oils as base stocks. Furthermore, palm oil-based lubricant was a lot effective in diminishing the emission levels of carbon monoxide gas and hydrocarbon that indirectly will save the environment. It even have a potential to be develop commercially as a result of it give vital benefits as an alternative lubricants for industrial and maintenance applications, thanks to their superior inherent qualities.

However, due to the several weakness of palm oil such as it is low oxidative stability and weakness in term of viscosities, it cannot be used directly as a lubricant. In order to improve palm oil to have satisfactory lubricant performance, nanoparticle additives, hexagonal boron nitride (hBN) can be added and blend together. It normally gives positive feedback as the coefficient of friction are slightly reduced due to the rolling effects between the rubbing surfaces and contribute to the wear prevention (Wu et al., 2007). By adding nanoparticles agent as an additive, it is believed that the vegetable oil such as palm oil can be improved as a new lubricant.

1.3 Objective

The objective of this project is:

1. To investigate the effect of different hexagonal boron nitride nanoparticles compositions on the tribological properties of palm oil.

1.4 Scope of Project

The scopes of this project are:

1. Test were conducted by a four-ball friction and wear tester equipment according to the ASTM D4172 standard.
2. The palm oil were blended with various concentrations of hexagonal boron nitride particles, ranging from 0.1 vol.% to 0.5 vol.%.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Tribology concept was articulated in a report of the UK Department of Education and Science in 1966. It includes the knowledge domain science and technology of cooperating surfaces in relative movement and related subjects and practices. It encompasses elements of chemistry, physics, solid mechanics, materials science, reliability, lubricant natural philosophy, heat transfer and performance. The constituent elements of tribology enveloping friction and wear are as old as history, despite of the fact that the name tribology is new (Dongare & Gite, 2014).

Conservation of materials and energy is becoming an awfully necessary issue. The main explanation for energy loss in a mechanical system is that the friction but this can be reduced by using a lubricant. Thus, it is very important to boost the lubrication properties. Many recent studies on bio-lubricants focused on modifying vegetable oils to create a better base. This can be done by formulating vegetable oils with additives that can enhance some base oil properties or present a new oil property (Reeves et al.,2012). A good combination between oil base and additives is the key to improve this process. Wear is one of the major causes of metal loss in industrial processes. Enhancement of lubricants has been shown to cut back the friction and wear of mechanical parts, that may save billions of dollars (Tung and McMillan 2004; de Barros' Bouchet, Martin et al. 2005).

2.2 Lubricant

Lubricant is extremely important to reduce wear and friction in tribological performance. The researchers need to investigate and study the reaction and fluid between the moving surfaces to better understand the characteristic effect of wear and friction between two moving surfaces. A sufficient protective lubricant film on the rubbing surfaces plays a key role in the construction of the lubricant film layer and in the control of the wear behavior of the test system under limited lubrication conditions (T.C. Ing et al., 2012). Lubrication is simply the use of material to improve the smoothness of movement of one surface over another, and the material, that is used during this manner known as a lubricant (Lansdown, 1982).

Nowadays, lubricant plays a very important role in engines and machines which are essentially used to lessen the friction and wear between two surfaces in contact. It can performs a variety of functions such as flushes out contaminants, acts as a heat transfer agent, protect metal surfaces against corrosion, absorbs shock and act as a seal against dust, water and dirt. By giving a defensive film between two sliding solid bodies, it can decrease the amount of wear, frictional force, and the degree of surface adhesion (Arif & Syahrullail, 2017). Lubricant is being produced dependent on their properties as well as requires the parameters such as temperature, speeds, and load for the researcher to explore the modification that happens on bulk material once the surface of material contact and moving comparatively to one another. Aiman et al. (2017) stated that lubricants also are normally utilized in minimising and reducing the friction and wear of interacting surface in mechanical system with the goal that the system can operate easily and running in long amount of time.

There a many main function of lubrication. Firstly, is to reduce heat loss and wear that cause from the contact of surfaces in motion, thus lessen the coefficient of friction between two interacting surfaces. Secondly, is to diminish oxidation and prevent rust. While thirdly, is to act as a dielectric in electrical device applications and lastly, is to act as a seal against dust, water and dirt. Lubrication happens when two surfaces are isolated by a film of lubricant. It is accessible in liquid, solid, and gaseous forms. A decent lubricant displays the accompanying attributes which is low freezing point, thermal stability, corrosion prevention capability, high boiling point, and high protection from oxidation (Mobarak, et al., 2014).

Generally, global environmental awareness has encouraged the production of environmentally-friendly lubricants. Due to developing regard for the environmental issues, the industry has been attempting to formulate biodegradable lubricants which can be utilized to substitute the usage of petroleum-based oils or gasoline as lubricants. Based on the study of White JJ et al. (1997), it has shown reduced carbon monoxide by the maximum amount as 38 % by using this biodegradable lubricant. To date, biolubricants are as yet not broadly being utilized on account of the difficulties and troubles regarding their performance.

2.2.1 Classification of Lubricants

Lubricants can be classified based on the following criteria (Mobarak, et al., 2014).

Physical appearance

Solid	The solid material film is made of natural or inorganic compounds, such as cadmium disulphide, molybdenum disulphide and graphite.
Semisolid	Liquid is suspended in a solid matrix of thickener and additives, such as grease.
Liquid	The examples are oils such as synthetic oils, vegetable oils, animal oils, and petroleum.

Base oil resource

Natural oils	Oils derived from vegetable oils and animal fats.
Refined oils	Oils derived from reserves of crude or petroleum, such as naphthenic, aromatic and paraffinic oils.
Synthetic oils	Synthesized as end products of reactions that are necessarily tailored; such as silicones, synthetic esters and polyalphaolefines.

Applications

Automotive oils	Engine oils, gear box oils, transmission fluids, as well as hydraulic and brake fluids used in the automotive and transportation industries.

Industrial oils	Compressor oils, machine oils, hydraulic oils and metal-working fluid used for industrial purposes.
Special oils	Oils used for special purposes referring to specific operations; such as white oils, instrumental oils, and process oils.

2.3 Mineral Oil Based Lubricant

In automotive engines, commercial lubricants that being used today are mostly manufactured from mineral oil (MO) due to its accessibility, cost intensity and satisfactory performance. For the time being, mineral oil and synthetic oil are widely used in the lubrication business. The majority of the lubricating oils used nowadays are based on mineral oil which being extracted from petroleum oil. Mineral oil-based lubricants such as petroleum have been used broadly in industry of lubrication especially for engines and mechanics industry. In 2005, with reference to the statistic, lubricants were used around 37.9 million metric tons globally (Siniawski et al., 2011). However, the use of these lubricants posed a risk to our environment that could have a greenhouse effect and cause global warming, as the mineral oil-based lubricants are dangerous and are not promptly biodegradable (Castro et al., 2006; Zulkifli et al., 2013). In view of the real harm to the environment, the worldwide concern about health increases. Today, therefore, the vegetable oil-based industry has begun to replace mineral oil as lubricants in lubrication industry as a result of the growing global concerns about the production of environmental-friendly lubricants.

2.3.1 Limitations of Mineral Oil Based Lubricant (Boyde S, 2002)

- Mineral oil-based lubricants are derived from non- renewable petroleum.
- Mineral oil-based lubricants cause air quality environmental concerns as they produce nitrogen, carbon and sulfur oxides. They also produce substances such as xylene, benzene and ethane during the processes of production, use, disposal and recycling processes.
- Direct contact with mineral oils may likewise lead to skin irritation, eczema contact and oil acne. In addition, it also causes irritation in the mucous membranes.
- A drop mineral oil has been discovered to defile 10 million liters of water and take nearly 100 years for ultimate degradation. Indeed, even small amounts of mineral oil can prevent tress from growing and can harm aquatic life. For example, as little as 0.1% contamination can reduce the shrimp's life by 20%.
- Mineral oil-based lubricants are not biodegradable and are environmentally hazardous.
- Mineral oils in ink may enter foods when packaged in recycled carton. European and USA manufacturers have stopped using recycled carton in food packaging because they are cancer-causing.

2.4 Vegetable Oil as Green Lubricant

Most of the lubricants were produced from vegetable oil and animal fats during the 16th century. When petroleum was introduced into the machinery industry, demand for vegetable and animal fat-based lubricants decreased. This expanded demand for petroleum- based lubricants has led to a rare lack of petroleum sources, which can lead to higher prices of petroleum products (Jayadas et al. 2007, Md Alias and Azhari 2017). The vegetable oils are the main choice in the formulation of green lubricants because they are non-toxic, renewable and readily biodegradable. Wan Nik et al. (2005) stated that the utilization of vegetable oil as a lubricant in industries such as the food industry is not new and that this type of industry must ensure that their products are not contaminated by the risky synthetic concoctions in the base oil.

Along these lines, vegetable oil products are now available, and global awareness of the environment encourages researchers to produce these green lubricants. Vegetable oil lubricants are a renewable source of green lubricants related to the biodegradability of the lubricant into innocuous products. Vegetable oils are also an easily reproducible renewable source compared to mineral-based oil and has very low in volatility due to the high molecular weight of its triglyceride molecule. Besides, they have good lubricity due to their polar ester groups, which can adhere to the metal surface (Campanella et al., 2010). There has recently been a growing concern about improving the use of biodegradable vegetable oils in lubricants, mainly due to environmental as well as health and safety issues, due to changes in supply and economic factors. In contrast to mineral oils, the benefits of vegetable oils as base oil in lubricants are biodegradability, nontoxicity, reasonable application cost, resource renewability and so forth. Zulkifli et al., (2013) state that the vegetable oil has a high viscosity index that should be high enough to maintain the thickness of the lubricating film and low enough to ensure that the oil flows through all engine components. In addition, its metal surface affinity also has superior anti-corrosion properties (Salimon et al., 2010). The vegetable oil-based lubricant was therefore promoted to replace mineral oil-based lubricants.

Vegetable oils are unique because some of their properties are not found in mineral oil with many possibilities (Lathi & Mattiasson, 2007). Quinchia et al. (2014) reported an amphipilic nature of vegetable oils. This characteristic provides a good force/film relationship between vegetable oils, which increases the strength of the lubricant films when interacting with metal surfaces, thereby reducing friction and wear. Fox and Stachowiak (2007) also reported that the high polarity of the vegetable base oil leads to strong interactions between the metal contact surface and the lubricant. From recent study of Arif and Syahrullail (2017), they stated that vegetable oils can possibly be utilized as alternative lubricants for automotive applications and industrial due to their natural cordial attributes. Vegetable oil, particularly palm oil is one of the promising hopefuls that can be develop to supplant petroleum base oil as an alternative lubricant in the future. Since vegetable oil lubricants are sustainable raw materials as well as they are non-toxic and can be dispose after use, they are potential substitutes for mineral oil. In addition, they show most of properties required for lubricants, such as low vitality, high index viscosity, good lubricity, as well as excellent fluid additives solvents (Lathi & Mattiasson, 2007).

2.4.1 Palm Oil

Palm oil is one of vegetable oil-based product that has been widely tested in lubrication industry for its advantages over mineral oil which are biodegradable, cheap, environmental-friendly, readily available and inexhaustible (Lewate, 2002; Battersby, 2000). There are many studies to test the execution of palm oil as lubricants and they report that they have the ability to be a decent lubricant since it give a low coefficient of friction (Jabal et al., 2014). Research conducted by Chew and Bhatia (2009) on the use of palm oil with additive has shown that palm oil has satisfactory results and a bright future that can be widely used in engineering applications. It has also been proven that palm oil has good lubrication performance and has the potential to reduce the reliance on mineral-based oil lubricants. Moreover, a comparative study was conducted by Masjuki et al. on friction, wear, degradation of lubricants, viscosity and exhaust emissions from palm oil and commercial lubricating oil. Their results showed that the palm oil-based lubricating oil had better wear performance and that the commercial oil had better friction performance. However, the palm oil-based lubricant was more effective in reducing hydrocarbon and CO emissions which is good for the environment.

2.4.2 Overview of Malaysia's Palm Oil Plantation and Utilization

Palm oil from the yellow-reddish colour oil palm (Elaeisguianensis) fruits has surpassed the highest yield production quantity on the universal market compared to other vegetable oils (USDA 2014). As the USDA indicates, the estimated worldwide palm oil production in 2012 is approximately 65 million tonnes, representing 58 million tonnes of mesocarp oil and 6.8 million tonnes of kernel oil (USDA 2012). Palm oil is the most imperative vegetable oil and is commercially transformed into numbers of product, from soap to biodiesel, with the billions of dollar of world trade. As for Asia, including Malaysia and Indonesia, palm oil production in these countries are dominant with an aggregate of up to 45.1 million tons, representing over 85% of the world total in 2010 (Kiran et al., 2014).

Palm oil has been planted at about 4.85 million hectares, which covers relatively 14% of the total land in Malaysia (Pandey et al., 2012). At global level during 2013, Malaysia was the second largest producer of palm oil and the largest exporter with 19.4 million tonnes or 41.3% of the total world oil palm production (Kumar et al., 2015). The palm oil industry in Malaysia can be divided into four sections. The first section is the plantations that includes planting, seed nursery, harvesting, milling and collecting. The second section deals with bulking, refining and trading activities. While the remaining two sections are health-based and food business as well as non-food business section including the production of biodiesel. As for the record, in 2009 Malaysia planted 4.7 million hectares of palm oil (Mohd Hafizil, et al., 2017).

2.4.3 History of Palm Oil in Malaysia

During 1911 and 1912, Henri Fauconnier, a Frenchman who planted oil palm seeds at his Rantau Panjang estate in Selangor, has established the palm oil industry in Malaysia. Then, in the following year he returned to Sumatra to buy more seeds from a Belgian agronomist, M. Adrien Hallet and established the Tennamaram Estate's first commercial oil palm plantation (Liaquat et al., 2011). There are three phases involved in the development of oil palms in Malaysia, including the experimental phase between the late 1880s and 1916, the expansion phase from the 1960s due to the government's diversification policy, which reduces the dependence of the national economy on natural rubber by establishing the Federal Land Development Authority (FELDA), focused on the socio-economic responsibility of developing the land in rural areas for the poor and landless (Toeh CH, 2010). The third phase also includes the rapidly growing palm oil industry in Sarawak and Sabah and the comprehensive industry expansion in Indonesia. Modern planting techniques and new hybrid oil palm seeds are introduced to satisfy the extensive planting in expansive scaled areas.

2.4.4 Types of Palm Oil

There are two types of oil that can be obtained from the oil palm: palm oil from the fruit flesh (mesocarp) and palm kernel oil from the kernel or seed (endocarp) as shown in Figure 2.1. Each bunch of fresh fruit has about 21–23% palm oil, 14–15% mesocarp fiber, 6–7% palm kernel shell and 23% empty fruit bunches (EFB) (Hambali et al., 2011). The mesocarp of ripe fruits has an oil content of 70%–75% of its total weight but the unripe fruits contain almost no oil (Arif & Syahrullail, 2017).

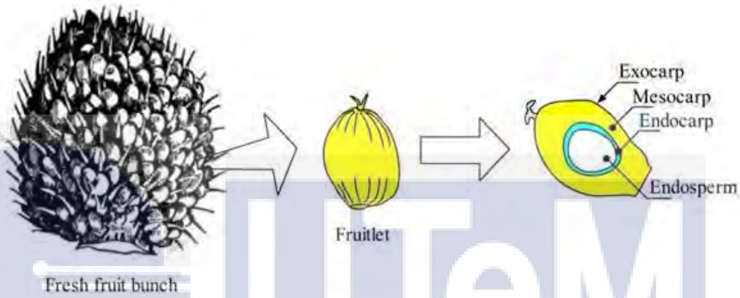


Figure 2.1: Palm fruit cross section diagram (Arif & Syahrullail, 2017)

Palm oil is semi-solid at room temperature and has a saturation level of approximately 50%. The oil is bright orange-red color in its virgin form due to its high carotene content. Palm oil contains palmitic acid (fatty acid produced by our bodies), polyunsaturated linoleic acid (essential fatty acid), the monounsaturated oleic acid, and stearic acid (Masjuki et al., 1999). Because of the strong interactions with the lubricated surfaces due to this composition, it can act as anti-wear protector and friction modifiers. In addition, their amphiphilic nature also gives them a good relationship between film and force, due to the presence of polar groups and long fatty acid chain in the palm oil (Adhvaryu et al., 2004). Palm oil has the potential to grow commercially because it offers significant benefits for industrial and maintenance applications due to its superior inherent qualities as an alternative lubricant. It can be used in various industrial and maintenance applications very well. The following are some of their important applications: industrial oils such as metalworking fluids, machine oils, compressor oils, hydraulic oils and special oils such as process oils, white oils and instrumental oils (Arif & Syahrullail, 2017).

Palm oil can also cover the majority of the use of lubricants in automotive applications. These oils can replace mineral oil constructively, such as hydraulic oils, engine oils, pump sets, compressor oils, generator lubricants, transmission fluid and metal-working oils. Furthermore, Syahrullail et al. (2013) stated that the production of mineral based lubricants, such as petroleum lubricants, uses more energy and generates additional pollution during the refining process than the corresponding process for vegetable oils. It will definitely diminish high rate utilization of petroleum based lubricant. In a few previous studies, palm oil-based lubricants were found to be more effecient in reducing the emission levels of hydrocarbon and carbon monoxide (Masjuki et al., 1999).

2.4.5 Benefit of Palm Oil

The primary essential angle to consider palm oil as a new alternative lubricant is because of its biodegradability, generally less toxic and can be renew. Due to their environmental benefits, it can therefore be used in sensitive environments and prevent pollution. A few researches have been done to study the performance of palm oil when contrasted with the commercial engine oil. The outcomes demonstrate that palm oil produce lower coefficient of friction and establish strong stability of the lubricant film (Masjuki et al., 1997; Maleque et al, 2000). It will contribute to the wear prevention of the interacting surfaces and increment the effectiveness of the mechanical system.

Another important characteristic of palm oil is its high flash points. Mobarak & E. Niza (2013) reported that vegetable oils typically have a flash point of 326 °C, while common mineral oils have a flash point of 200 °C. Flash and fire points generally identify the volatility of the lubricant and the properties of the fire-resistance. These two factors are essential for the requirement of both transportation and storage. Due to higher flashpoint value as compared with mineral oils, it can impressively decrease the risks of fire if there should arise an occurrence of a lubricant spill, and providing extra safety. Table 2.1 below summarizes some of the upsides of palm oil as an alternative lubricant.

Table 2.1: Advantages of palm oil as lubricant (Arif & Syahrullail, 2017)

Properties	Advantages
Higher lubricity	Better fuel economy due to lower friction losses
Lower volatility	Reduce exhaust emissions
Rapid biodegradation	Decreased environmental hazards
Better skin compatibility	High cleanliness and less dermatological conditions at work
Higher flash points	Provide higher safety
Higher boiling temperatures	Less emissions

2.4.6 Disadvantage of Palm Oil

Despite the advantages mentioned above, palm oils suffer from several major drawbacks in term of thermal and oxidative stability. Low oxidative stability indicates that palm oil oxidizes quickly when untreated during use, ending up thick and polymerized to a plastic-like consistency. Moreover, it has shortcoming in term of viscosities as well. It will constraint the use of palm oil as an engine oil. For engine oil, a slight change in viscosity is desirable to provide wide range of operating temperatures over which satisfactory lubrication is provided by a given oil.

The remaining base stock of mineral oil resources is attracting regard for the researchers everywhere throughout the world as the innovation advancement continue expanding over the course of the years. Researchers also keep trying to discover this issue by redirecting the attention regarding different resources, for example, vegetable oil like palm oil. However, it has a low oxidative stability, low temperature behaviour and poor thermal stability that limit its potential use in industrial lubricants (Aiman & Syahrullail, 2017).

2.5 Hexagonal Boron Nitride Nanoparticles

Nanoparticles are classified as a new low-friction technology and as a wear reduction method. Nanoparticles have many important advantages over organic molecules, and their nanometer size enables them to easily enter contact zones. Different types of nanoparticles such as metals, polymers and organic and inorganic materials have been used in the preparation of nano luricants (Muhammad et al., 2013). Nanoparticles currently are among the most demanded and promising additives, where low concentration between 0.2 vol.% and 3 vol.% are added into lubricating oil that can improve the tribological performance (Muhammad et al., (2014). Recently, boron-based nanoparticles were investigated due to their load carrying and anti-wear behaviors. It is also thermally stable and environmentally friendly, making them a reliable candidate to use as a lubricant oil additive (Sheida et al., 2015). In order to improve the friction and wear behaviours of the lubricant, the addition of anti-wear additives was used to avoid surface damage. In the boundary lubrication regime, the formation of a surface chemical reaction film is the determining factor in minimizing the friction and wear (Dongare & Gite, 2014).

Most of the research for the vegetable oil lubricant has been led to enhance the thermo-oxidation property by chemical process or additives to improve the characteristics equivalent or higher compared to mineral oil-based lubricant. The nanoparticles additive exhibits good anti-wear and anti-friction properties on vegetable-based lubricant. Additives are substances formulated to improve the anti-friction, chemical and physical properties of base oils (animal, vegetable, mineral or synthetic), which will enhance the performance of the lubricant and extend the life of equipment. In recent years, numerous investigations have been carried out into the applications of nanoparticles in the lubrication field. Friction and wear reduction are depends on the nanoparticle characteristics such as shape, size and concentration.

Figure 2.2 shows the hexagonal boron nitride (hBN) structure. HBN has a crystalline lamellar structure in which the bonding between molecules within each layer is strongly covalent, while the binding of layers is almost entirely by weak van der Waals forces. This structure is similarly to graphite and molybdenum disulfide (MoS2), which are highly successful solid lubricants, and the mechanism behind their effective lubrication performance is understood to make it easy shearing along the basal plane of the hexagonal crystalline structures. That is why hBN also known as white graphite. Then, hBN was once considered as a potential solid lubricant for general use on account of this comparability, and its tribological properties were evaluated (Yoshitsugu et al., 1999).

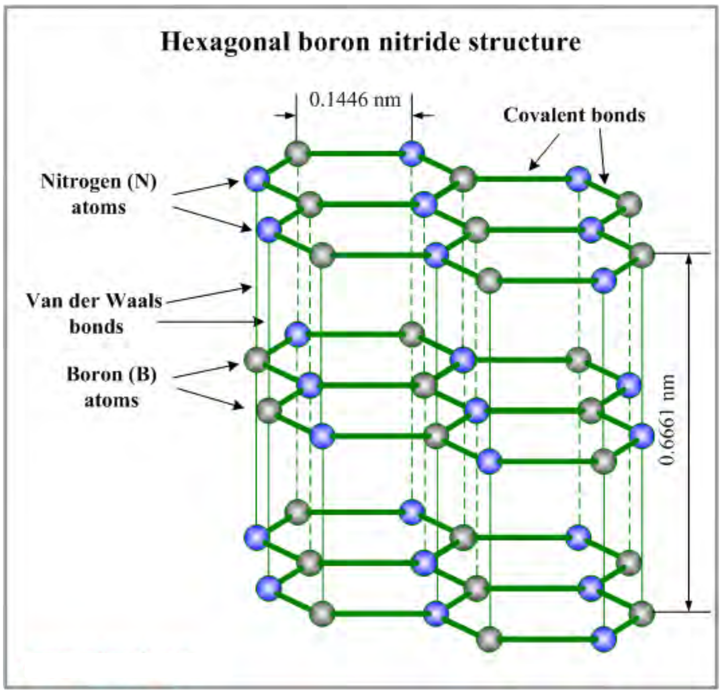


Figure 2.2: The structure of hBN (Kopeliovich, D., 2012)

Hexagonal boron nitride nanoparticles have been used generally in many researches as additive since it conveys remarkable tribological properties, create a formation of defensive film impact which lessen friction & wear and mainly its environmental friendly. The hBN particles formed extremely stable compounds that can be handled safely, free of toxicity and have no operational restrictions (Reeves et al., 2013). These compounds demonstrated a viable additive property of lubricant with their anti-wear ability. Notably, N. Talib and E.A. Rahim (2018) reported that hBN offered great anti-wear and anti-friction abilities leading to reduced wear, low coefficient of friction and improved surface roughness.

Alluding to investigation of Sheida et al. (2015), they reported that the addition of the nano hexagonal boron nitride particles to engine oil changed the coefficients of friction, but it did not change the consistency of the lubricants. The presence of adequate nano hBN additives in oil prevents direct contact and minimize the friction and wear. Besides that, based on the study of Y. Kimura et al. (1999), they determined that the addition of hBN as little as 1 wt.% in the sliding of the bearing steel vs. itself results in reduction of wear by more than an order of magnitude, and further reduction is found higher concentrations. The friction coefficient is increased slightly by adding hBN, but small fluctuations in the friction traces are eliminated. In conclusion from this result, hBN is regarded as a potential lubricant oil additive for some applications.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter discusses the methodology that's utilized in this study including the process of preparing the mixed lubricant which is palm oil with several of % concentration of hBN. This chapter also carries the material of ball bearing used, tools and equipment while doing this project. It starts with the gannt charts that shows the process of finishing the task with the time frame. All the work of experiment was according to the flow chart. The experimental started with the sample preparation where the lubricant and additives was mixed together with different hBN compositions. 6 samples were prepared with various % of concentration of hBN ranging from 0.1 vol.% to 0.5 vol.% and the first sample was started with the lubrication without the additives to see how anti-wear additives helps in improving the lubricant properties in reducing wear and friction coefficient. After that, tribological testing is conducted, thus the coefficient of friction can be determined. The final process is to determine the wear scar diameter of the ball bearing of different % concentrations of hBN to compare in order to get optimized compositions.

3.2 Gannt Chart

This project has several tasks that need to be done in order to achieve the objective. Table 3.1 explained on what tasks have been done along with the time frame.

Table 3.1: Gannt Chart of Final Year Project

NO	TASK	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation of Samples Experiment															
2	Preparation of Progress Report															
3	Progress on Experiment of Friction and Wear															
4	Progress on Result and Discussion															
5	Progress on FYP Full Report															
6	Preparation of Slide Presentation															
7	Submission of FYP Full Report															
8	Presentation FYP															

3.3 Flow Chart

Figure 3.1 shows the details of the overall thesis methodology flow chart. According to the flow chart, every decision making is guided with the systematic work's plan.

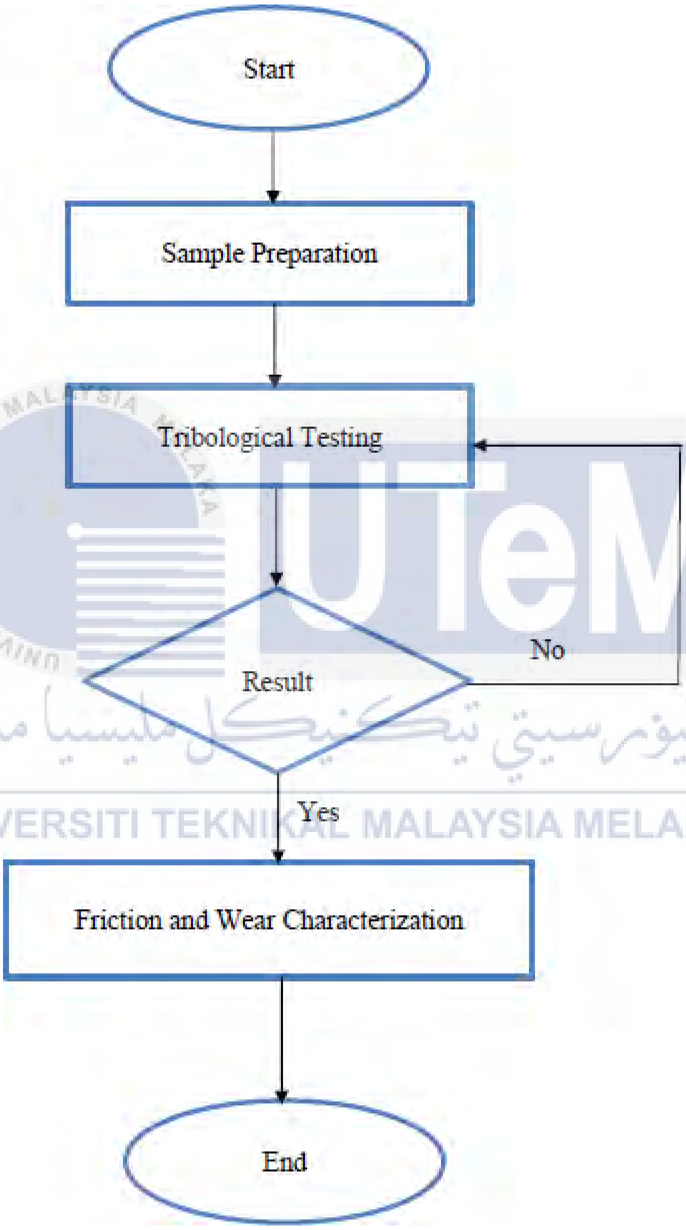


Figure 3.1: Flow Chart

3.4 Sample Preparation

Figure 3.2: Ultrasonic Homogenizer

In this study, a commercial cooking palm oil was used as a base lubricant and treated by adding various percentage concentration of hBN. It was added and mixed with the palm oil and tested at concentrations of 0.1 vol.%, 0.2 vol.%, 0.3 vol.%, 0.4 vol.% and 0.5 vol.%. The samples of mixture were prepared carefully by using an ultrasonic homogenizer machine as shown in Figure 3.2, so that the additives were evenly distributed into the palm oil. Ultrasonic homogenization is a mechanical process that reduces small particles in a liquid so that they become uniformly small and evenly distributed. Each sample was homogenized for 30 minutes and the setup is shown in Figure 3.3.

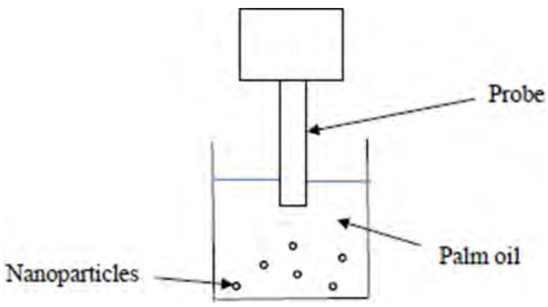


Figure 3.3: Schematic diagram of sample preparation by using ultrasonic homogenizer

According to Table 3.2, the formulated bio lubricant has started by combining the additives into the palm oil. Figure 3.4 and Figure 3.5 shows the sample solution of palm oil and after it being homogenized with various volume percentage of hBN.

Table 3.2: Type of sample solution with different volume percent of hBN and palm oil

No	Percentages of sample solution
1	100 vol.% palm oil
2	0.1 vol.% hBN and 99.9 vol.% palm oil
3	0.2 vol.% hBN and 99.8 vol.% palm oil
4	0.3 vol.% hBN and 99.7 vol.% palm oil
5	0.4 vol.% hBN and 99.6 vol.% palm oil
6	0.5 vol.% hBN and 99.5 vol.% palm oil

Figure 3.4: 100 vol.% palm oil sample solution

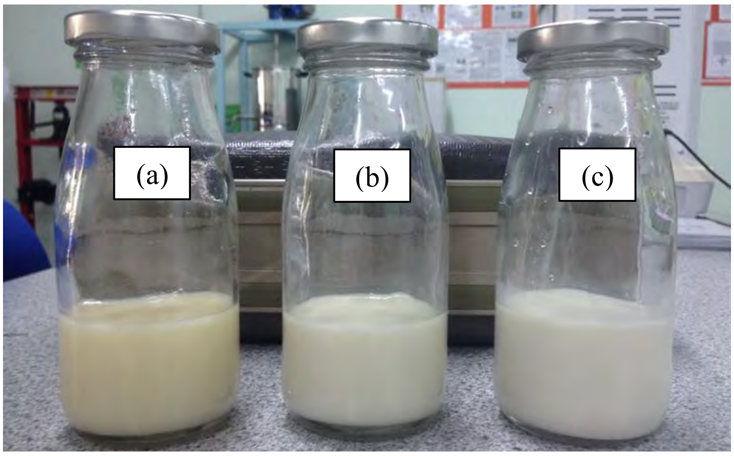


Figure 3.5: Sample solution of (a) 0.1 vol.% hBN, (b) 0.3 vol.% hBN and (c) 0.5 vol.%

3.5 Four-ball Tester

Figure 3.6: Four-ball tester machine

Afterwards, the tribological test was performed using a four-ball tester (DUCOM Instruments) as shown in Figure 3.6. Four-ball tester is to be used to determine the coefficient of friction. There are three controllable parameters for this machine which are the rotating speed, applied load and also the ball cup temperature. The parameter controlled is adjusted by referring to the ASTM D4172 standard used in this experiment. ASTM D4172 is a standard procedure for determining the lubricant properties at standard temperature, load and speed. The result of these tests can calculate the coefficient of friction as well as wear scar diameter. Table 3.3 below shows the test parameters according to ASTM 4172.

Table 3.3: Test parameters according to ASTM 4172

Duration	60 minutes
Load	392 N
Temperature	75°C ± 2°C
Speed	1200 rpm

Four-ball tester is used to assess the friction and wear characteristics of the lubricant oil under various of test conditions. This machine works by pressing the three ball with same diameter, which are held together at bottom against a rotating ball at the top and immersed in the tested lubricant. The top ball was pressed into the cavity formed by the three clamped balls to create a three-point contact with 392 N (40 kg) of force. The test lubricant temperature was maintained at 75°C and the top ball was rotated clockwise by an AC motor at 1200 rpm for 60 minutes. The bottom three balls are held in the ball cup together, while the rotating top ball is held by collet which attached to the vertical rotating shaft in the machine. The important component of the experiment such as oil cup, ball bearing and collet must be washed with acetone before start testing. Figure 3.7 below shows the setup of the ball bearing for four-ball tester machine.

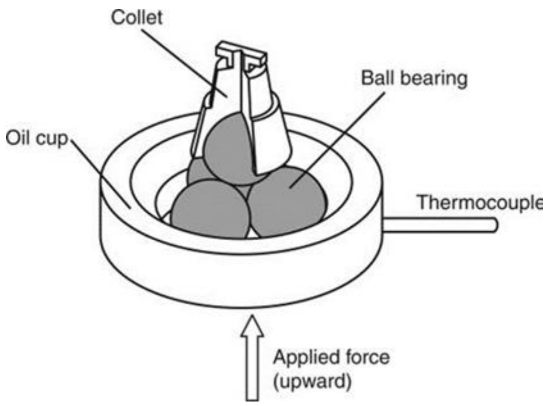


Figure 3.7: Assembly of four ball

After the test, the efficiency of the lubricant samples was evaluated by comparing the average size of the scar diameters on the three lower clamped balls which had been worn. In order to reduce experimental errors, each test was supposed to be repeated three times. The schematic diagram for a four-ball test showed in Figure 3.8. A data terminal processing system was used to record the COF and the raw data was imported into the Excel worksheet.

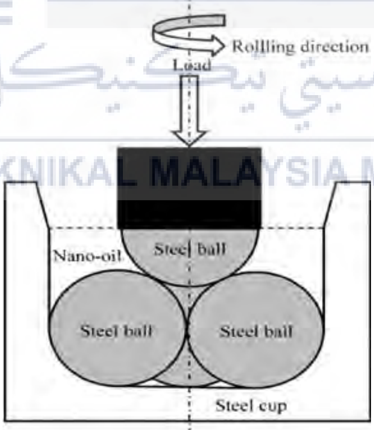


Figure 3.8: Schematic diagram of a four-ball tester

3.5.1 The Coefficient of Friction (COF)

The friction torque was recorded using specific data acquisition system from the four-ball testing machine. The frictional torque of test lubricants quickly increased at the beginning of the test after 5-10 minutes, the friction torque data became a steady-state condition. Average of friction torque at the steady state was recorded and the coefficient of friction. The friction coefficient (COF) was calculated using Equation (1).

$$COF = \frac{T\sqrt{6}}{3Wr} \quad (1)$$

Where T is the frictional torque (Nm), W is the applied load (N) and r is the distance from the center of the contact surface on the lower balls to the axis of rotation which was determined to be 3.67mm.

The volume (V) of the ball's worn material was estimated geometrically; using the basis of the radius of ball, wear scar and its height using the following equations:

$$V = (\frac{\pi h^2}{3})(3R - h) \quad (2)$$

$$h = R - \sqrt{R^2 - a^2} \quad (3)$$

Where *V* is the wear volume in mm^3, *h* is the height of wear scar in mm, *R* is the radius of steel ball in mm and *a* is the radius of wear scar in mm. The wear rate was then calculated using the following equation:

$$Wear\ rate, k = \frac{V}{t} \quad (4)$$

Where t is a sliding time in unit second.

3.5.2 Material of Ball

In this experiment, the standard balls used are made of chrome steel (ASTM 52100/EN31), with specifications of the following: diameter 12.7 mm; mass 0.009 kg; density $7.81 g/cm^3$ and Poisson's ratio 0.3. For each test, four new balls were used. The balls were cleaned with acetone and wiped dry using a fresh lint-free industrial wipe every time before starting a new test

3.6 Friction and Wear Characterization

Figure 3.9: Inverted microscope

After four-ball test was conducted, the ball bearings were detached from the test cup and rinsed with acetone until the ball bearing surfaces was clearly clean. The ball bearing wear scar diameter (WSD) was measured using an inverted microscope shown in Figure 3.9. Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray Spectroscopy (EDX) were used to observe worn surfaces. SEM was utilized to examine the topography of the worn surface, whereas EDX was utilized to determine the significant compounds of the elements that occur on the worn surfaces.

3.6.1 Wear Scar Diameter

The material removed from the surface or the unwanted displacement is called as wear. The wear often occurs when there relative force or sliding is present. It should clearly understood that the actual contact area between two objects is very small in comparison to the apparent contact area. The wear scar diameter of the three balls at the bottom is measured by the microscope to measure its diameter in order to determine its performance of lubricity. Generally, the more severe the wear, the larger the wear scar diameter.

CHAPTER 4

RESULT & DISCUSSION

This chapter explain about results or outcomes that are achieved after the whole procedure being done. The result achieved must correspond to the problem statements and objective and undergo steps mention in the Chapter 3 of the Methodology.

4.1 Effect of Coefficient of Friction (COF)

Coefficient of Friction is a dimensionless scalar value to described friction force ratio between two bodies that presses together by force. Less COF means less friction, which helps to increased efficiency. In this study, palm oil was used as a base lubricant and treated with the addition of different hexagonal boron nitride (hBN) concentrations. From the four-ball tribotester, the friction torque was recorded using a data terminal processing system and coefficient of friction was calculated by using Equation (1). A graph of COF against time is generated with addition percentage concentration of hBN from 0 vol.% to 0.5 vol.% with palm oil (shown in Appendix A). As shown in the graph, the friction coefficient lubricated by palm oil and 0.1~0.5 vol.% hBN are 0.076, 0.082, 0.093, 0.100, 0.095 and 0.111, respectively.

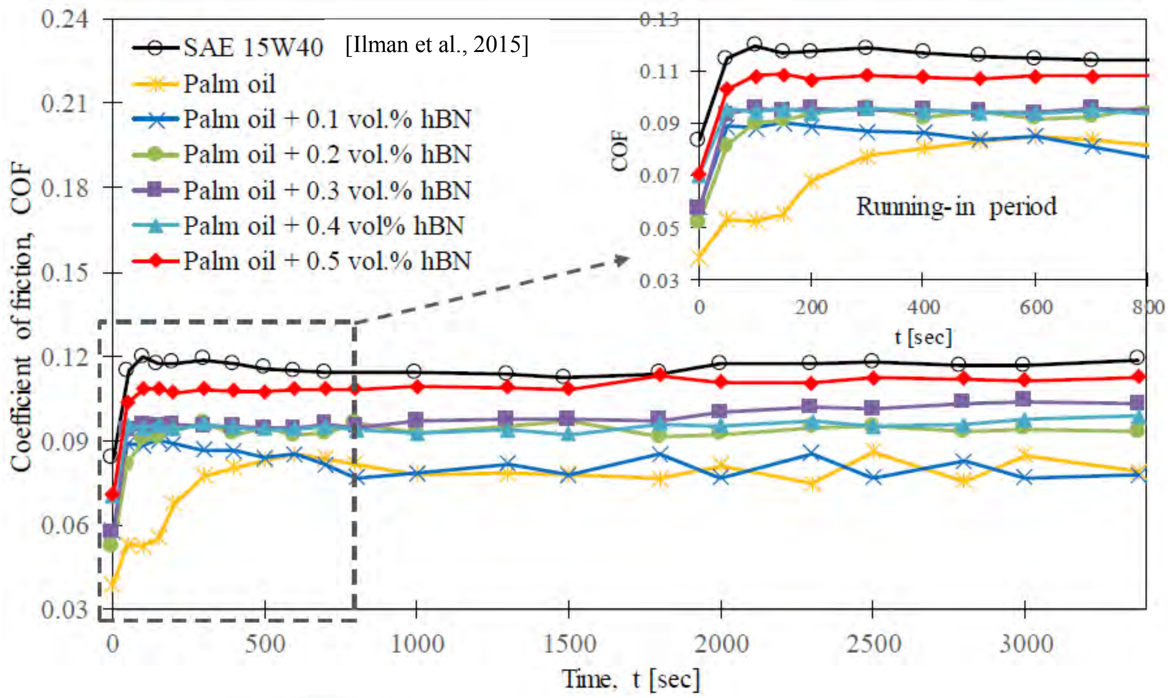


Figure 4.1: COF variation of palm oil with hBN nanoparticles and engine oil

Figure 4.1 shows the palm oil COF variation with hBN nanoparticles and the COF for conventional diesel engine oil with respect to time. The small graph at the top right corner shows the running-in period in which the COF varies from its initial value to a relatively stable value. Based on the graph, the running-in period of palm oil mixed with hBN nanoparticles is less compared to the pure oil, which is palm oil alone. This means that the addition of additives into the palm oil is just as good and effective as existing engine oil as the running in period of palm oil with nanoparticle additives are more likely the same as the running-in period for conventional diesel engine oil. Besides that, the coefficient of friction for all samples from 0.1 vol.% to 0.5 vol.% of hBN is still in the acceptable range, which is lower than the COF of SAE 15W40. From Figure 4.1, the steady state friction coefficient of 0.1 vol.% hBN decreased by 33%, as compared with conventional diesel engine oil. The friction coefficient reduction is from about 0.12 to 0.08

Figure 4.2 shows the trend of COF with different value of compositions of hBN. The graph of COF against time for all samples are shown in Appendix A and the average COF of sample were taken at their steady-state condition, starting from 1000 seconds until 3600 seconds.

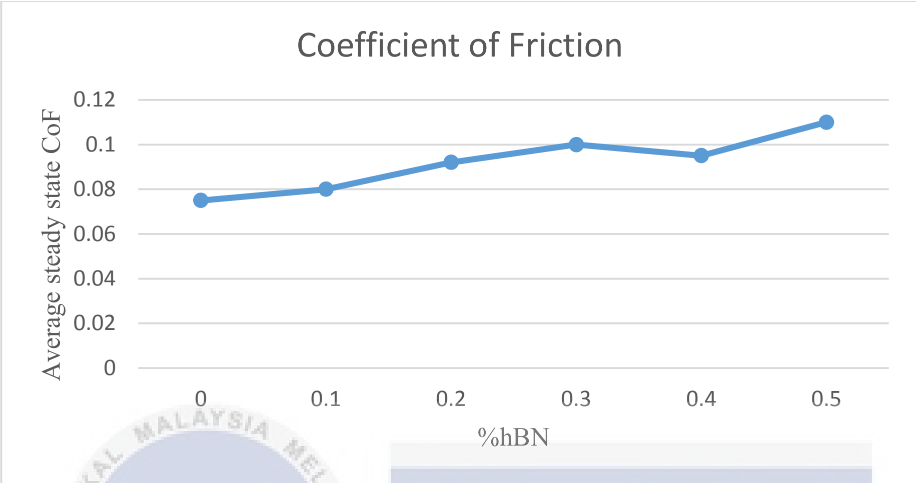


Figure 4.2: Graph of average steady state COF against % hBN

From Figure 4.2, by using 100 vol.% palm oil as reference, it can be observed that the addition of higher percentage compositions of hBN to the palm oil caused the friction coefficient value to become slightly higher. This is due to greater amount of hBN that are considered to be an abrasive particle when sliding along the contact surfaces which damaged the worn surfaces and may reduce the lubrication. Excessive particles remaining entrapped in the asperity valley limited the motion of nearby particles resulting in greater concentrations of stress (Reeves et al., 2013) leading to the formation of abrasive wear.

To explain the reason of increasing graph in Figure 4.2, a schematic model of friction is built based on the study by Talib et al. (2017). As shown in Figure 4.3 (a), a boundary film is formed through the reaction of palm oil with the rub surfaces. Some bulging points on the surface of the friction pairs are in direct contact with each other when the hBN nanoparticles are not added in palm oil. When a lower ratio of hBN nanoparticles is added to the palm oil, the nanoparticles mainly exhibit a rolling effect, as shown in Figure 4.3 (b), and low shear strength that will result in reduction of the friction force and wear. The polishing effect becomes prominent with the increase in the hBN concentration, which would cause the agglomeration effect to occur as shown in Figure 4.3 (c), thus increases the friction but still low wear because of non-direct contact phenomena between surfaces.

The friction mechanisms of the rolling effect and polishing effect coexist, but the dominant effect changes with the variation of hBN concentration. This result was in agreemen with the finding of Wan et al. (2015) who found that the 0.5 wt.% of hBN in the engine oil increased the COF and impaired the sliding surface. The results validated the ability of hBN particles as an additive in palm oil samples, a crucial factor in reducing the friction between the interfaces of the steel ball.

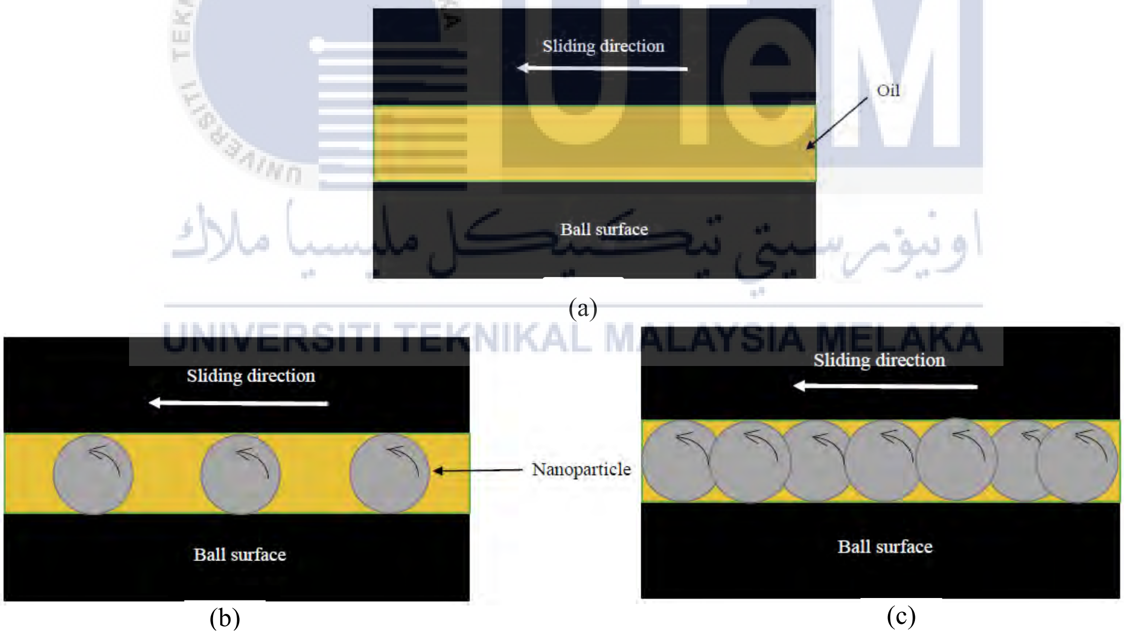


Figure 4.3: Schematic diagram of lubrication film in palm oil (a) direct contact, (b) low vol.% hBN and (c) high vol.% hBN

4.2 Effect of Wear

The wear scar diameter shown in Table 4.1 was taken from the average of the scar of the three lower clamped balls. Images of wear on steel ball for all samples was captured by using an inverted microscope as shown in Appendix B.

Table 4.1: Measurement of wear scar

Sample	Diameter Ball 1 (μm)	Diameter Ball 2 (μm)	Diameter Ball 3 (μm)	Average diameter (μm)
Palm oil + 0 vol.% hBN	531.43	586.97	558.23	558.88
Palm oil + 0.1 vol.% hBN	581.20	565.30	488.10	544.87
Palm oil + 0.2 vol.% hBN	572.90	506.80	512.70	530.80
Palm oil + 0.3 vol.% hBN	488.00	486.80	439.50	471.43
Palm oil + 0.4 vol.% hBN	489.10	465.00	476.90	477.00
Palm oil + 0.5 vol.% hBN	462.90	448.90	477.40	463.07

Then, wear rate is calculated for all oil samples by using Equation (4) in Chapter 3. The average wear rate values from three bottom chrome steel ball bearing were plotted as shown in Figure 4.4.

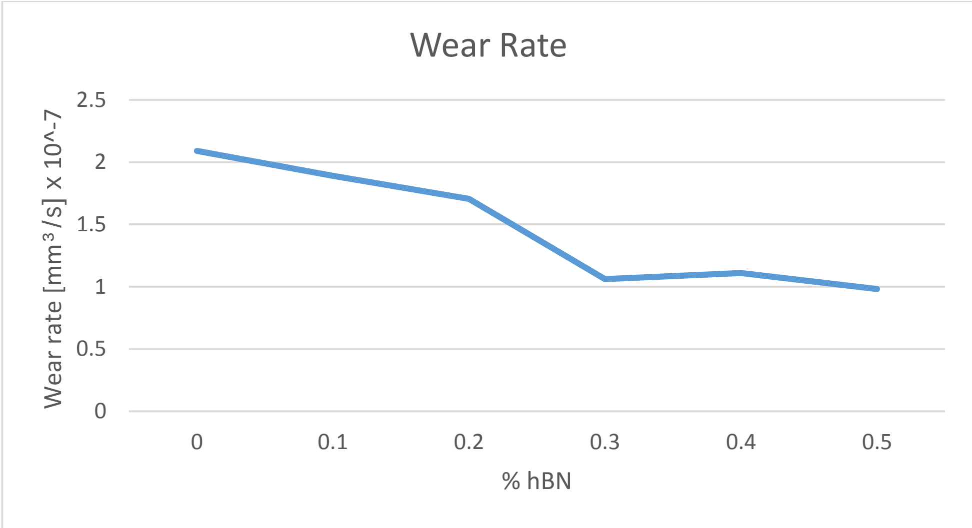


Figure 4.4: Wear rate of palm oil with hBN nanoparticles

The hBN was in the form of lamellar powder which developed layered crystal structures, with weak Van der Walls bonds between individual layers and strongly covalent bonded within a layer, minimizing contact surfaces and minimizing wear. From Figure 4.4, it has been observed that the palm oil with hBN nanoparticles have relatively smaller wear rate as compared to palm oil without additives. The wear rate value of concentration 0.1 vol.% hBN reduced by approximately 10%, in comparison to the pure oil. The graph also clearly shows that the higher concentration of hBN resulted in lower wear rate. This is in accordance with a significant reduction of wear scar diameter. This behaviour is ascribed to the lamellar structure of hBN particles, resulting in improved tribological characteristics.

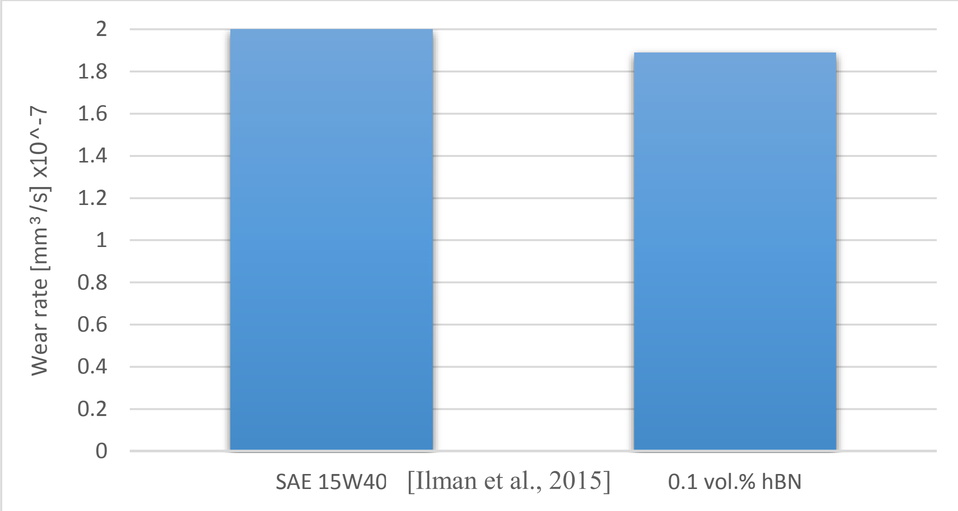


Figure 4.5: Wear rate of ball materials lubricated under convenctional diesel engine oil and 0.1 vol.% hBN

Figure 4.5 shows the comparison of wear rate value between the conventional diesel engine oil and bio-based oil derived from palm oil mixed with nanoparticles. The addition of 0.1 vol.% hBN reduced the wear rate by approximately 6%, compared to SAE 15W40 petroleum-based oil. Also, the formation of tribofilm of nanoparticles might have taken place, which has helped in lowering the wear of the surfaces.

4.3 Relationship between COF and Wear

Table 4.2 below listed the friction and wear test results for all samples. The wear scar diameter was taken from the average of the scar of the three lower clamped balls and coefficient of friction were taken at their steady-state condition.

Table 4.2: Testing parameters

% concentration of hBN	Coefficient of Friction	Wear Scar Diameter (µm)
0	0.076	558.88
0.1	0.082	544.87
0.2	0.093	530.80
0.3	0.100	471.43
0.4	0.095	477.00
0.5	0.111	463.07

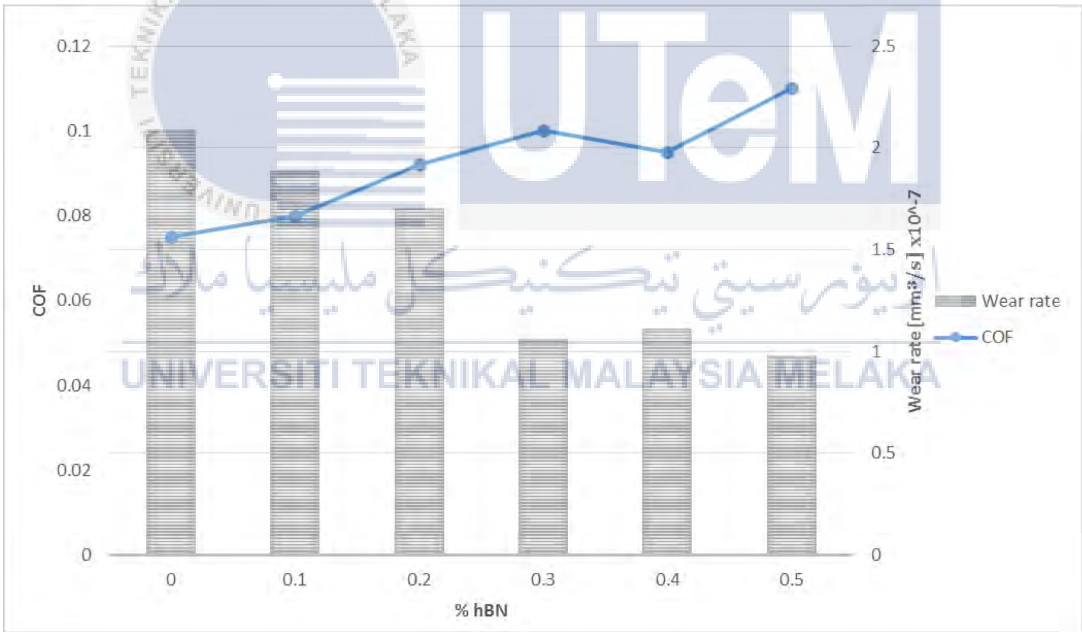


Figure 4.6: Graph of COF and wear rate

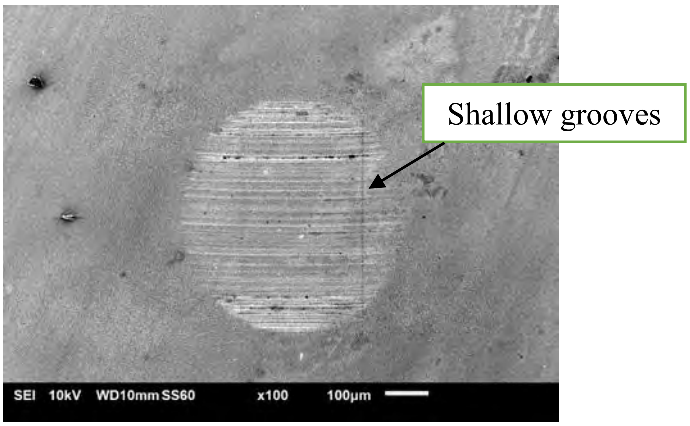
Based on the graph in Figure 4.6, the suitable amount concentration of hBN mixed with palm oil is 0.1 vol.% hBN. Although the nanoparticle concentration of 0.5vol.% has the lowest value of wear rate among all samples, it cannot be chosen as the appropriate amount as it has higher friction coefficient. The addition of hBN as little as 0.1 vol.% in the palm oil results in reduction of wear and required less time for the COF to achieve a relatively stable value as indicated in the graph of COF against time in Appendix A. Higher nanoparticle concentration resulted in lower wear rate and higher COF because of the agglomeration of hBN in palm oil (Figure 4.3 (c)). However, both values are still lesser than SAE 15W40 petroleum-based oil due to the nanoparticles exhibit a rolling effect.

4.4 Wear Characterization

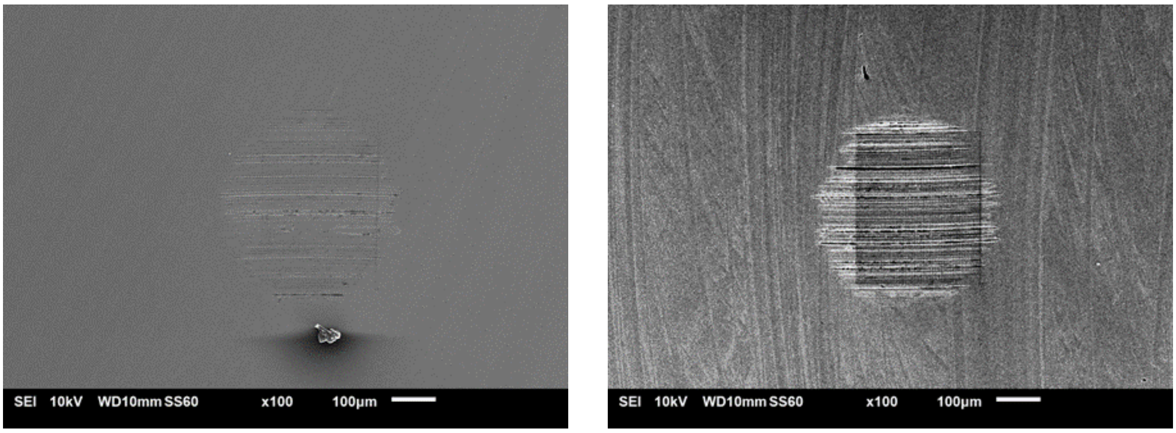
4.4.1 Introduction

In friction and wear characterization, Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray Spectroscopy (EDX) are used to observe worn surfaces. SEM is used to examine the topography of the wear surface and EDX is used to determine the significant compounds of the elements that occur on the worn surfaces. Typically, SEM provides the visual “answer” while EDS provides the elemental “answer”. In both cases, areas of interest can be observed aerially or in cross section.

4.4.2 Scanning Electron Microscopy



(a)



(b) (c)

Figure 4.7: SEM images of wear corresponding to the palm oil mixed with (a) 0 vol.% hBN, (b) 0.3 vol.% hBN and (c) 0.5 vol.% hBN

Results and wear scar Figure 4.7 (a), Figure (b) and Figure (c) shows worn surfaces on the carbon chrome steel ball lubricated with palm oil and mixed with hBN nanoparticles. Higher wear scar diameter and more shallow groves are observed when lubricated with pure oil (Figure 4.7 (a)), compared to the palm oil with additives (Figure 4.7 (b) and Figure 4.7 (c)). It is due to the lamellar structure of h-BN nanoparticles, it gets easily sheared between the moving surfaces, thus prevents the wear. This little damage to surface is due to the abrasion as seen in the form of parallel grooves. These observations provided information on the anti-wear properties of hBN nanoparticles.

Worn surfaces of the material for all oil samples were characterized by abrasive wear. Abrasive wear is the removal of material from a surface by a harder material impinging on or moving along the surface under load. However, the worn surfaces of the material lubricated by palm oil with additives show a reduction in abrasion. This directly responsible for the reduction in friction and wears.

4.4.3 Energy-dispersive X-ray Spectroscopy

The surface topography of wear scar balls and dot mapping was examined with Scanning Electron Microscope attached with Energy dispersive X-ray Spectroscope, to understand the wear mechanisms. Coinciding with any images obtained via SEM, EDS can be used to obtain elemental information about the area of interest. Figure 4.8~4.10 represents the elemental result of palm oil, 0.3% of hBN with palm oil and 0.5 vol.% of hBN with palm oil respectively.

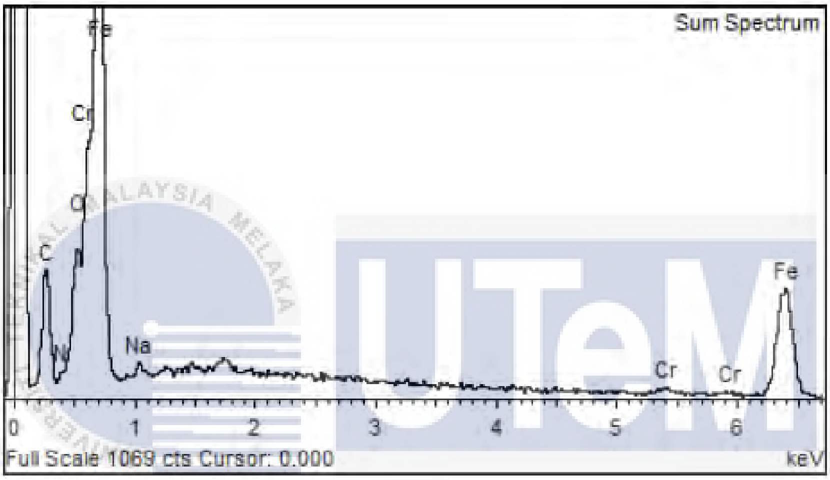


Figure 4.8: EDS image for wear scar lubricated with palm oil

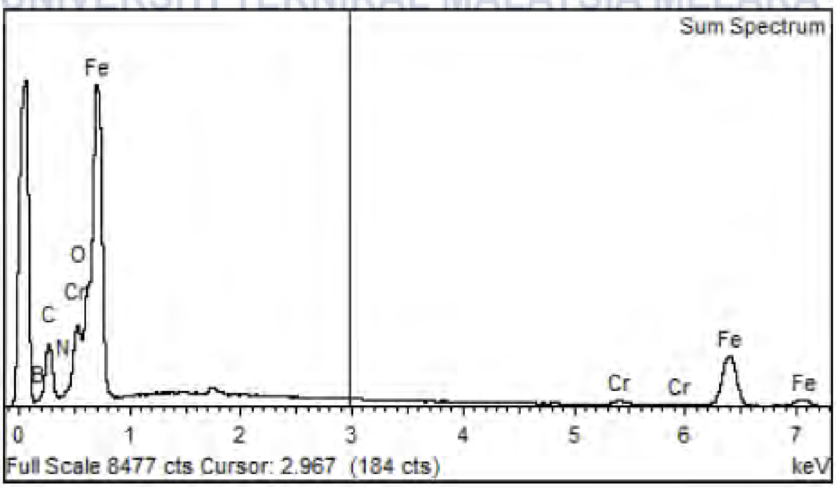


Figure 4.9: EDS image for wear scar lubricated with palm oil and 0.3 vol.% hBN

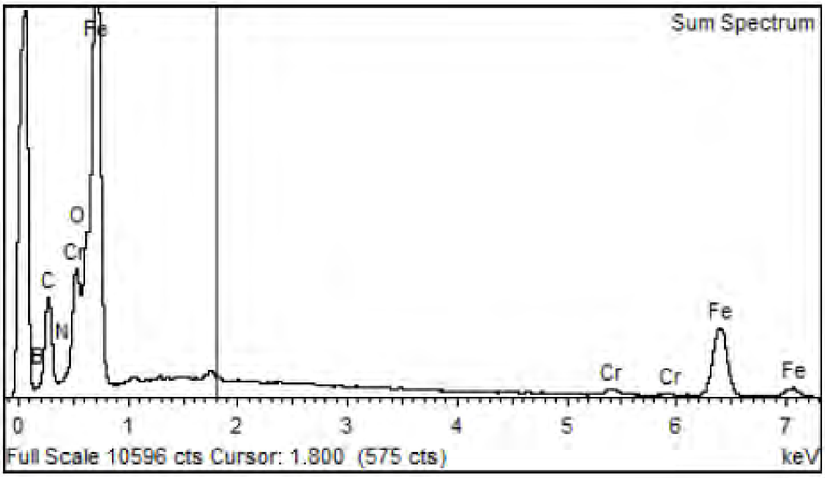


Figure 4.10: EDS image for wear scar lubricated with palm oil and 0.5 vol.% hBN

In some special situations, it may also be important to observe the "exact" orientation of the elements detected in an EDS scan. This technique is called Elemental Mapping. An elemental map is an image showing the spatial distribution of elements in a sample. It can be obtained for each element of interest and use varying color intensities to visually show the concentrations of a specific element across the area being inspected. Element map for all elements in palm oil, addition of 0.3 vol.% and 0.5 vol.% of hBN is shown in Appendix C.

(a)

(b)

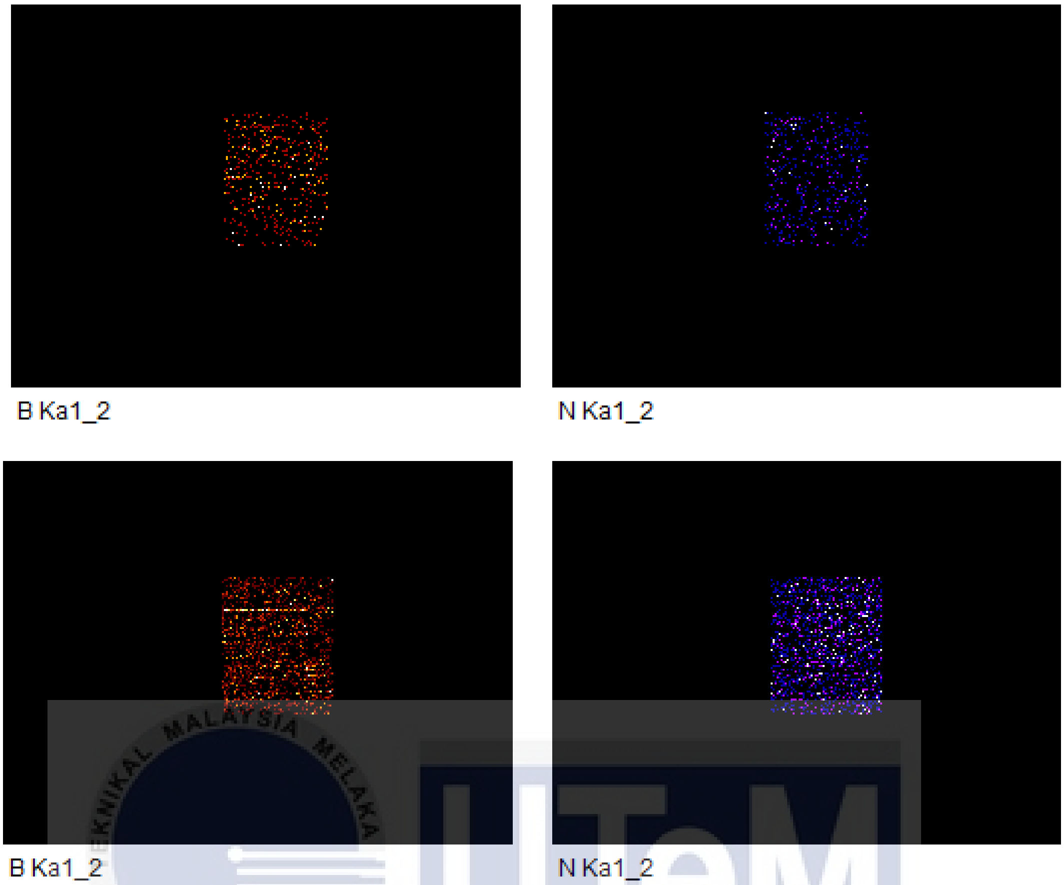


Figure 4.11: Elemental mapping for (a) 0.3 vol.% hBN and (b) 0.5 vol.% hBN

Based on Figure 4.11, the EDX elemental mapping from the EDX analysis clearly confirms the presence of Boron (B) and Nitrogen (N) in the hexagonal boron nitride nanoparticles. It has been observed that the wear scar of chrome steel ball with 0.5 vol.% hBN oil bio-lubricant, Figure 4.11 (b) have higher boron and nitrogen distribution as compared to wear surface with 0.3 vol.% hBN bio-lubricant showed in Figure 4.11(a). This increase in boron and nitrogen composition is due to deposition of hBN nanoparticles in surface asperities.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION FOR FUTURE RESEARCH

This chapter basically conclude the whole report based from the result. The result must be shown it correspond towards the objective and propose the final design. Recommendation should be given in order for future reference in improving the method to carry out the experiment flow.

5.1 Conclusions

In conclusion, after all of the information has studied in detail and experimental result was obtained and accumulated, hBN has potential to improve the friction and wear. The bio-lubricant of palm oil blended with hBN could significantly improve the anti-wear properties of the base oil, and lower nanoparticle concentration exhibited better tribological performance. Higher vol.% of hBN resulted in higher COF and lower wear rate because of the agglomeration of hBN in palm oil. However, both values are still less than SAE 15W40 petroleum-based oil due to the nanoparticles exhibit rolling effect. The objective of this study is to investigate the effect of different hexagonal boron nitride nanoparticles compositions on the tribological properties of palm oil.

The presence of hBN nanoparticles in palm oil can promptly change the unsteady-state COF (running-in period) into steady-state condition. The running in period of conventional diesel engine oil are most likely the same as the running-in period of palm oil with various concentrations of hBN. This shows that the bio-lubricant of palm oil with hBN as additives are just as effective as the engine oil, with lower coefficient of friction. The presence of 0.1 vol.% of hBN nanoparticles in palm oil exhibited low friction and wear as compared to the petroleum based oil by reduction of 33% and 6%, respectively. Besides that, addition of 0.1 vol.% hBN into palm oil reduced wear rate by approximately 10%. The EDX elemental mapping shows the element distribution, thus proven the presence of boron and nitrogen in hexagonal boron nitride. The element maps of higher vol.% concentrations of hBN has more element distribution of boron and nitrogen compared to low vol.% concentration of the nanoparticle additives.

5.2 Recommendation for Future Research

This study has been conducted to understand the behaviour of hBN on tribological characteristics of palm oil blended with different compositions of hBN. There is still room for improvement in order to carry out the selection with better judgment. In order to improve this project for future research, there are three methods should be carried out which are:-

1) Determining the viscosity index of each sample solution
2) Modified hBN
3) Conduct repeated experiment

5.2.1 Determining the viscosity index of each sample solution

Viscosity is the measure of fluid friction which can be considered as the internal friction resulting when a layer of fluid is made to move in relationship to another layer. Theoretically, higher viscosity index and flash point value with lower friction coefficient and wear scar diameter will increase the performance of lubrication. Due to that, different viscosity can affect the change of coefficient of friction and wear. Therefore, it has strong support for any changes that occur in the coefficient of friction.

5.2.2 Modified hBN

It is difficult to disperse hBN nanoparticles evenly in base oil even though hBN has excellent tribological properties. Poorly dispersed hBN nanoparticles in suspension do not generate excellent nanofluid properties. Therefore, by using a modified hBN nanoparticles is great to enhance their compatibility with the base oil.

5.2.3 Conduct repeated experiment

Conduct tribological testing for each sample solution repeatedly to verify results. Refining experimental observations is another reason to repeat. More measurements of one sample solution lead to greater confidence in calculating an accurate average measurement.

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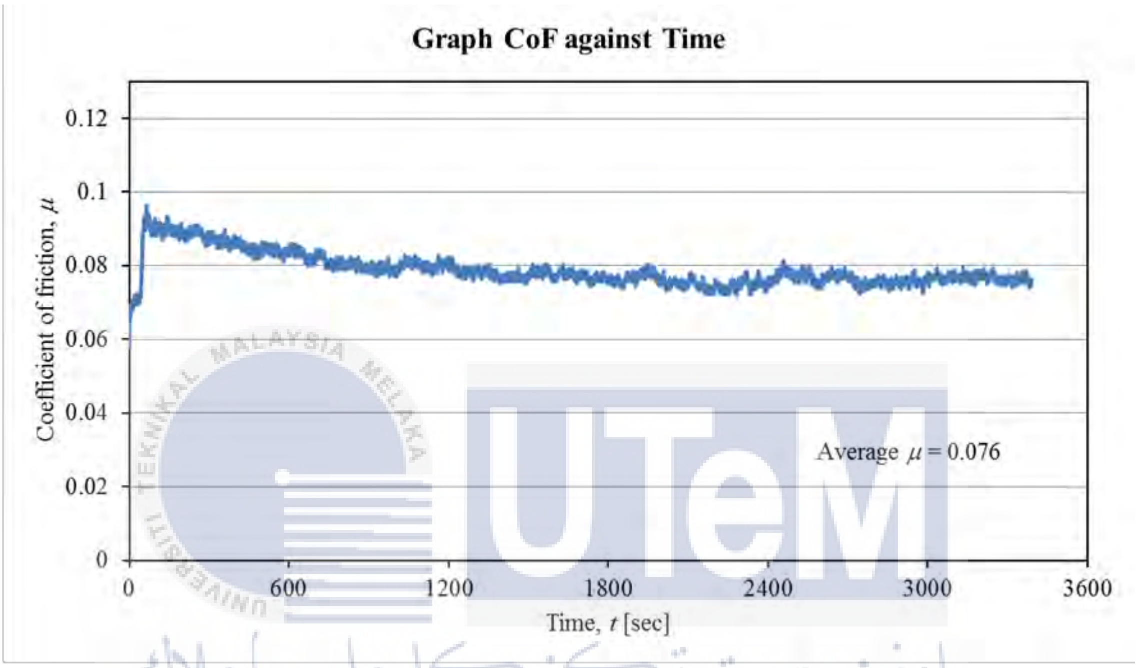
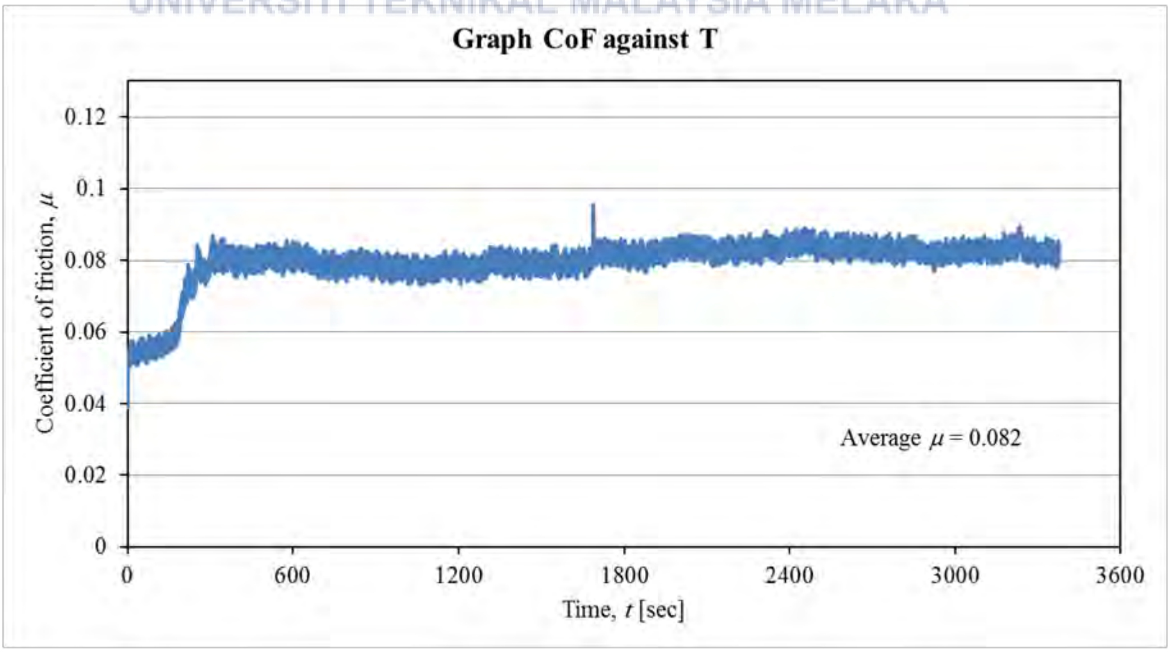
APPENDIX

Appendix A

No hBN



0.1 vol.% hBN



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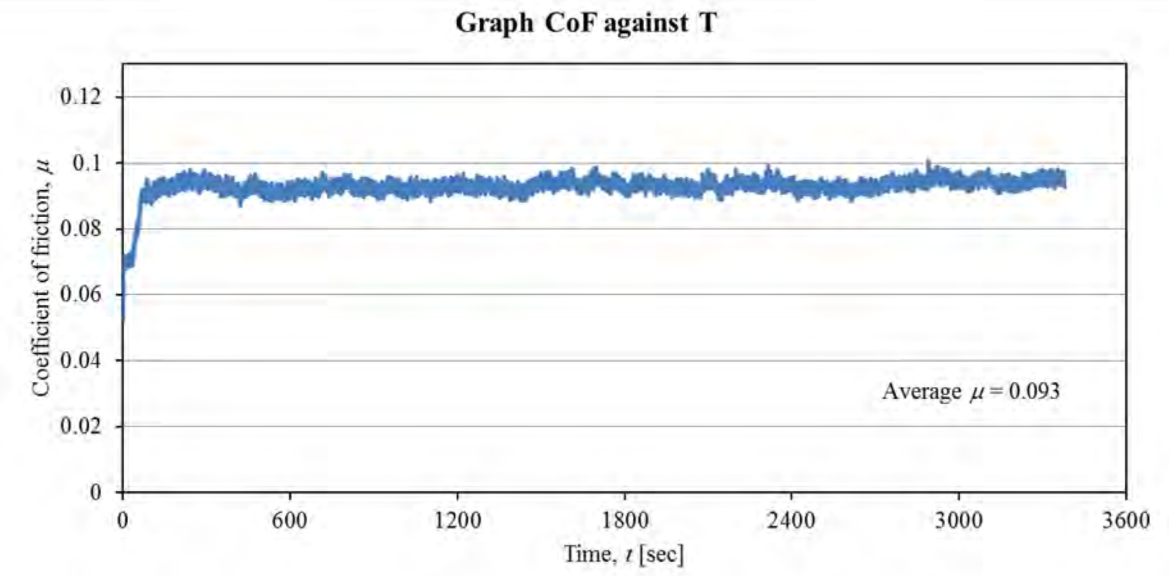
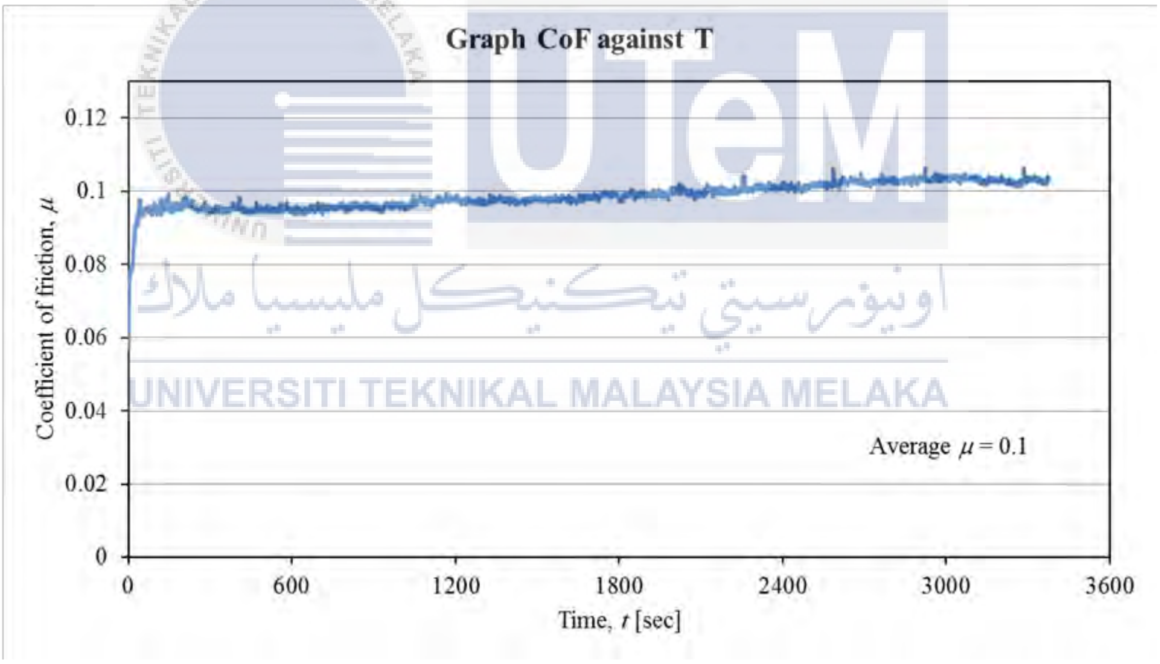
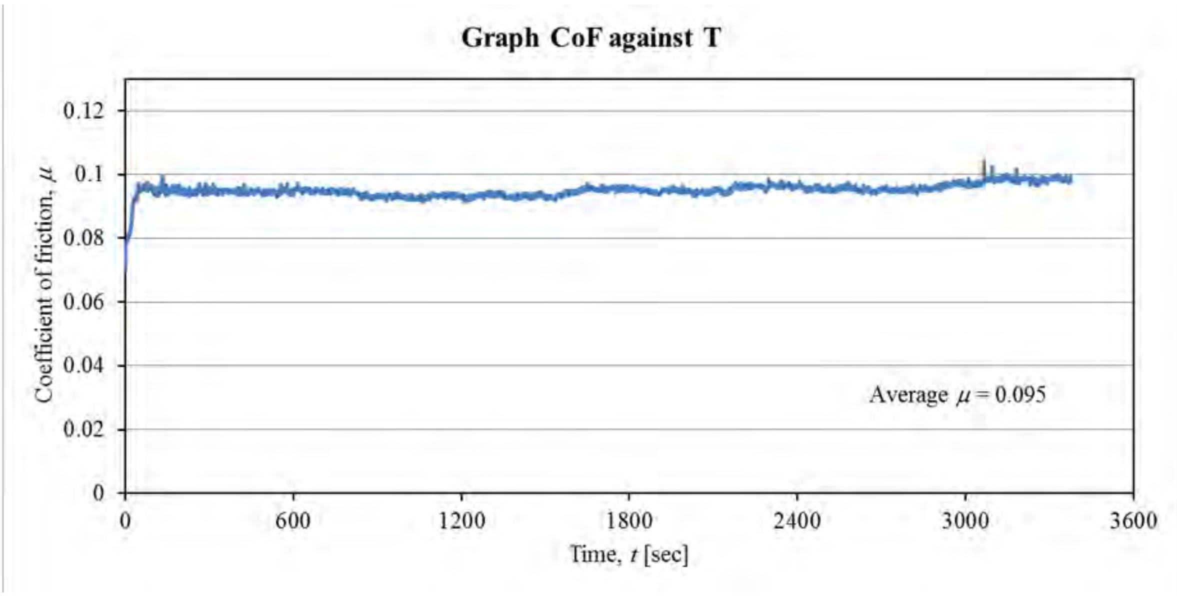


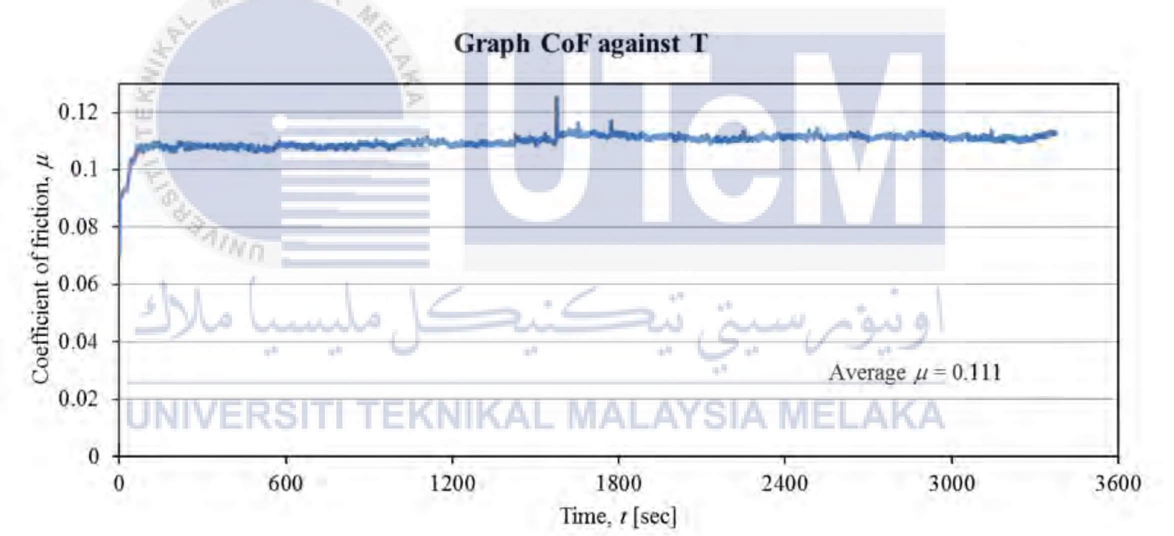
0.3 vol.% hBN



0.4 vol.% hBN

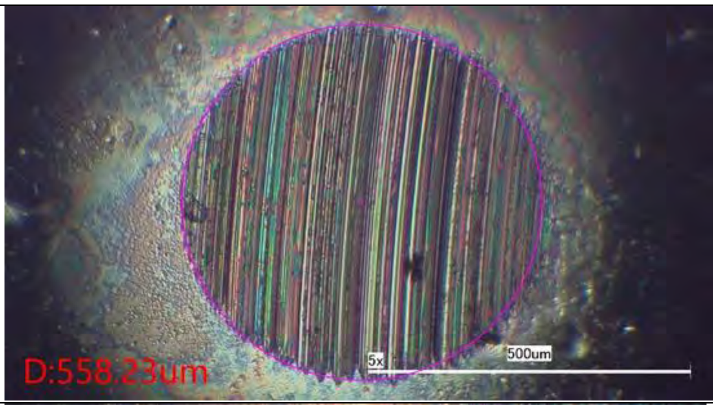
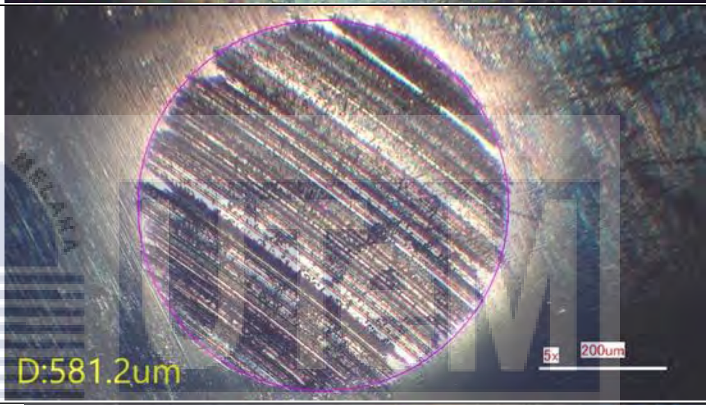
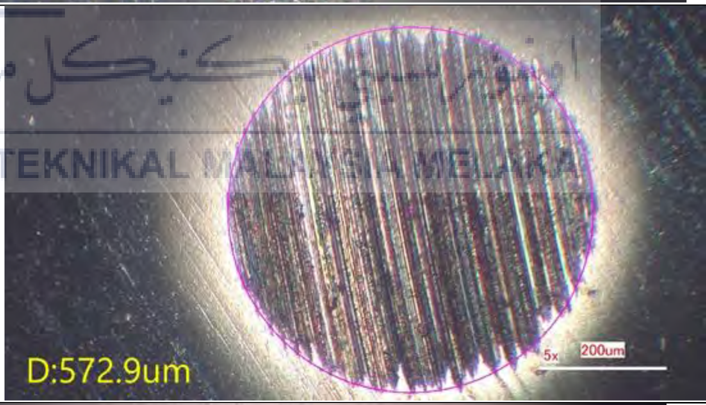
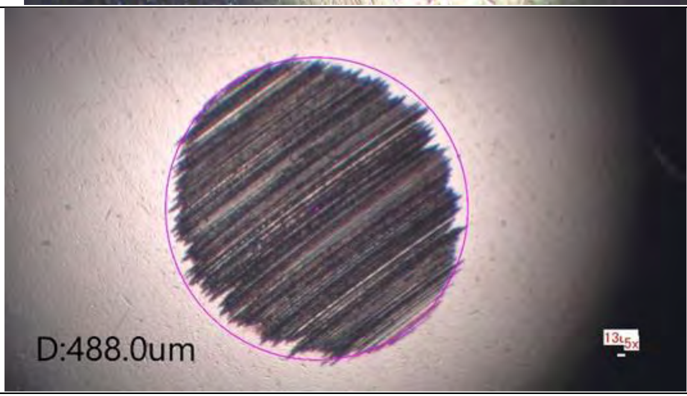


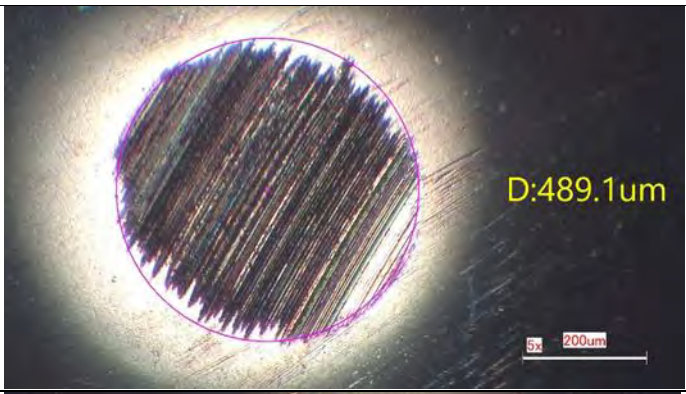
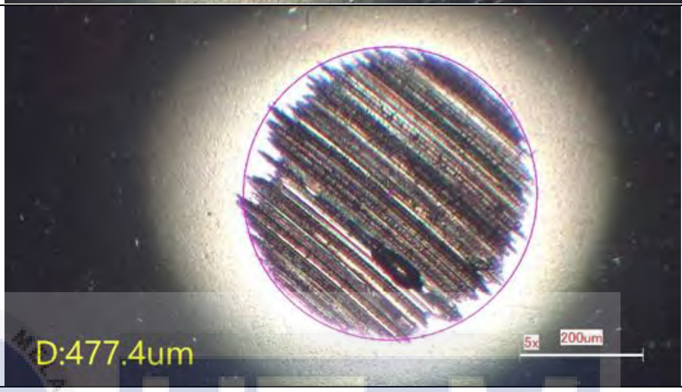
0.5 vol.% hBN



Appendix B

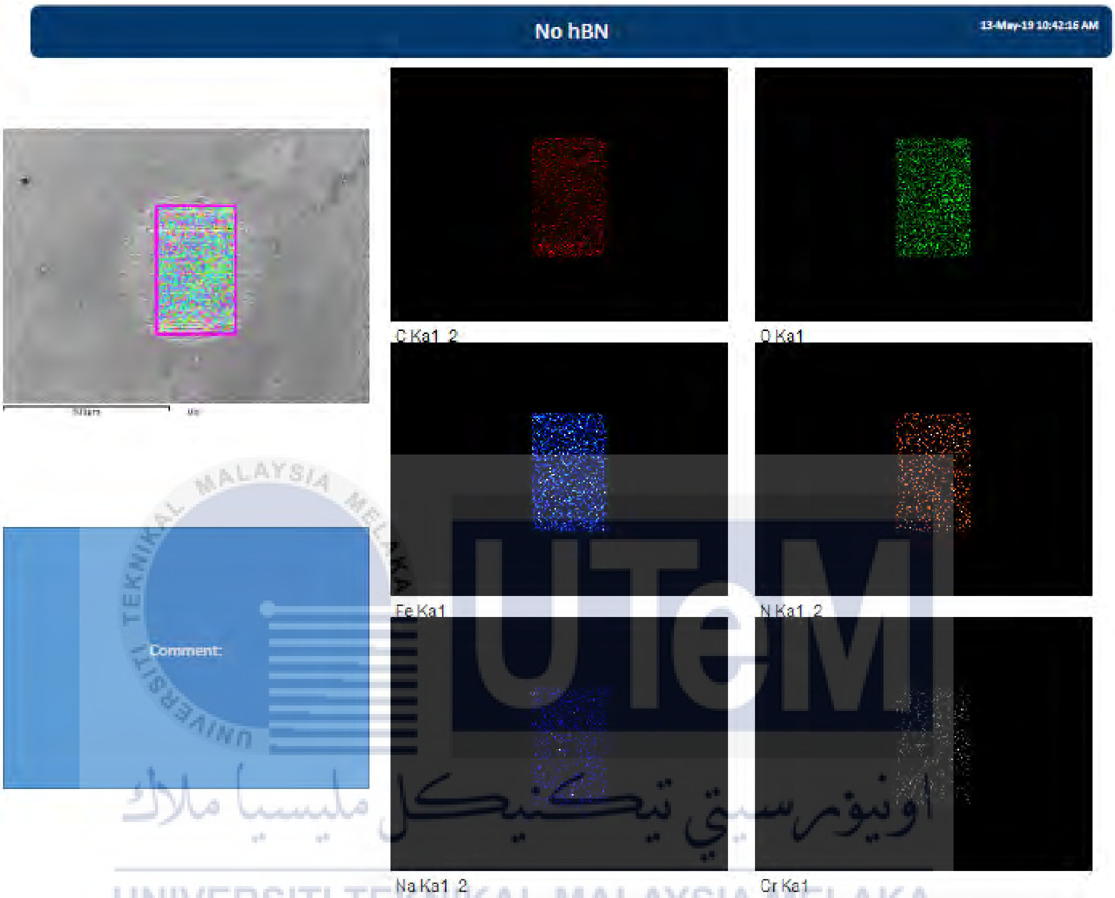
Wear scar diameter (WSD)

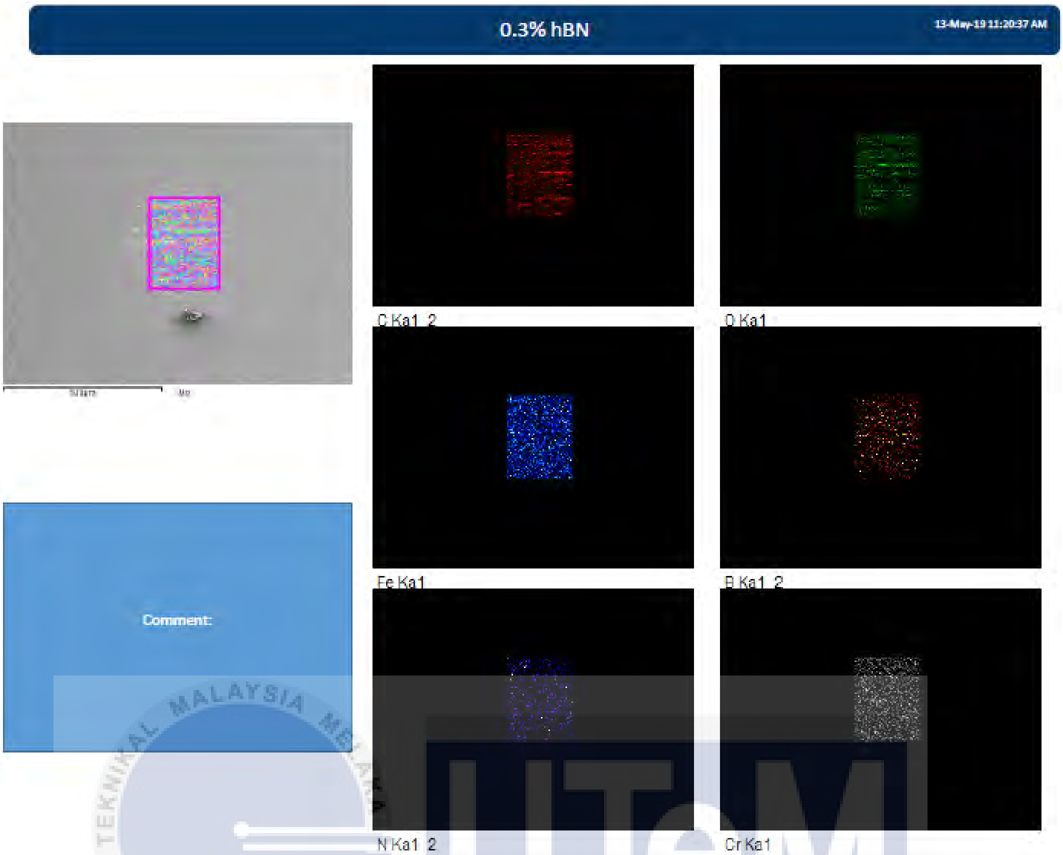
0 vol.%	
0.1 vol.%	
0.2 vol.%	
0.3vol.%	

0.4 vol.%	
0.5 vol.%	

Appendix C

EDX Elemental mapping




0.3% hBN
13-May-19 11:20:37 AM
Comment:
C Ka1_2
O Ka1
Fe Ka1
B Ka1_2
N Ka1_2
Cr Ka1


0.5% hBN
13-May-19 11:38:00 AM
Comment:
C Ka1_2
O Ka1
Fe Ka1
B Ka1_2
N Ka1_2
Cr Ka1