TRIBOLOGICAL STUDIES ON ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE WITH PALM KERNEL SHELL IN DRY CONDITION

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2019

DECLARATION

I declared that this project entitled "Tribological Studies on Ultrahigh Molecular Weight Polyethylene with Palm Kernel Shell in Dry Condition" is the result of my own work except as cited in the references.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor Mechanical Engineering

Signature	:	....
Supervisor's Name	:	....
Date	:	....

DEDICATION

To my beloved mother and father, family members and friends who's been with me throughout an incredible journey of this 23 years of life.

ABSTRACT

Ultra high molecular weight polyethylene (UHMWPE) is self-lubricating polymers that widely used for reducing friction and wear in dry condition. Despite that, there are some aspects such as poses a low load bearing capacity and inferior thermal conductivity which can limit its application. Therefore, this study is conducted to develop a composite of UHMWPE reinforced with palm kernel shell (PKS) with varying compositions and investigate the tribological performance of the composite. All specimens were fabricated into 74 mm diameter disc of 4 mm height with different compositions (0, 5, 10, and 15 wt%) of PKS by undergo hot press process. Tribological test was run utilizing pin-on-disc tribometer. The outcomes demonstrated that the coefficient of friction (COF) and wear rate were steadily decreased as the composition of PKS is enhanced. The pure UHWMPE have the highest COF and wear rate of 0.086 and 6.24 x 10^{-6} mm^3/N.mm while the UHMWPE reinforced 15 wt% PKS have lowest COF and wear rate of 0.063 and 5.13 x 10^{-6} mm^3/N.mm. PKS is considered as one of the most potential reinforcement as carbonaceous fillers among the engineered and other agrarian waste based polymeric composite

ABSTRAK

Ultra high molecular weight polyethylene (UHMWPE) merupakan polimer pelincir diri yang digunakan secara meluas untuk mengurangkan geseran dan kehausan pada keadaan geser kering. Walau bagaimanapun, terdapat beberapa aspek seperti ianya mempunyai kapasiti galas bebanan yang rendah dan kekonduksian terma yang kurang baik yang boleh menghadkan penggunaannya. Oleh itu, kajian ini dijalankan adalah bertujuan untuk menghasilkan komposit UHMWPE yang diperkuat oleh cengkerang kelapa sawit (PKS) dengan komposisi yang berbeza serta mengkaji prestasi tribologi komposit tersebut. Semua spesimen telah difabrikasi yang berbentuk cakera mempunyai diameter 74 mm dan ketinggian 4 mm dengan komposisi PKS yang berbeza (0, 5, 10, dan 15 wt%) melalui proses 'hot press'. Ujian tribologis dijalankan menggunakan mesin pin-on-disc tribometer. Keputusan menunjukkan bahawa pekali geseran (COF) dan kadar kehausan semakin berkurang apabila komposisi PKS dipertingkatkan. UHWMPE tulen mempunyai COF dan kadar kehausan yang paling tinggi iaitu 0.086 dan 6.24 x 10-6 mm^3 / N.mm manakala UHMWPE yg diperkuat 15 wt% PKS mempunyai COF dan kadar kehausan yang paling rendah iaitu 0.063 dan 5.13 x 10-6 mm^3 / N.mm. PKS dianggap sebagai salah satu agen pengukuh paling berpotensi sebagai pengisi karbon di antara komposit polimer berasaskan buangan sintetik dan pertanian.

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TABLE OF CONTENT

CHAPTER 3
METHODOLOGY

CHAPTER 4
RESULT AND DISCUSSION

CHAPTER 5
CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UHMWPE	-	Ultra-High Molecular Weight Polyethylene
PKS	-	Palm Kernel Shell
COF	-	Coefficient of Friction
PTFE	-	Polytetrafluoroethylene
DLC	-	Diamond-Like Carbon
GNPs	-	Graphene Nanoplatelets
DSC	-	Differential Scanning Calorimetry
CF	-	Carbon Fibre
PKAC-E	-	Palm Kernel Shell Activated Carbon-Epoxy
ASTM	-	American Society for Testing and Material
SEM	-	Scanning Electron Microscopy
EDX	-	Energy-dispersive X-ray Spectroscopy

LIST OF SYMBOLS

D	-	Distance of slide, m
r	-	Radius wear track, m
N	-	Sliding speed, rpm
t	-	Time, min & sec
F	-	Frictional force, N
W	-	Applied load, N
V_{loss}	-	Volume loss, mm^3
a	-	Wear scar radius, mm
h	-	Wear depth, mm
L	-	Sliding distance, mm

CHAPTER 1

INTRODUCTION

1.1 Background of study

Tribology is the study and application of principles of friction, wear and lubrication. As indicated by Oxford Dictionary 'tribo-' is gotten from the Greek word '*tribos*', which means rubbing and friction. The phenomena of tribology have been discovered for decades ago. In 1996, it was published in the Jost Report (Lubrication (tribology) Education and Research, Department of Education and Science, HMSO, 1966) and was officially clarified as 'The science and technology of contact surfaces in relative movement and the practices identified with that (Jin & Fisher, 2014). Since then, the word 'tribology' has been generally used and study on this field has been widely researched. Tribology is a branch of science and engineering that deals with the contact of surfaces in relative movement in man-made and artificial systems. These systems include mechanical components, transportation systems), biomedical devices, living bodies, manufacturing technologies, electrical contacts and others.

Wear and friction are the two fundamental sources of energy and material losses in tribological conjunctions of mechanical systems. Lubrication is the principal focus to enhance energy efficiency and mechanical durability. Previous studies on tribology have resulted some favourable techniques of controlling wear, for example, film coating, multi-stage alloying, and composite structuring (Mat Tahir et al., 2015). In dry sliding state, ultrahigh molecular weight polyethylene (UHMWPE) which is a self-lubricating polymer have been explored as the solution to minimize wear and friction (Aliyu et al., 2018). UHMWPE is a subset of the thermoplastic polyethylene that are widely used in industrial application such as unlubricated bearings, liners, gears, and seals due its attractive properties (Ahmad et al., 2013). According to (Aliyu et al., 2018), these include high abrasion resistance, good impact strength, low coefficient of friction (COF) and resist to wear better than other polymers. Despite of that good properties of UHMWPE, there are also some factors that affect its properties. Therefore, the incorporation of reinforcement like carbonaceous fillers can result a better tribological properties of UHMWPE.

Previous research discovered that carbon-based materials can act as a self-lubricating material when reinforced with various materials. Palm Kernel Shell (PKS) is a palm oil extraction waste material consisting of carbon characteristics which can be transformed into a self-lubricating material with a low COF and high resistance to wear (Mahmud et al., 2017). Malaysia produces around 4 million tons of PKS every year. (Itam et al., 2016) stated that both policy of "Zero Waste Concept" introduced by Malaysian Palm Oil Board (MPOB) and improving tribological properties at a low cost can be accomplished by utilizing carbon-based materials from agricultural waste materials to formulate a new polymer matrix composite. PKS is easy to conduct with no side effects, so that make it as environmentally friendly and renewable resources. PKS has good thermal insulation, low density, structurally adequate, lightweight and high in strength. (Dnoke, 2006) studied that the utilization of PKS in the development of structural lightweight concretes improved the mechanical strength, thus PKS is capable to be used as base material in friction composites, to resist the high impact and variable force. The coefficient of friction (COF) of PKS on metal surfaces is in the range of 0.37-0.52 (Mgbemena et al., 2014). Thus, PKS is likely a suitable substance to be reinforced with UHMWPE to improve the tribological properties.

1.2 Problem statement

Despite of the wide use of UHMWPE in mechanical component, transportation system and manufacturing technologies, the poor load bearing capacity of UHMWPE limit its utilization in tribological applications. Besides, its high viscosity cause complication in the fabrication process and also the restriction for high contact sliding speed application due to its poor thermal conductivity (Aliyu et al., 2018).

Researchers over the years have studied various method to overcome these hurdles, and one of the methods is by developing a matrix composite of UHMWPE reinforced with ceramic, metallic, carbon-based, and mineral fillers (Mohammed, 2018). However, the current commercial self-lubricating filler materials such as graphite, layered silicate and etc, are relatively expensive in the global market (Mat Tahir et al., 2016). Thus, it required high cost in order to produce a new polymer matrix composite.

Lastly, the utilization of PKS, which produce in large quantities per year as reinforcement in the fabrication of polymer matrix composite have potential to achieve zero waste strategy with economical budget. The physical properties of PKS, which its biodegradability ensures the environmental friendliness when the product wears debris decomposes. Therefore, the tribological studies on UHMWPE with PKS in dry condition will be investigated in this study.

1.3 Objective

The objective of this study is to study the effect of different composition of PKS reinforcement to the tribological performance of UHMWPE.

1.4 Scope

The study covers the development of specimen of UHMWPE reinforced with PKS with different compositions. Hardness, surface roughness, friction and wear test were directed and the characterization of mechanical and tribological properties was observed. The test conducted also to determine the optimum composition. The analysis of the composites will be done by using scanning electron microscopy (SEM) in order to investigate the tribological properties of the composites.

1.5 General Methodology

The descriptions and details of methodology to achieve the objective will be explained in Chapter 3. Generally, the flow in order to accomplish this project are as follows;

a) Literature review

Collecting data of previous studies from journal, article, book, website and any related material about the project.

b) Experiment setups

The specimen of UHMWPE reinforced with PKS will be prepared with varying compositions of 0.5, 0.10 and 0.15 wt% through the ball milling process to ensure the materials are homogeneously dispersed. Hot pressing will be used to consolidate the prepared powder.

c) Experiment and analysis

The experiment will focus on friction and wear test by using a pin on disc test. The test will be conducted for pure UHMWPE and composites with varying compositions. The tribological properties will be collected and analysed to investigate the tribological performance.

d) Thesis writing

A complete thesis will be written which include all the data and analysis from the experiment.

The general methodology of this study is simplified in the flow chart as shown in Figure 1.1.

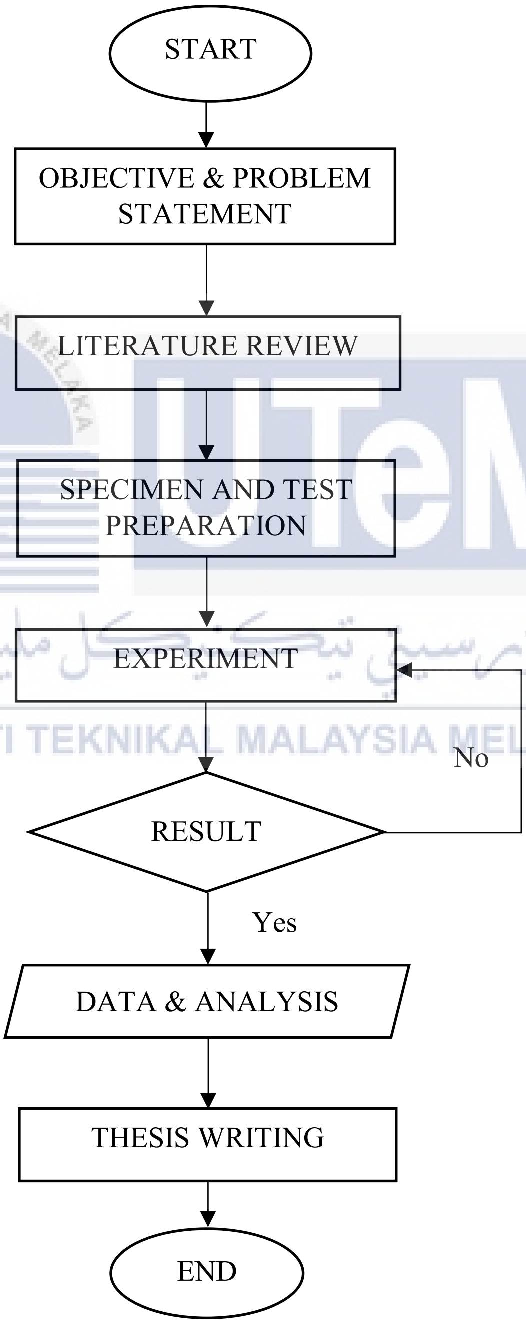


Figure 1.1: Flow chart of general methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews previous research and sources obtained from journals, articles, reports, books and web sites to find the information related to this study. The aim of this chapter is to create a guideline from previous knowledge and ideas in order to complete this project. The information is selected based on the objectives of this study. For instance, the information about tribological studies, UHMWPE, PKS and pin-on-disc test are acquired to achieve the objectives.

This chapter is organized as follows. The second section which is Section 2.2 describes on tribological studies. Section 2.3 continues with the discussion of the UHMWPE studies while Section 2.4 explains about previous study on PKS, which will be reinforced with UHMWPE to be investigated in this study.

2.2 Tribological study

Tribology is characterized as the investigation of science and technology of contact surfaces in relative motion. Friction, wear and lubrication are the main components in tribological study. In 1966, Peter Jost introduced the word tribology which comes from the Greek, meaning 'the study of things that rub' and it was officially published in Jost Report. Leonardo da Vinci was the first to discover the two-fundamental law of frictions back in 1943, however, his discovery remains unpublished. In the beginning of the twentieth century, the extensive growth in industrialization led to the needed for a better understanding of tribology. Since then, the knowledge in all fields of tribology has enlarged widely. (Kapsa, 2011) stated that the mechanism of tribology needs to be studied in order to understand this field and improves the technology. The mechanisms are consisting of machine components, for example, gears, bearings, clutches, cables and all the way to human joints. The mechanisms are operators which require forces, speeds, etc., act on the moving object and form the output of friction force, wear and temperature.

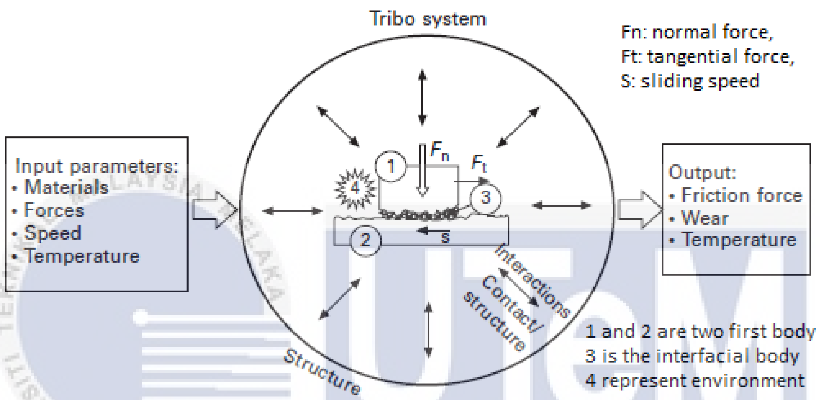


Figure 2.1: The various components of the tribo system (Kapsa, 2011)

2.2.1 Tribology in automobile engine

In the automotive sector, the utilization of tribological principles is important for the reliability of motor vehicle and has the prompted broad development in the tribology field. Engine durability improvement and lower vehicles maintenance cost are the most crucial challenges for the automotive industry. Energy lost in vehicles is mainly from the engine which approximately 62% of the lost. The high percentage of energy lost increase the amount of the fuel consumption, thus, result to the lower fuel efficiency. Nevertheless, in the past few years, the industry has gained extraordinary ground in improving energy utilization by limiting rubbing in vehicles. The turbocharged, direct-injection spark ignition engine with scaling back is one of the elective ways that have been utilized in the market (Wong & Tung, 2016).

Significant results on the fuel economy and the environment in a long term can be accomplished even with the littlest enhancements in the effectiveness of engine, emission quantity and durability. The energy from the fuel combustion process will be diffused in an engine and powertrain system. For medium size passenger car, just 12% of the energy has been accessible to drive the wheels while some 15% being dematerialized as energy lost mostly frictional losses. Previous fuel utilization information shows that, a decrease of 1.5% in fuel utilization was occurring due to 10% reduction in mechanical losses (Tung & McMillan 2004).

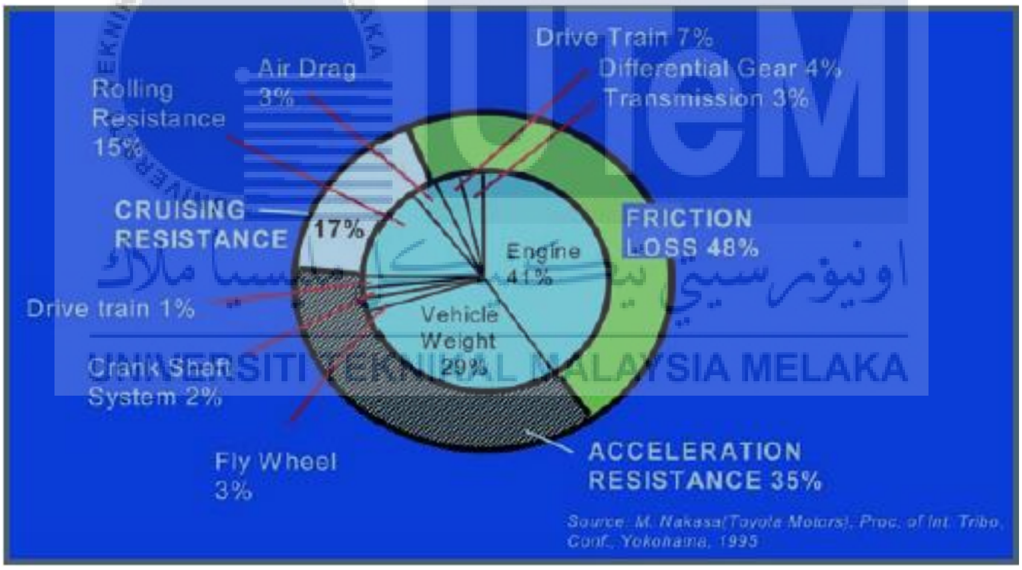


Figure 2.2: Energy utilization develop in an engine (Tung & McMillan, 2004).

Figure 2.2 shows that the crucial part of the energy utilization develops in an engine is friction loss (48%) followed by the second significant portion, acceleration resistance (35%) and the other portion is cruising resistance (17%).

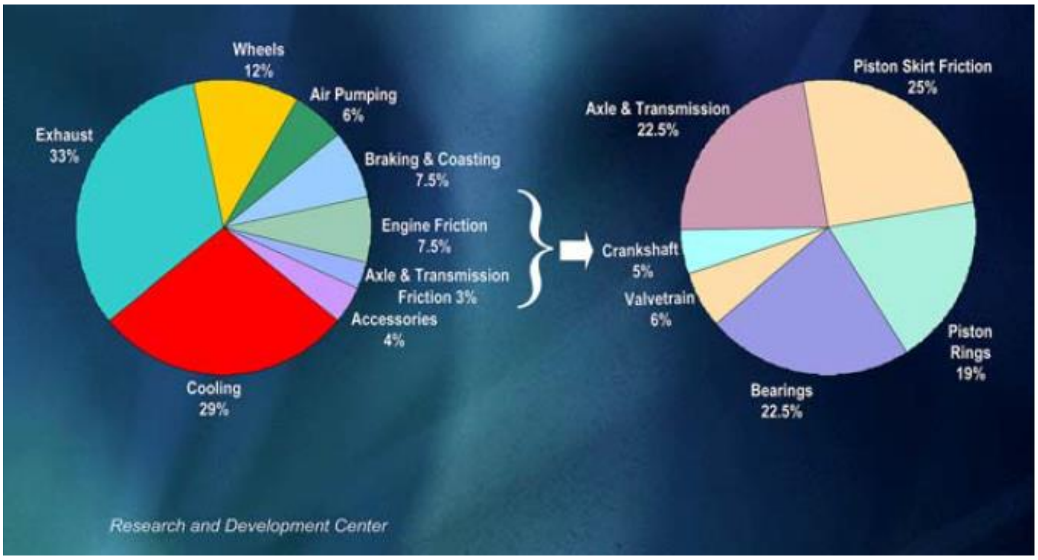


Figure 2.3: Distribution of energy consumption in a light-duty vehicle
(Tung & McMillan, 2004)

Based on the overall friction loss portion as shown in the Figure 2.3 combining the piston skirt friction, piston rings, and the bearing is 66% of the overall friction loss and the total of the valve train, crankshaft, transmission and axle are about 34%. Focusing only on powertrain friction, piston skirt friction and piston rings are the enormous contributions to friction in a powertrain system followed by rotating engine bearing, valve train and the aide like an oil pump, water pump, and alternator.

Tribological performance can be improved in three ways; by enhancing the tribological properties of the material used for the mechanical parts, coating surface and developing lubricants that improve tribological behaviour. The improvement of tribological performance can reduce fuel and oil consumption, increased power outputs, decline discharges of fumes, enhanced durability, reliability and engine life.

Lubrication includes the smoothing of the rubbing action between interacting surfaces. A direct solid-to-solid contact can be prevented by the formation of lubricant film between the contact surfaces. The applied mechanical forces, relative velocity, surface profiles, roughness, textures, including lubricant properties, are the factor that can affect the degree of the contact and the oil film thickness. The lubricant is a multi-constituent fluid that vigorously affect the lubrication regime of the greased parts. Different additives give numerous purposes in the oil such as to retain the temperature sensitivity of the oil viscosity, to preserve against wear through the presence of surface films, and to minimize solid contact friction by developing a slippery surface. Moreover, other additives remain the component surfaces clean and maintains the adequate level of the oil properties.

2.2.2 Tribology in a brake system

Nowadays, friction brakes were broadly used in many transportations and industrial equipment such as cars, trains, planes and industrial devices such as mine hoisters, lifts, and so on due to their noteworthy quality of their performance and safety application. The main effect on the brake system performance and its failure are the tribological properties of the friction couple materials. The failure symptoms in the brake system are the sound produce and vibrations caused during braking (Stoica et al., 2017).

As a crucial component of friction brake, the contact materials such as brake shoe, brake lining, and so on should possess a high and stable COF, good thermal conductivity, outstanding heat and wear resistance, and poor absorbability of water, oil, or brake fluid. Higher requirements on the security, knowledge, eco-friendliness of brake mechanisms, and operating comfort of mechanical devices were the most important consideration as the innovative development and priority of safety concerns. Thus, excellent tribological properties are important to develop novel brake's friction materials and to study their friction and wear mechanism in the braking system.

According to (Xiao et al., 2016), the braking process allows the kinetic energy to be transferred into heat. The frictional heat causes a temperature increment, which will influence the friction and wear. In general, with the rise in temperature, will cause the COF to increase gradually. While the temperature rising, the rate of wear will continuously increase. The wear will be progressively critical at a higher temperature. The variation of COF and wear rate with temperature for the organic friction material is shown as in Figure 2.4(a) and the variation for powder metallurgy friction material is shown as in Figure 2.4(b).

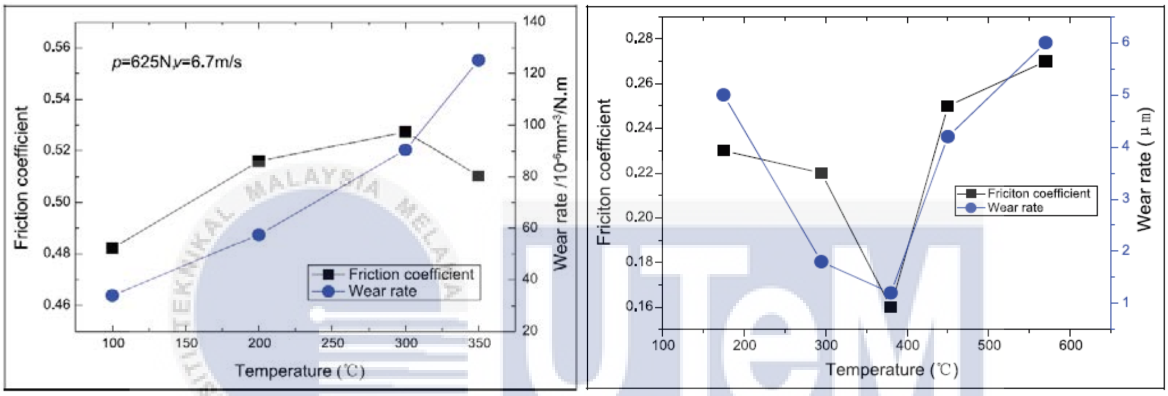


Figure 2.4: Effect of temperature on the friction and wear of (a) organic material (b) powder metallurgy friction (Xiao et al., 2016)

At first, the increment COF and wear rate of organic material are proportionally with the temperature, but then it starts to drop when the temperature attains at 300°C as shown in Figure 2.4(a). Anyhow, as the temperature increase, the wear rate will keep rising while the wear rate is reduced. This shows that the wear of friction material is more critical at a higher temperature. In general, for the powder metallurgy, both the COF and the wear rate decline at the first as shown in Figure 2.4 (b). Nevertheless, both COF and wear rate start to increase with the rise in temperature after reaching a certain value of temperature.

2.3 Ultra High Molecular Weight Polyethylene (UHMWPE)

Ultrahigh molecular weight polyethylene (UHMWPE) is a subset in thermoplastic polyethylene. It is known as a very tough material, with high impact strength. Besides, it also has sufficient strength which acquired from the length of each individual particle even though the Van der Waals bonds between its molecules are comparatively weak. Great tensile loads can be supported because each chain bonds with numerous Van der Waals bonds. The polymer chains can achieve a parallel orientation higher than 95% and a crystallinity degree up to 75% when it formed into fibers. Local thermal excitations disturb the crystalline order, results much lower heat resistance than other high strength fibers. Table 2.1 shows the properties of UHMWPE.

Table 2.1: Properties of ultrahigh molecular weight polyethylene (Yan, 2016)

Properties	Items	Typical value
Water resistance and chemical resistance	Moisture regain	0
	Water erosion	None
	Acid resistance	Good
	Alkali resistance	Good
	Ultraviolet resistance	Good
Thermal properties	Boiling water shrinkage (%)	<1
	Melting point (°C)	144-155
	Thermal conductivity (along the fiber axis) [W/(m.k)]	20
	Coefficient of thermal expansion (K^{-1})	-12×10^{-6}
Electric properties	Resistance (Ω)	>14

	Dielectric strength (kV/cm)	900
	Dielectric constant (22°C, 10GHz)	2.25
	Tangential loss angle	2 x 10^{-4}
Mechanical properties	Tensile modulus (GPa)	100
	Tenacity (GPa)	3
	Creep (22°C, 20% load, %day)	1 x 10^{-2}
	Compression axial strength (GPa)	0.1
	Compression axial modulus (GPa)	100
	Shear strength (GPa)	0.03
	Shear modulus (GPa)	3

Although the COF of UHMWPE is lower than nylon and acetal, it is approximately when compared to the polytetrafluoroethylene (PTFE) and even resist to abrasion better than PTFE. It has significantly low moisture absorption and a very low COF and high abrasion resistance, being 15 times more resist than carbon steel in some forms (Ali et al, 2016). Besides, UHMWPE was also known as a self-lubricating polymer, which has been studied as a result to reduce wear and friction in dry sliding condition (Aliyu et al., 2018) (Ali et al., 2016). Lightweight, self-lubricating, and low cost are the characteristics of polymer that applicable for use in automotive bearing applications due to their excellent properties contrasted to other modern materials, such as ceramics and metals. UHMWPE in the pure form as well as reinforced with micron and nanofiller composites have shown favourable capability to be utilized in mechanical and tribological applications due to their high strength to weight ratio (Ali et al., 2016).

Significant priorities in both academics and industries have been emphasized due to the excellent properties of UHMWPE such as low COF, good corrosion resistance against steel, high wear resistance for use, high strength, and biocompatibility for use in total joint replacement (Ahmad et al. 2013) (Dangsheng, 2005) (Tai et al., 2012) (Grinev et al., 2018). Thus, they were practiced broadly in industrial bearing and clinical applications (Mohammed, 2018). Apart from being impervious to concentrated acids, alkalis, and other organic solvents, it is particularly impervious to corrosive chemicals except for oxidizing acids. The mechanical and physical properties of UHMWPE can be modified through a manufacturing process because of the material intrinsic properties (Baena et al., 2015).

Presently, direct compression moulding process or ram-extrusion process pursued by machining are the processes that usually used to produce UHMWPE. The atomic weight and viscosity of UHMWPE which extremely high cause complication in fabrication process makes it processes a challenging task (Fang et al., 2006) (Aliyu et al., 2018). The slow diffusion of UHMWPE chains during consolidation is caused to the high viscosity of UHMWPE. The fusion defects existed due to these factors, which possibly created sites for failure under cyclic loading possibly created, thus, resulted in less toughness (Ahmad et al., 2013). Moreover, the low load-bearing capacity of UHMWPE has often limited the practice of pure UHMWPE systems in requirement tribological applications (Mohammed, 2018) (Samad and Sinha, 2011) (Selvam & Marimuthu, 2016). Moreover, (Samad & Sinha 2011) stated in their study, UHMWPE has also got some limitation for high contact sliding speed application due to its poor thermal stability.

To overcome these problems, numerous researchers have utilized to improve the properties of UHMWPE over the past few years using a variety of techniques, including radiation crosslinking, ion implantation, diamond-like carbon (DLC) top coat application, and ceramic, metallic, carbon-based, and mineral fillers' reinforcing with UHMWPE matrix to create a nanocomposite system (Mohammed, 2018) (Chen et al., 2012). Various fillers such as Quartz, kaolin, zirconium particles and carbon nanotubes, carbon fibers, metal oxide particles, and layered silicates have been used to be reinforced in the composites (Tai et al. 2012) (Chen et al., 2012) (Ali et al., 2016). Furthermore, good thermal stability, low shear strength and surface adherence, and excellent solid lubrication attribute of carbon materials, consist of carbon fiber, carbon black, and carbon nanotubes, have been explored as fillers to enhance the tribological performance of UHMWPE (Tai et al. 2012). Therefore, the mechanical and tribological properties of the composites were enhanced when compared with those of pure UHMWPE (Srivastava, 2017).

2.3.1 Tribological Performance of Ultra High Molecular Weight Polyethylene Nanocomposites Reinforced with Graphene Nanoplatelets

Many attempts have been made by adding the reinforcement such as carbonaceous filler to improve the tribological properties of Ultrahigh molecular weight polyethylene (UHMWPE). The wear properties of UHMWPE can be enhanced by reinforced with Graphene Nanoplatelets (GNPs) resulted in an increment of strength and minimized friction along with enhanced thermal conductivity. GNPs is a suitable filler because of its large 2D surface area, excellent mechanical and thermal properties (Jang & Zhamu, 2008) (Lahiri et al., 2012). The achievement of desired properties for the utilization of UHMWPE-graphene composite as a boundary lubricant cannot be achieved due to inefficient processing such as inhomogeneous dispersion and poor composite fabrication (Aliyu et al., 2018). However, it can be avoided by undergoing an ultra-sonification process with correct choice of mixing composition and processing hot pressing with chosen sets of parameters. This purpose of this study is to fabricate GNPs reinforced UHMWPE nanocomposites with different compositions and verify the optimum composition. The UHMWPE nanocomposites of pure matrix, 0.1 wt%, 0.25wt % and 0.5wt% GNPs were prepared and followed by dispersion and phase analysis, differential scanning calorimetry (DSC) test, measure of consolidation, hardness measurement, friction and wear tests, wear rate measurement and imaging using a scanning electron microscope (SEM) were conducted and analysed.

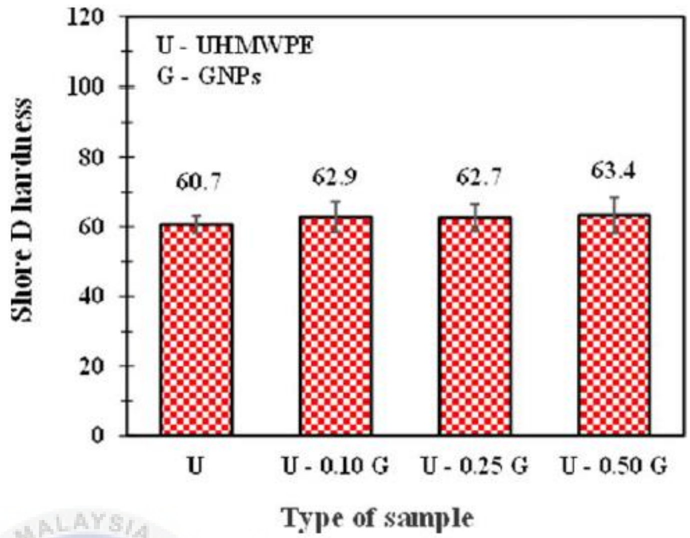


Figure 2.5: Shore D hardness of UHMWPE with 0–0.5 wt% GNPs (Aliyu et al., 2018)

The hardness of the composite increased when GNPs were added as reinforcement, achieves a maximum of 63.38 at 0.5 wt% of GNPs as shown in Figure 2.5. The hardness of the composites increases compared to the pure UHMWPE is attributable to the 2D nature of GNPs that strengthen the interfacial bond between the matrix and the reinforcement results in efficient load transfer mechanism. Good mechanical properties of GNPs also positively affect the properties of the matrix.

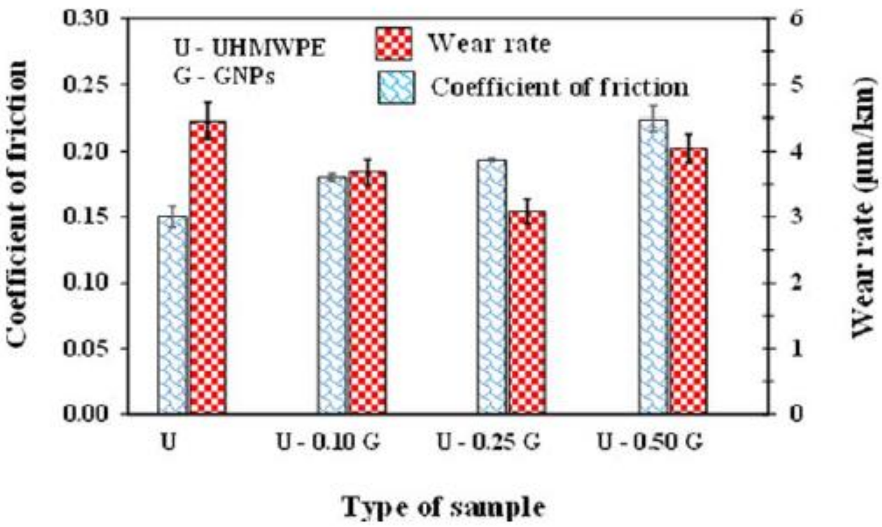


Figure 2.6: COF and wear rate of UHMWPE with 0–0.5 wt% GNPs (Aliyu et al., 2018)

For the tribological properties analysis, four composites were run at 0.1 m/s and 8 MPa as demonstrated in Figure 2.6. The coefficient of friction (COF) of pure UHMWPE is seen to be 0.15. The enhancement of GNPs increased the COF until 0.24. The connection of the UHMWPE chains by GNPs avoiding them from sliding over one another. Meanwhile, the wear rate of the nanocomposites is much lower as contrasted to that of pure UHMWPE. A further increment of GNPs results in the reduction of wear rate because the mechanical strength and thermal conductivity which have been enhanced. However, it is to be observed that composites reinforced of 0.25 wt% GNPs resulted the lower wear rate. This can be occurred due to the agglomeration of unexfoliated GNPs in the matrix of 0.5 wt% GNPs reinforcement cause the wear rate to incline.

Figure 2.7 interpreted a compatible relative degree of wear depth and rate, groove relative depth, volume and the pile-up edge. The 2D profile is to verify the wear rate of the nanocomposites whilst the 3D gives a superior visualization of the wear track in terms of morphology.

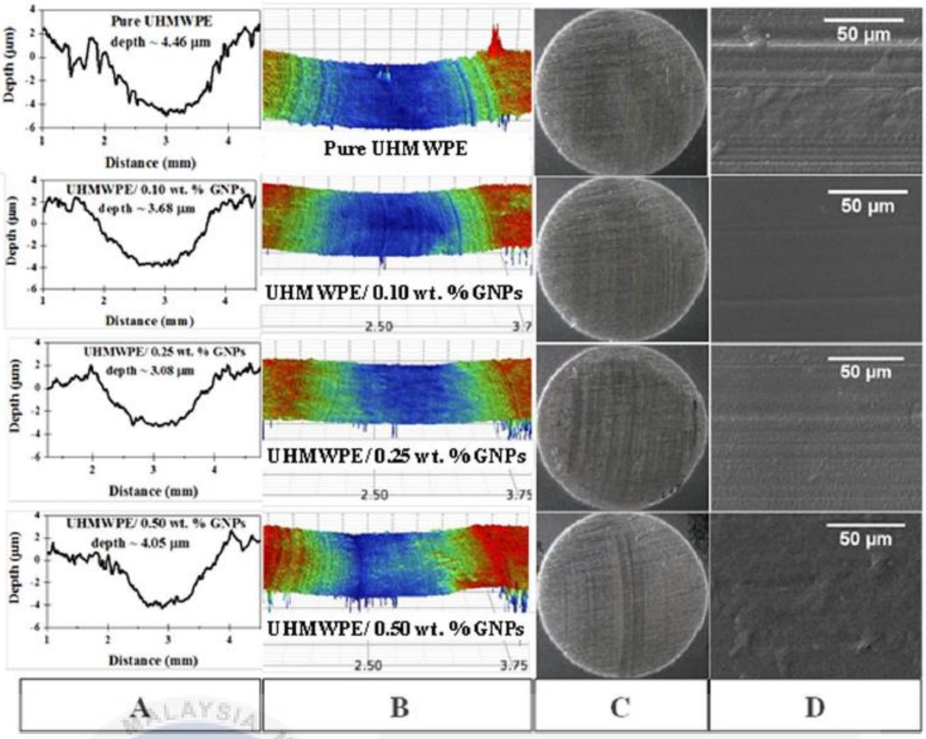


Figure 2.7: Wear tracks (A) 2D and (B) 3D profilometric images, (C) optical microscope image and (D) SEM images of the wear tracks of UHMWPE with 0–0.5 wt% GNPs (Aliyu et al., 2018)

The SEM wear track morphology of all the composites were shown in Figure 2.7 (D). Smoother wear tracks can be seen in the composite strengthen with 0.1 and 0.25 wt% of GNP whilst the pure UHMWPE and UHMWPE strengthen 0.5 wt% GNP wear tracks look rougher in nature.

Conclusively, the reinforcement of GNPs from 0 to 0.5 wt% increased the shore D hardness. The nanocomposites of UHMWPE 0.25 wt% GNPs resulted the optimum wear resistance with a reduction of 31% of wear rate as contrasted to the pure UHMWPE. The increasing of contact pressure from 8 to 20 MPa resulted in the linear increment of the wear rate and decrement of the COF. Hence, the enhancement of reinforcement carbonaceous filler such as graphene nanoplatelets can improve the tribological properties of UHMWPE.

2.3.2 Friction and Wear Properties of UHMWPE Composites Reinforced with Carbon Fibre

The strength, modulus, and creep resistance were outstandingly enhanced after reinforced UHMWPE fibers into a UHMWPE matrix, but the wear resistance of the self-reinforced UHMWPE composites is not enhanced. (Deng & Shalaby, 1997). (Dangsheng, 2005) has conducted tests to investigate the effect of the carbon fibre (CF) content reinforced with UHMWPE composites on the hardness and tribological properties under both dry and distilled water lubrication states. Samples were prepared, friction and wear test were performed, and the data were analysed.

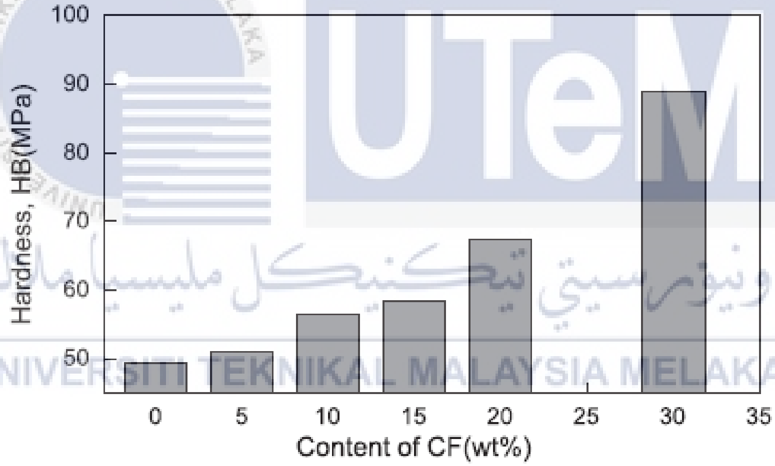


Figure 2.8: Effect of carbon fibre content on UHMWPE hardness (Dangsheng, 2005)

Figure 2.8 displays the effect of CF content on the hardness of the samples. The hardness of the composites increased steadily with the increment of CF content from 0 wt% to 15 wt% CF content, and further quickly above 15 wt% CF.

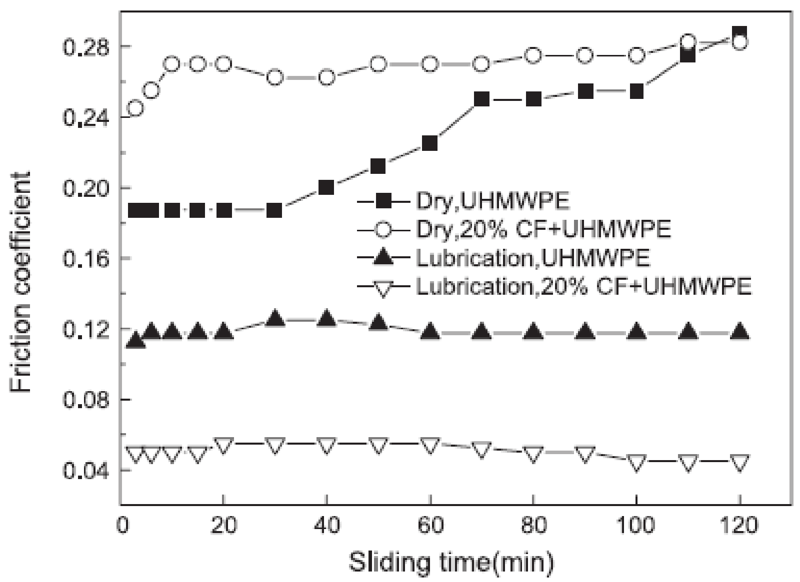


Figure 2.9: Variation of coefficient of friction with sliding distance (Dangsheng, 2005)

The variation of coefficient of the friction (COF) with sliding time is illustrated in Figure 2.9. It is observable that the COF of the UHMWPE reinforced 20 wt% CF was higher but steadier than that of the pure UHMWPE under dry sliding state. Meanwhile, the COF of the UHMWPE reinforced 20 wt% CF was inferior than that of the pure UHMWPE under lubrication state.

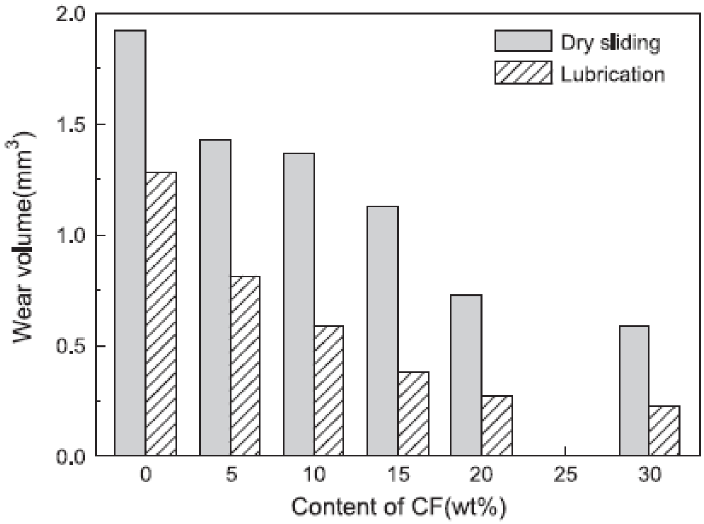


Figure 2.10: Effect of carbon fiber content on wear volume loss under dry and distilled water lubrication states (Dangsheng, 2005)

Figure 2.10 represents the effect of CF content on the wear of samples. The pure UHMWPE has the highest wear volume loss for both dry and distilled water lubrication states. The sample for dry sliding has greater volume loss compared to that sample for lubrication states. The wear volume loss reduced with the increment content of CF and the wear decline rate of samples at CF content was faster from 0% to 20%, but a bit slower from 20% to 30% for both states.

To sum up, the increment of CF content increases the hardness of the UHMWPE reinforced CF composites and reduce the wear volume loss of the composites for both states. The COF of the CF reinforced UHMWPE composites are all higher and steadier than the pure UHMWPE for dry sliding state and much lower than the pure UHMWPE for lubrication state. Carbon fiber is a good filler to be reinforced with UHMWPE in order to improve the mechanical and tribological properties of UHMWPE.

2.4 Palm Kernel Shell

Palm Kernel Shell (PKS) are by-product materials from agricultural sector consist of carbon characteristic, which are not primarily used. PKS is the residual waste obtained from the extraction of the kernel from the nut, during the crude palm oil process (Afolabi et al., 2015). One of the countries in South East Asia, Malaysia is predicted to grow five million hectares of oil palm trees continuously to 2020 since over four million tonnes of PKS already produced per annum (Khankhaje et al., 2017). Although PKS are produced annually in huge quantities, just a small selection is used for fuel and other applications, such as palliative for un-tarred road and activated carbon production (Fono-Tamo, 2014). The poor disposal techniques of unused PKS including open burning and dumping around the processing mill, assisting to environmental issues. (Mat Tahir et al., 2016) mentioned that huge potential for a zero-waste strategy in enhancing of the tribological properties at a reasonable expense can be achieved by implementing carbon materials from agriculture by-product wastes as new reinforcement substitutes in the fabrication of polymer matrix. Hence, sustainable, clean and green development can be achieved with the utilization of by-product waste material.

In the area of composite development, a lot of studies have been conducted by the researchers such as the practice of PKS based material for the brake pad, some on automobile application and many on the suitability of some natural filler reinforced composite material (Samotu et al., 2015). Recent research efforts in the development of non-asbestos brake lining have established that the ground PKS (0.2 to 0.4 mean particle diameter) is suitable as a friction material since the effect of asbestos is harmful (Fono-Tamo & Koya, 2013). In previous research, (Mgbemena et al., 2014) obtained the coefficient of friction of PKS on a metal surface are in the range of 0.37-0.52. With this low range of coefficient of friction and resistance to the hard and variable braking forces, PKS is applicable to be used as base material in friction composites (Fono-Tamo, 2014). Even though the main concern is focused on the physical properties of the PKS, its biodegradability also gave a guarantee to the environmental friendliness when the product wear debris decomposes (Fono-Tamo & Koya, 2013). The physical structure and weight of PKS did not affect by organic solvent, hydraulic fluid spilling on the element or varying ecological conditions. These observations, hence, create an attraction in considering PKS for use as a friction material in industrial brake system (Fono-Tamo, 2014).

Furthermore, in the construction field, (Ndoke, 2006) found that the mechanical strength of structural lightweight concretes increased by the integration of PKS in the production. The shell could be categorized as a lightweight aggregate as past tests conducted demonstrate that the shell has a specific gravity of 1.14 and a loose bulk density of 545 kg/m^3 (Okpala, 1990). PKS is more competent as precursors compared to other oil palm solid residues such as mesocarp fibre and empty fruit bunch because of its porous surface, excellent mechanical strength, good chemical stability, insolubility in water, low density, which implicit reduction in self weight of the material, good thermal insulation and good sound absorption (Rashidi & Yusup, 2017) (Okpala, 1990).

2.4.1 The Effect of Temperature on the Tribological Properties of Palm Kernel Shell Activated Carbon-Epoxy Composite

Recently, many researchers are preferred composite materials, compared to monolithic materials so as to achieve the global requirement for lightweight, high performance, eco-friendly, wear and abrasion resistant material. The composite material attracted the researcher's attention due to their permeability, cost efficiency and different strengthening mechanisms. (Mat Tahir et al., 2015). Graphite and activated carbon such as palm kernel activated carbon have been discovered which can act as self-lubricating material when reinforced with aluminium alloy and it can enhance the wear resistance by rising carbon content up to 10 mass% (Zamri & Shamsul, 2011). This study's purpose is to explore the effect of temperature on the tribological properties of PKAC-E composite. The specimen was prepared, and the pin-on-disc test was performed. Then, the quantitative and qualitative data were analysed.

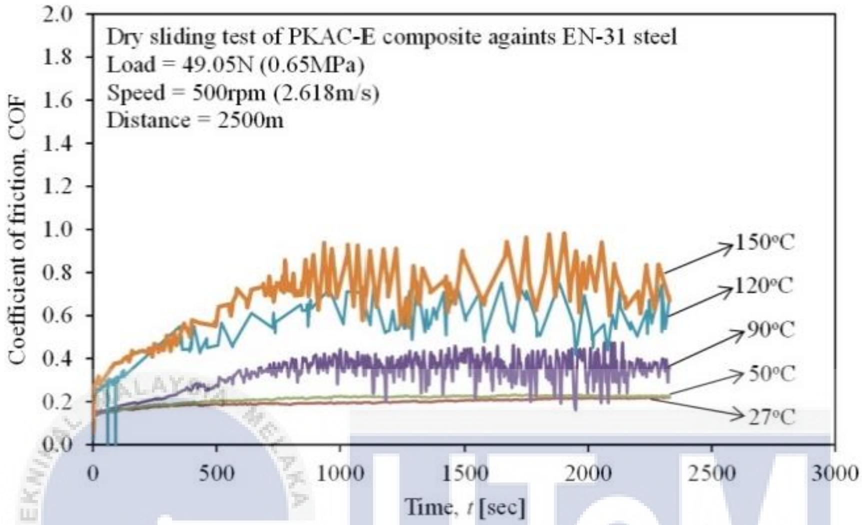


Figure 2.11: COF at different temperature of PKAC-E composite (Mat Tahir et al., 2015)

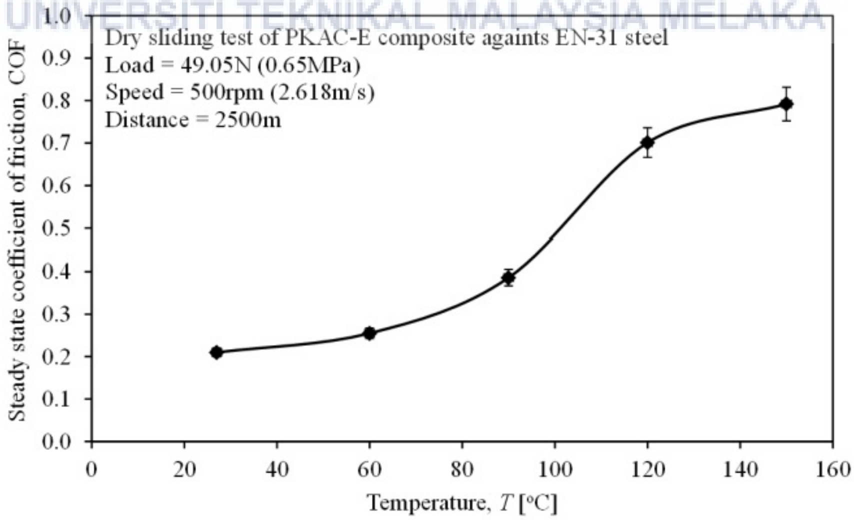


Figure 2.12: Average steady state COF of PKAC-E composite at temperatures (Mat Tahir et al., 2015)

Based on both Figure 2.11 and Figure 2.12, it is clearly illustrated that the COF of PKAC-E elevated quickly with the increasing operating temperature. This may be caused by frictional heating and failure of the epoxy bond. Nevertheless, the COF look to be constant in the range of 0.7 to 0.8 starting at temperature 120 °C due to formation of tribo-film on the counter surface after 120 °C.

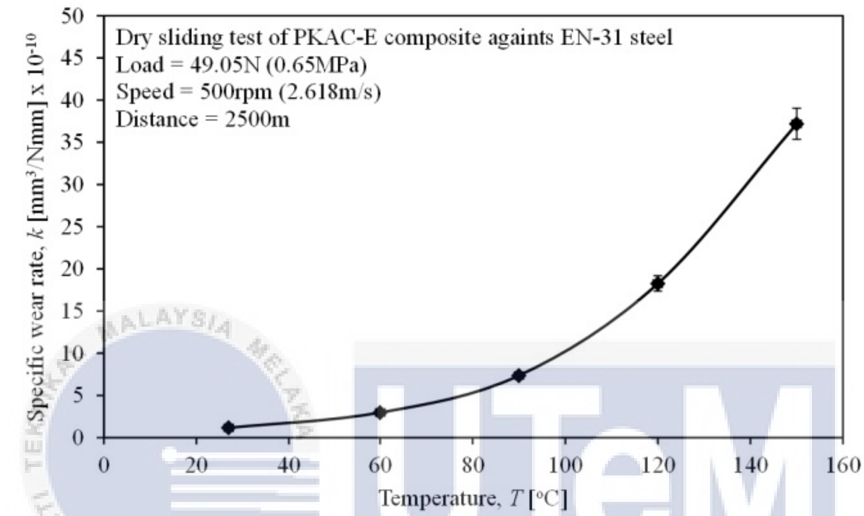


Figure 2.13: Specific wear rate of PKAC-E composite at different temperatures (Mat Tahir et al., 2015)

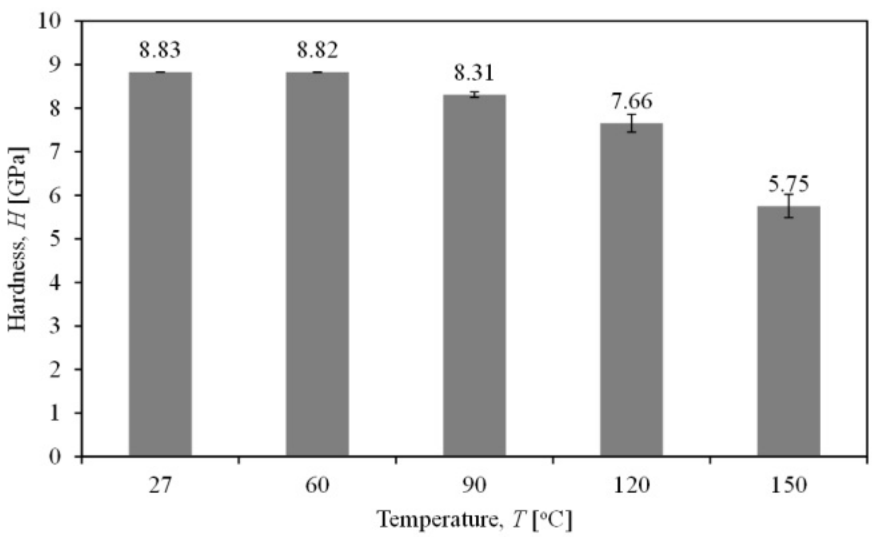


Figure 2.14: Average hardness of PKAC-E composite at different temperatures (Mat Tahir et al., 2015)

The specific wear rate against temperature graph was shown in Figure 2.13. and the hardness of PKAC-E composite at varying temperature was illustrated in Figure 2.14. The wear rate of the composite escalated with the increasing temperature. This is because of the presence of thermal activated process between the PKAC and the epoxy in the composite. This circumstance brought about a material hardness reduction, which could possibly increase wear. From Figure 15, after 90 °C, the average hardness of the composite started to reduce while at 150 °C, the composites lost almost 30% of its original hardness, thus causing the failure of the epoxy element in the composition.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The objective of this study is to investigate the tribological properties of UHMWPE reinforced with PKS in dry sliding condition using pin-on-disc. This chapter will describe the method used in this project to get the desired results. Overall operational flow is to illustrate the order to conduct the experiment as shown in Figure 3.1.

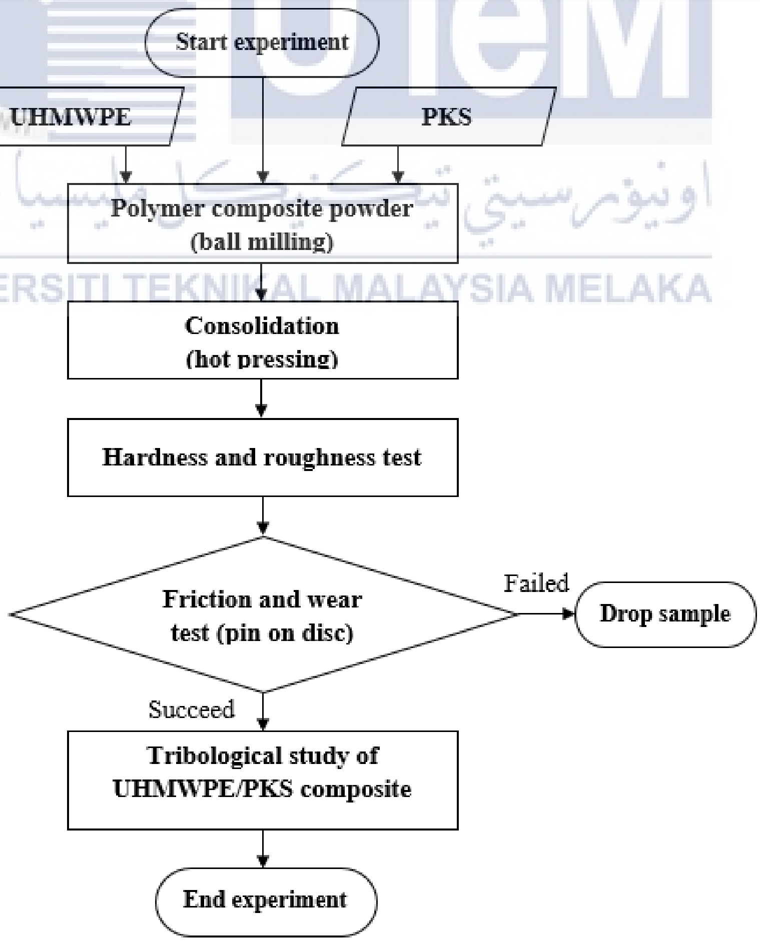


Figure 3.1: Overall flow of the experiment

3.2 Specimen preparation

3.2.1 Materials

The unused PKS was obtained from the Linggi Palm Oil Mill, Negeri Sembilan, in large quantities and without any charge. The UHMWPE was provided from Universiti Teknikal Malaysia Melaka, UTeM.

Figure 3.2: Material used for experiment (a) Palm kernel shell (b) UHMWPE

3.2.2 Preparation of pulverised PKS:

The PKS was first dried in the drying oven under the temperature of 100℃ for about 2 hours. The dried PKS then were crunched in the cutting mill SM200 machine until the pulverised PKS produced. Finally, the pulverised PKS were transferred into the sieving machine for about 10 minutes to filter the pulverised PKS into several fine sizes such as 250, 150, 125 and 63µm. The process had to be done several times to get much powder to be used in producing the composite

Figure 3.3: Cutting mill for crunch process

Figure 3.4: Pulverised PKS

Figure 3.5: Sieving machine

3.2.3 Preparation of UHWMPE-PKS composite:

The UHMWPE in a powder state were mixed with PKS powder in the HDPE bottle with several ball bearings. The function of ball bearing in the bottle was to mix homogenously the powder. Then, the bottle was placed on the ball milling machine and it was running for almost 1 hours with a speed of 10,000 rpm.

Figure 3.6: Ball milling machine

A 74 x 4 mm disc mould size was prepared to compact the composite specimen. Acetone was used to clean the mould disc since it is non-polar organic solvent and wax was applied at the inner surface before the mould contained with UHMWPE-PKS powder. Then, the mixed powder was filled in the mould disc.

Figure 3.7: A 74x4 mm disc mould use for compaction process

The mould was hot-pressed at 200 °C with 2.5 MPa load for approximately 1 minutes of pre-heat and 15 minutes for pressing. The moulded blends (specimen) left to cool at room temperature until the mould temperature decreased to approximately 40°C before the specimen being pressed out from the mould using bearing ‘shop’ press machine.

Figure 3.8: Hot press moulding machine for compaction process

Figure 3.9: Bearing ‘shop’ press machine

3.3 Hardness and surface roughness test

After the hot-pressing process, the hardness of the specimen was measured using Shore Hardness Durometer-D type based on American Society for Testing and Material (ASTM D2240) standard test method for rubber property. D type durometer is suitable for thermoplastic, elastomers and hard rubber. Meanwhile, there is another type of durometer being used commonly in the laboratory which is A-type applicable for soft vulcanized rubber, leathers, and flexible polyacrylics. By applying a force on the standardized presser foot, it will penetrate into the material and the indentation depth is measured by the durometer. Greater numbers on the scale indicate the materials are hard while lower numbers indicate the materials are soft.

Figure 3.10: Durometer for hardness test

The roughness of the specimen also will be tested to find out whether the surface is suitable for the specific purpose. The surface of the specimen will be resurfaced using sandpaper to obtain the required standard for surface roughness according to the ASTM G99 Standard Test Method for Wear Testing with a Pin-on-Disc Apparatus. Then, the roughness tester is used to determine the surface texture or surface roughness of the specimen.

Figure 3.11: Surface roughness tester profilometer

3.4 Friction and wear test

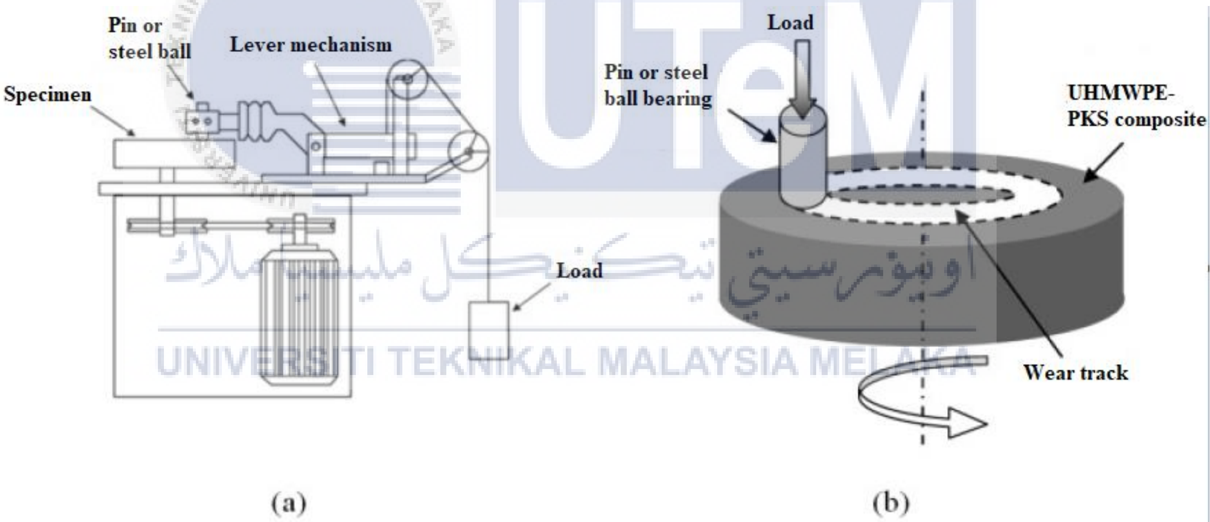


Figure 3.12: (a) Schematic diagram of a pin-on-disc tribometer and (b) illustration of the sliding test (Mat Tahir et al., 2015)

The dry sliding test was conducted following the ASTM G99 Standard Test Method for Wear Testing with a Pin-on-Disc Apparatus. Early phase in testing is to weight the specimen and then the specimen and ball bearing were cleaned with acetone before and after the test to prevent wear debris from entrapping on the specimen surface. The specimen will be securely placed in the sample holder and tightened with the screw perpendicular to the surface of the disc to ensure the contact conditions is not moving during the test. Meanwhile, the steel ball used as the pin was then mounted vertically on the tester arm at one end. The steel ball was positioned at a particular track diameter and for this test, the track diameter used were 20, 30 and 40 mm respectively.

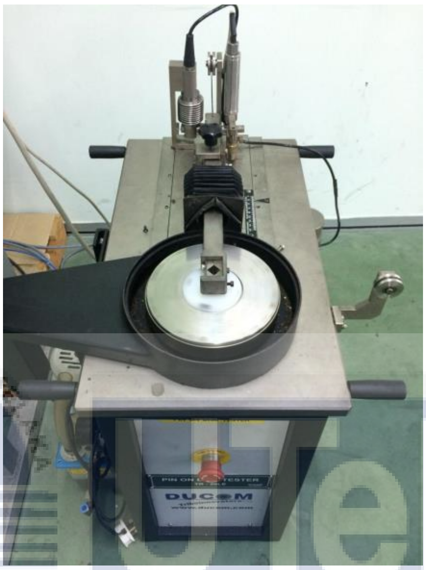


Figure 3.13: Configuration of pin on disc tribometer

All of the tests were performed at a constant sliding speed of 200 rpm, an applied load of 1 kg and constant sliding distance of 1000 m. The parameters for this experiment was shown below in Table 3.1 and the time required for each test was calculated using the equation 3.2;

$$D = 2\pi rNt \quad (3.1)$$

$$t = \frac{D}{2\pi rN} \quad (3.2)$$

Where, t is the time required in minute, D is the sliding distance measured in m, r is radius wear track in m, and N is the sliding speed in rpm.

Table 3.1: Parameter used for pin-on-disc test

Parameters	**Value**
Sliding distance	1000 m
Sliding speed	200 rpm
Applied load	1 kg
Wear track diameter	20 mm, 30 mm and 40 mm

For track diameter = 20 mm, the radius track = 10 mm = 0.010 m;

$$t = \frac{1000}{2\pi(0.010)(200)}$$

$$t = 1\ hr\ 19\ \text{min}\ 34\ sec$$

For track diameter = 30 mm, the radius track = 15 mm = 0.015 m;

$$t = \frac{1000}{2\pi(0.015)(200)}$$

$$t = 53\ min\ 03\ sec$$

For track diameter = 40 mm, the radius track = 20 mm = 0.020 m;

$$t = \frac{1000}{2\pi(0.020)(200)}$$

$$t = 39\ \text{min}\ 47\ sec$$

Table 3.2: Time for each test correspond to wear track diameter

Track diameter, mm	Track radius, m	Time required
20	0.01	1 hr 19 min 34 sec
30	0.015	53 min 03 sec
40	0.02	39 min 47 sec

PC-based data logging system was used to measure the coefficient of friction (COF) and frictional force. There are some important equations to find the COF and wear rate, k. The general equations are equations 3.3, 3.4 and 3.5 as shown below;

$$COF = \frac{F}{W} \tag{3.3}$$

Where *F* is the frictional force in *N*, and *W* is the applied load in *N*.

$$V_{loss} = 2\pi R \times \pi(a^2 + h^2) \tag{3.4}$$

Where V_{loss} is the volume loss in mm^3, *R* is the wear track radius in mm, *a* is the wear scar radius in mm, and *h* is the wear depth in mm

$$k = \frac{V_{loss}}{W \times L} \tag{3.5}$$

Where *k* is the specific wear rate in mm^3/N.mm, *W* is the applied load in *N* and *L* is the sliding distance in mm.

3.5 Wear scar observation

The magnified image of the specimen after done with the wear test is obtained using the 3D non-contact profilometer. It capable to focus on the wear track and produce a 3D profile of the magnified image. For this study, the 3D non-contact profilometer used to obtained wear scar radius and wear depth through 3D profile of wear track.

Figure 3.14: 3D non-contact profilometer

3.6 Surface morphology observation

The morphology of the particles and worn surface were observed and analysed using scanning electron microscopy (SEM) and energy-dispersive X-ray Spectroscopy (EDX). The composition weight percentage of elements can be obtained from this observation.

Figure 3.15: Scanning electron microscopy (SEM)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the results obtained from the experiment which contains the hardness, surface roughness, friction and wear data. Specific calculations are performed to obtain the wear rate of the specimens. All the data will be analysed and if there are failures occurred during the test, the solutions will be explained. This chapter is divided into four sub-section. Section 4.2 operates the experimental data obtained, such as hardness and surface roughness. Section 4.3 focuses on the coefficient of friction analysis and the last sub-section discussed on the wear rate analysis

4.2 Experimental data

4.2.1 Testing parameter

Table 4.1: Testing parameter for pin-on-disc test.

<table>
<tr><th>Specimen</th><th>Load</th><th>Sliding speed</th><th>Wear track diameter</th><th>Distance</th></tr>
<tr><td>Pure UHMWPE</td><td rowspan="4">9.81 N
(1 kg)</td><td rowspan="4">200 RPM</td><td rowspan="4">20 mm
30 mm
40 mm</td><td rowspan="4">1000 m</td></tr>
<tr><td>UHWMPE / 5 wt% PKS</td></tr>
<tr><td>UHMWPE / 10 wt% PKS</td></tr>
<tr><td>UHMWPE / 15 wt% PKS</td></tr>
</table>

4.2.2 Hardness and surface roughness of specimens

The Shore D hardness test and roughness test were conducted, and the data obtained were tabulated as shown in Figure 4.1 and Figure 4.2.

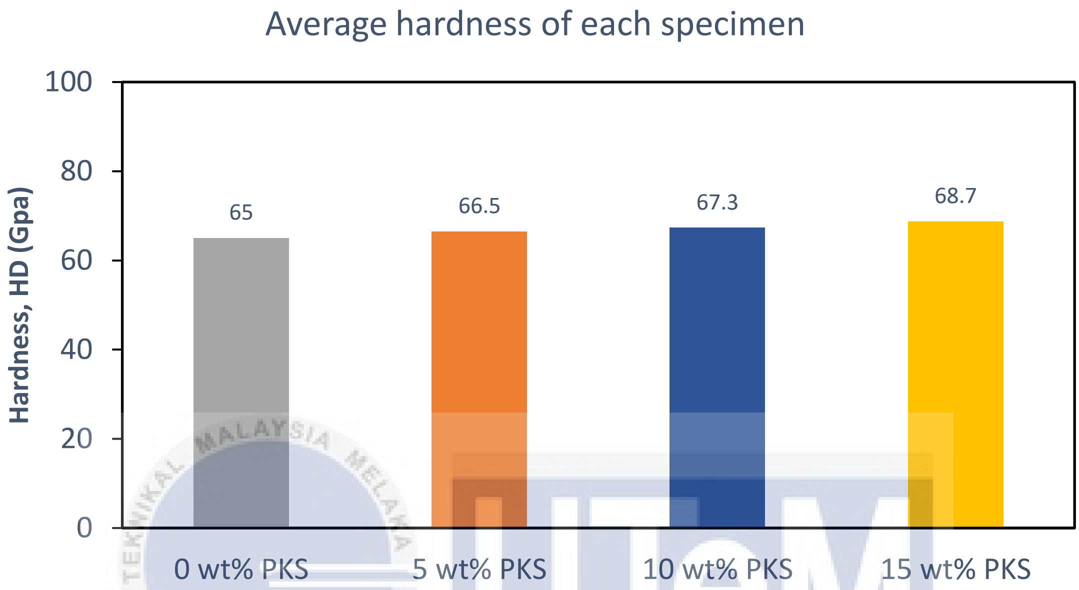


Figure 4.1: Average hardness for each specimen

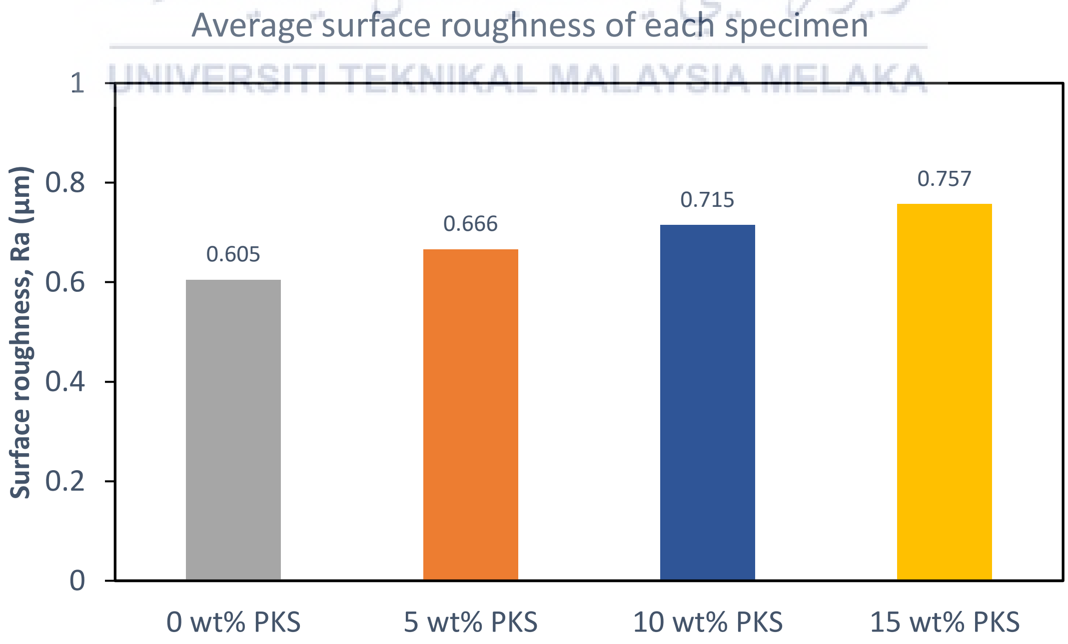


Figure4.2: Average surface roughness for each specimen

4.3 Coefficient of friction analysis

4.3.1 Coefficient of friction (COF) of each specimen.

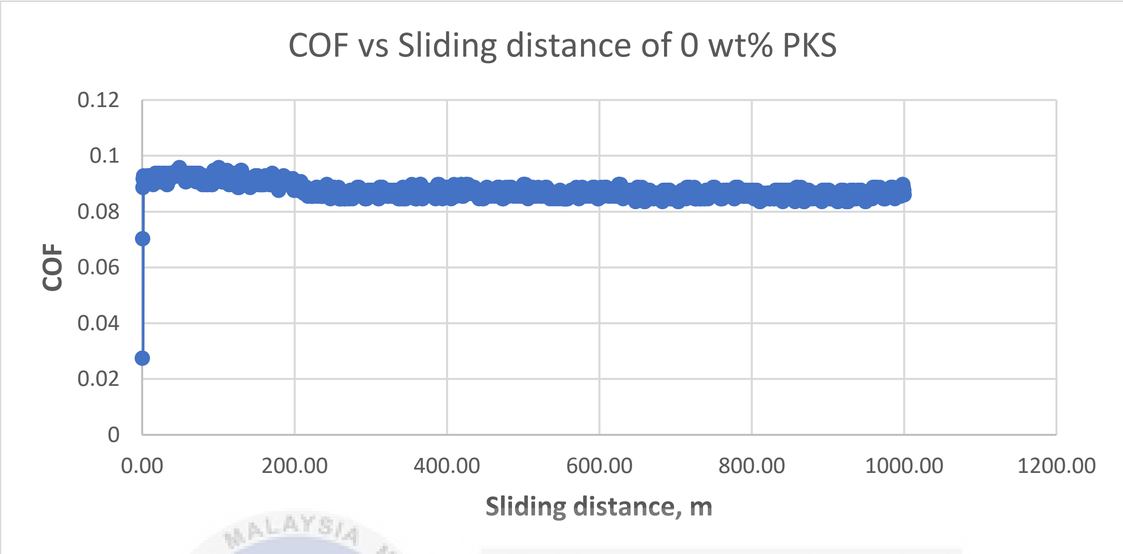


Figure 4.3: The effect of 0 wt% PKS content on COF of UHMWPE composite against stainless steel ball

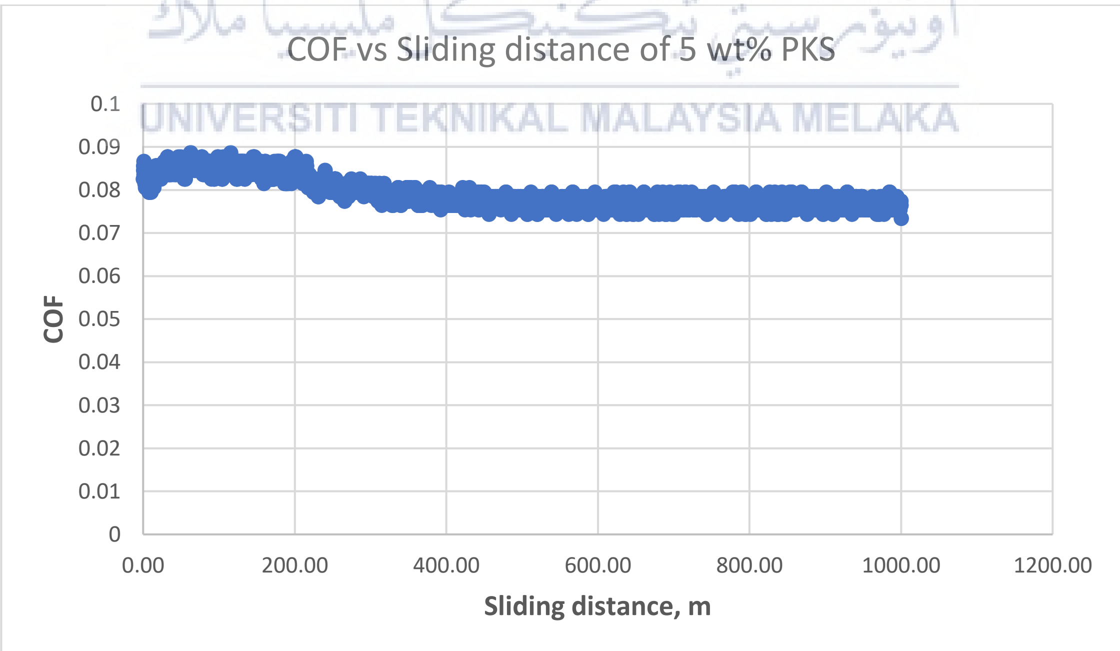


Figure 4.2: The effect of 5 wt% PKS content on COF of UHMWPE composite against stainless steel ball.

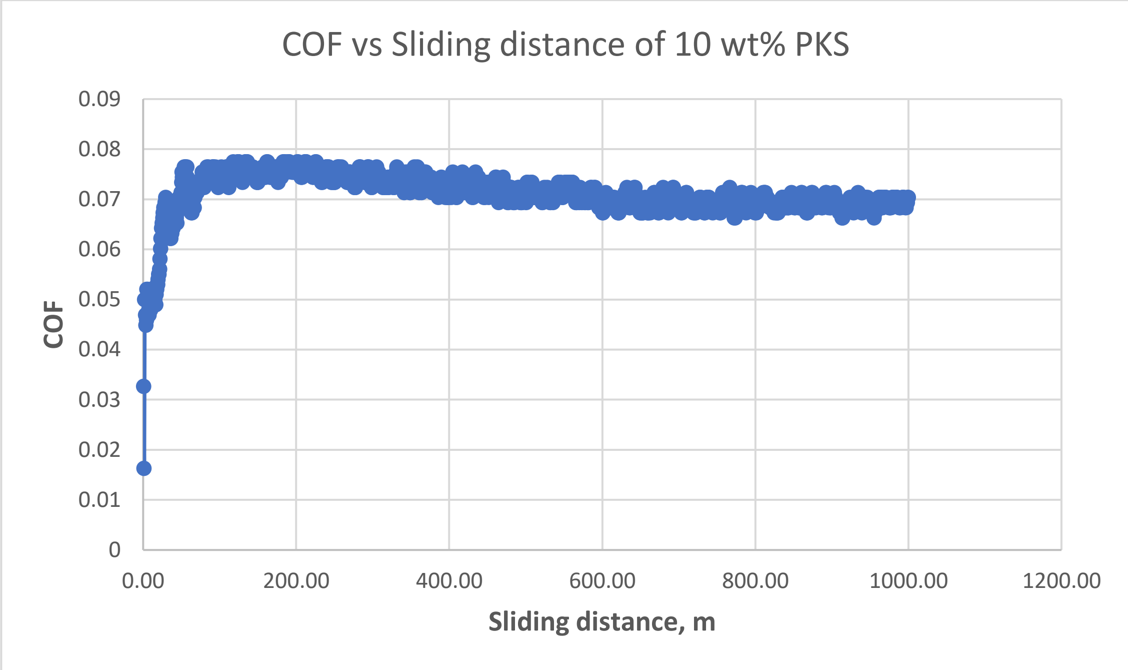


Figure 4.5: The effect of 10 wt% PKS content on COF of UHMWPE composite against stainless steel ball

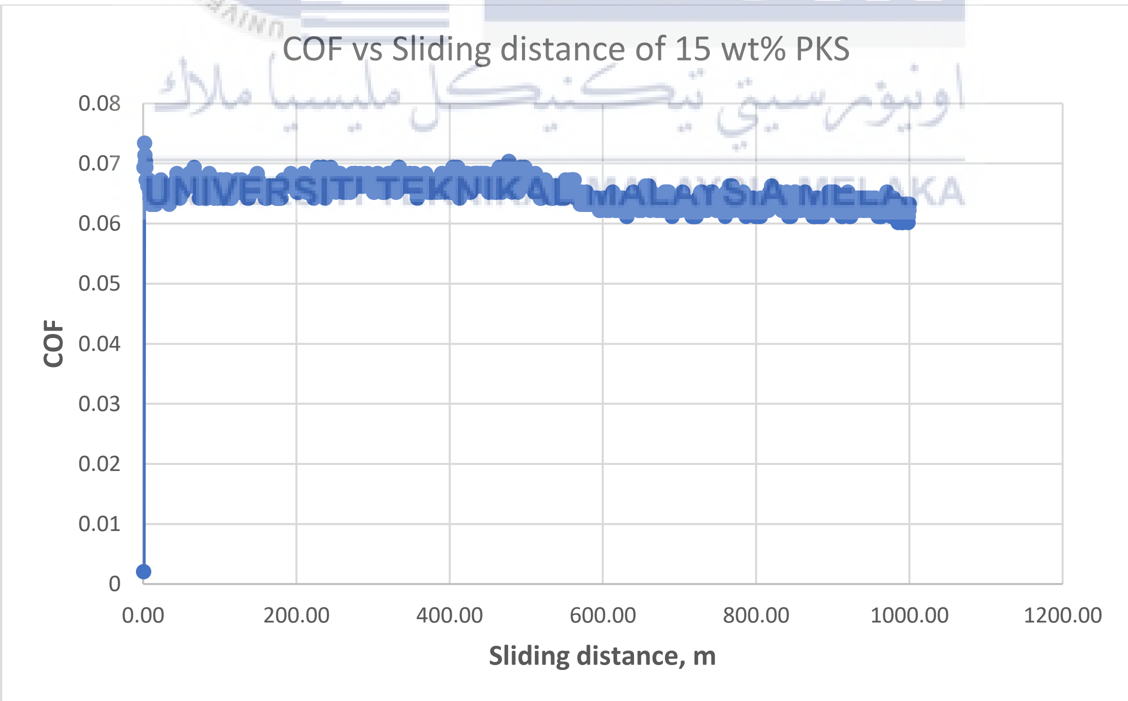


Figure 4.6: The effect of 15 wt% PKS content on COF of UHMWPE composite against stainless steel ball

4.3.2 Comparison of COF over sliding distance

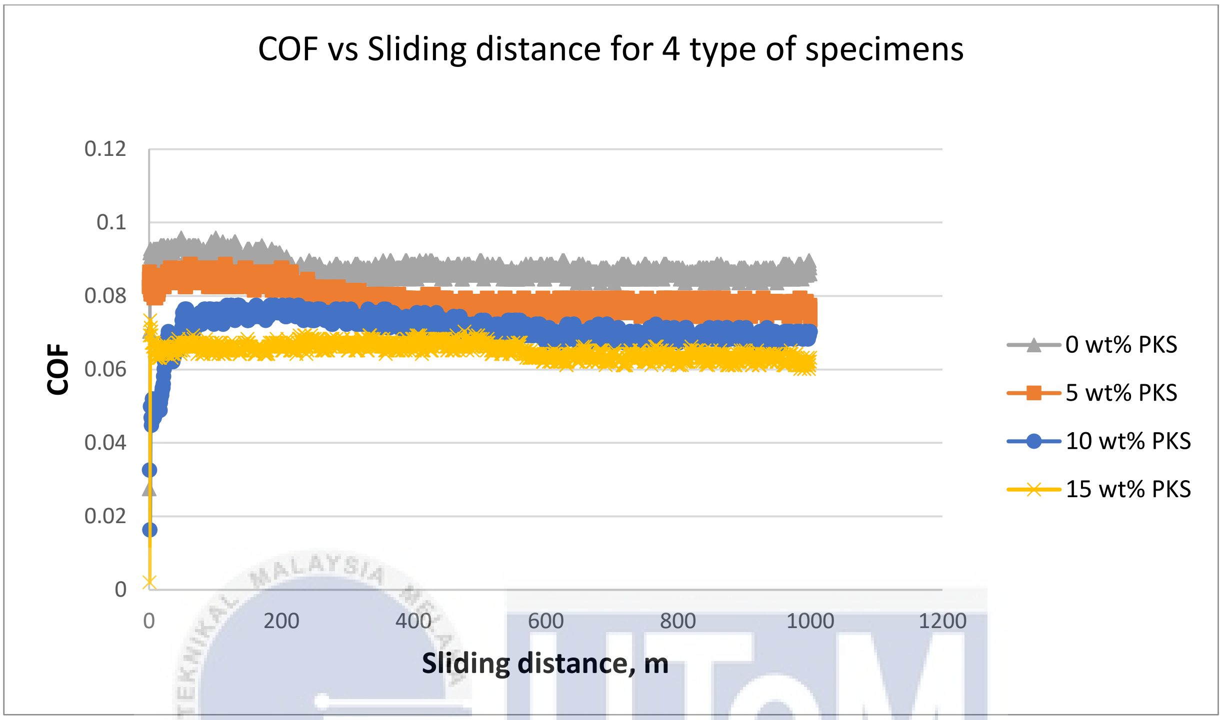


Figure 4.7: Variation of COF of UHMWPE composites with different content of PKS

The COF of the composite UHMWPE and PKS obtained from the experiment can be seen as shown in the Figure 4.5. The COF of the specimens show a decline trend which is decreased as the content of PKS increase. The UHMWPE reinforced 0 wt% PKS has the highest COF and the COF is reduced as the percentage content of PKS increased. The specimen with the highest percentage content of PKS, which is 15 wt% PKS has the lowest COF.

4.3.3 Comparison of average COF

The average COF of all the specimens are taken upon reaching steady state, 600m. The average COF of specimen 0 wt% PKS is 0.086 as shown in Figure 4.6. Then, it is followed by a 10.9% reduction of average COF of specimen 5 wt% PKS resulted in 0.077 of COF. Specimen 10 wt% PKS also experienced a reduction of average COF with 19.7%, recorded 0.069 of average COF. Lastly, the most specimen that affected by the reduction is specimen 15 wt% PKS which reduced by 26.8% and recorded 0.063 of the average COF.

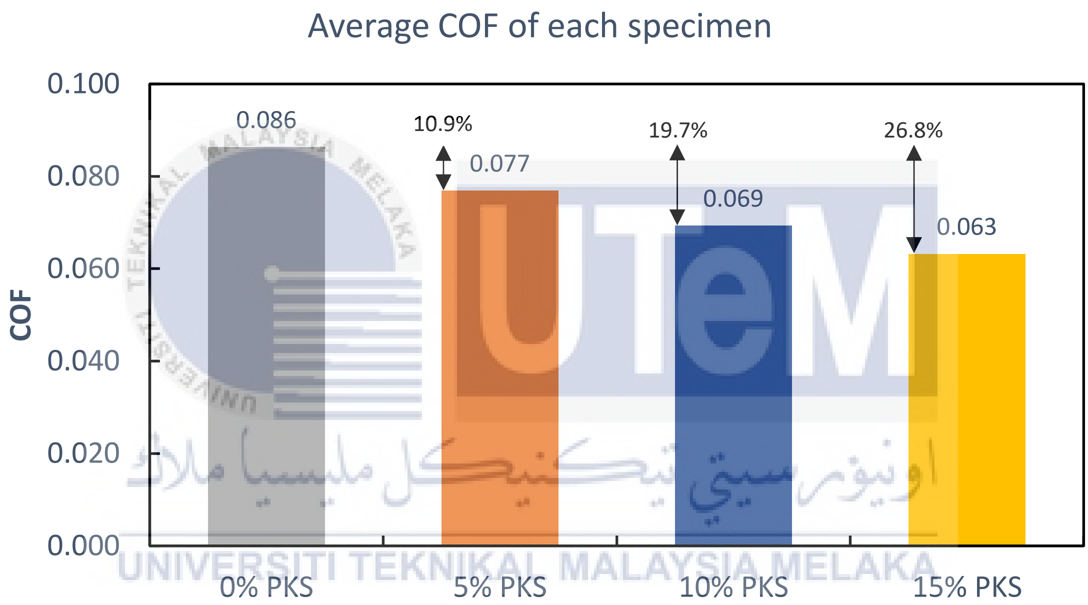
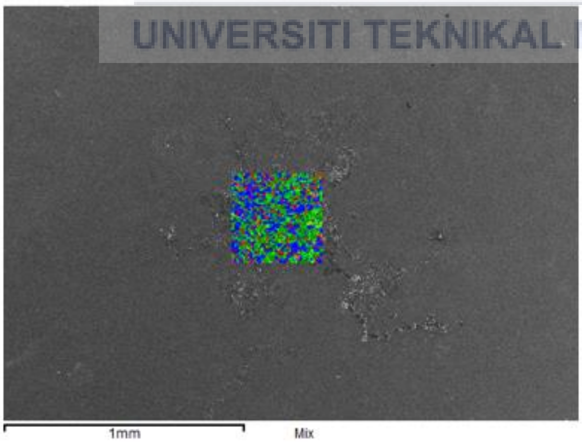


Figure 4.8: Variation of average COF of UHMWPE composite with different content of PKS

4.3.4 Discussion on coefficient of friction

From the results acquired, the COF is higher at the initial stage of testing. However, after a certain time, the COF starts to drop and approaching steady state. The average value of COF is described from the time where the graph is becoming stable, which means it have achieved the steady state. The graph plotted illustrate a decline trend where the COF is reduced as the percentage content of PKS is enhanced. The decrease in COF that is observed in the composites under the increased percentage content of PKS is due to surface softening arising from frictional heating (Dangsheng, 2005). As the percentage content PKS increasing, it is believed that the tribofilm is formed on the counter surface due to the formation of transfer film of carbon element on the counter surface and leads to the reduction of friction. (Mat Tahir et al., 2016). The carbon-based tribofilm is present due to the transferred carbon element of PKS from the composites to the counter surface of stainless-steel ball due to the wear of soft carbon material.



Element	Weight%	Atomic%
C K	7.46	20.13
O K	18.09	36.65
Fe L	74.46	43.22
Totals	100.00	

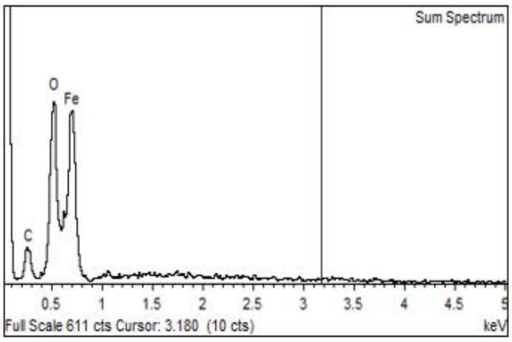
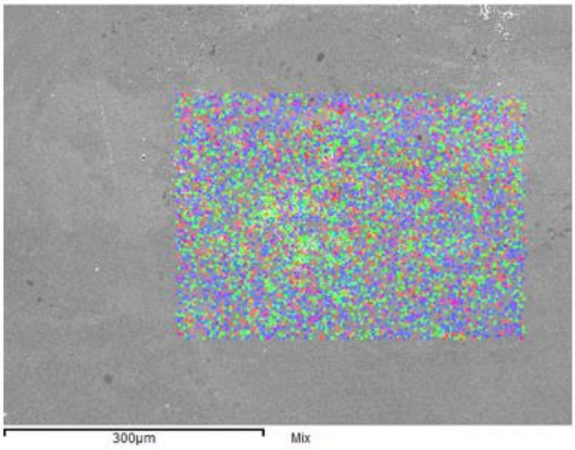


Figure 4.9: SEM micrograph and EDX spectrum of UHMWPE reinforced 5 wt% PKS

Element	Weight%	Atomic%
C K	10.12	25.54
O K	16.96	20.33
Fe L	72.92	40.77
Totals	100.00	



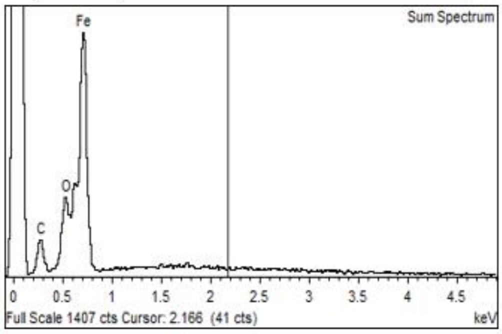
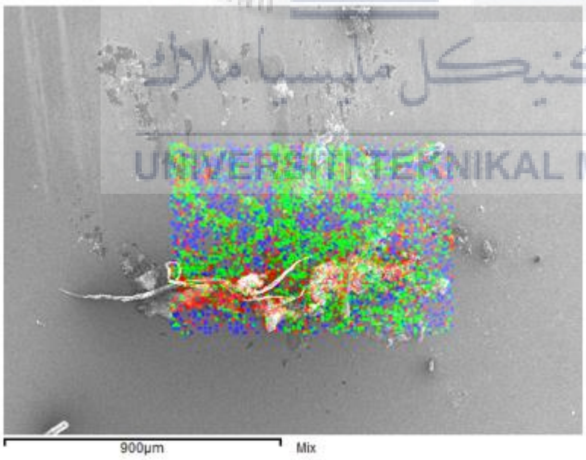


Figure 4.10: SEM micrograph and EDX spectrum of UHMWPE reinforced 10 wt% PKS

Element	Weight%	Atomic%
C K	14.48	35.22
O K	15.38	28.08
Fe L	70.14	36.69
Totals	100.00	



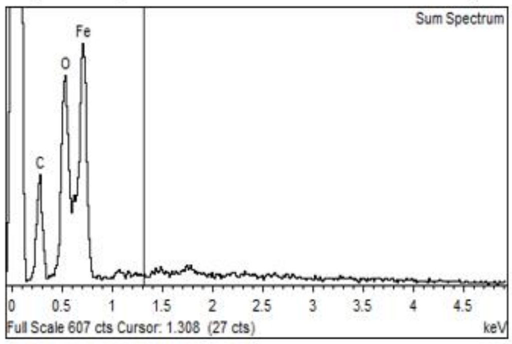


Figure 4.11: SEM micrograph and EDX spectrum of UHMWPE reinforced 15 wt% PKS

The SEM micrograph and EDX spectrum showing that the transfer film of the carbon element is generated at the counter surfaces of stainless-steel ball shown as in Figure 4.9, 4.10, 4.11. The composite of UHMWPE reinforced 5 wt% PKS has lowest weight percentage of carbon which is 7.46 weight%. Meanwhile, the composites of UHMWPE reinforced 10 wt% PKS resulted in higher weight percentage carbon of 10.12 weight% that can be found on the counter surface. The highest percentage content PKS reinforced in UHMWPE composites which is 15 wt% PKS has the highest weight% of carbon which is 14.48 weight%.

The increment of weight percentage of carbon element is attributed to the addition of the percentage content of PKS in the UHMWPE composites. This explained to the more carbon element in PKS composition is transferred to the counter surface, generated a carbon-based tribofilm. With the higher weight percentage of carbon transferred, the tribofilm formation is more reliable in order to reduce the friction between the two surfaces. The carbon-based tribofilm at the counter surface breaks the adhesive joints between the asperities and leads to lower the friction (Mat Tahir et al., 2016). In short, PKS consists of carbon element that can function effectively in reducing COF. These findings are tallied with the study carried out by (Tai et al., 2012).

4.4 Wear analysis

4.4.1 Calculation of specific wear rate

The specific wear rate is obtained by using these equations and the data is illustrated as in the graph.

$$V_{loss} = 2\pi R \times \pi(a^2 + h^2)$$

Where; V_{loss} = volume loss, mm^3

R = wear track radius, mm

a = wear scar radius, mm

h = wear depth, mm

$$k = \frac{V_{loss}}{W \times L}$$

Where; k = specific wear rate, mm^3/N.mm

W = applied load, N

L = sliding distance, mm

Specimen of pure UHMWPE

$$V_{loss} = 2\pi(20) \times \pi(0.3937^2 + 0.00383^2)$$

$$= 61.1972\ mm^3$$

$$k = \frac{61.1972}{(9.81)(1\times10^6)}$$

$$= 6.24 \times 10^{-6}\ mm^3/N.mm$$

Specimen of 5 wt% PKS

$$V_{loss} = 2\pi(20) \times \pi(0.3806^2 + 0.00323^2)$$

$$= 57.1911\ mm^3$$

$$k = \frac{57.1911}{(9.81)(1\times10^6)}$$

$$= 5.83 \times 10^{-6}\ mm^3/N.mm$$

Specimen of 10 wt% PKS

$$V_{loss} = 2\pi(20) \times \pi(0.3662^2 + 0.00263^2)$$

$$= 52.9443\ mm^3$$

$$k = \frac{52.9443}{(9.81)(1\times10^6)}$$

$$= 5.40 \times 10^{-6}\ mm^3/N.mm$$

Specimen of 15 wt% PKS

$$V_{loss} = 2\pi(20) \times \pi(0.3571^2 + 0.0023^2)$$

$$= 50.3451\ mm^3$$

$$k = \frac{50.3451}{(9.81)(1\times10^6)}$$

$$= 5.13 \times 10^{-6}\ mm^3/N.mm$$

4.4.2 Specific wear rate for 4 types of specimens

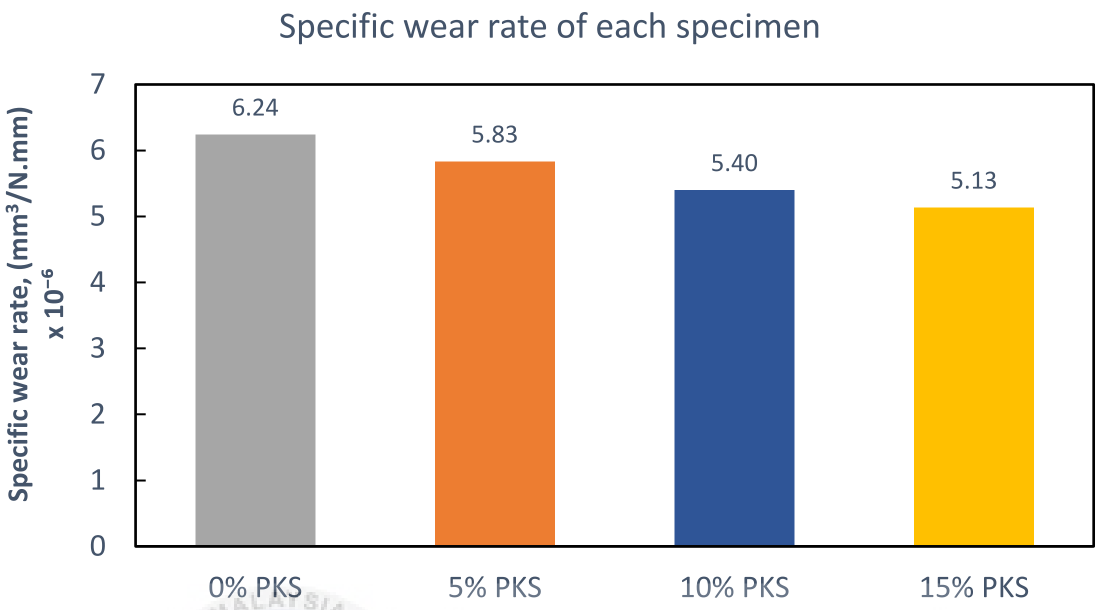


Figure 4.12: Variation of specific wear rate of UHMWPE composites with different content of PKS

The specific wear rate of UHMWPE composite with different content of PKS can be seen as illustrated in Figure 4.7. The specific wear of the composites showed a declined trend which is as the percentage content of PKS increased, the composites experienced the reduction of specific wear rate. The specimen of pure UHMWPE with 0 wt% PKS has the highest specific wear rate of 6.24 x 10^{-6} mm^3/N.mm. Then, as the percentage content of PKS increased to 5 wt%, the specific wear rate decline to 5.83 x 10^{-6} mm^3/N.mm followed by 5.40 x 10^{-6} mm^3/N.mm specific wear rate of specimen with 10 wt% PKS. Lastly, the highest percentage content of 15 wt% PKS resulted the lowest specific wear rate of 5.13 x 10^{-6} mm^3/N.mm.

4.4.3 Discussion on specific wear rate

As for the specific wear rate obtained from the tests, it resulted in the same decline trend where the pure UHMWPE has the highest specific wear rate and as the percentage content of PKS enhanced, the specific wear rate is reduced. The specific wear rate of the composite is slightly reduced compared to the pure UHMWPE correlate with the hardness of the composite which slightly increased when reinforced with PKS.

In this test, the composites are machined to be disc specimen and stainless-steel ball as the pin. The hardness of stainless-steel ball is much higher than the disc specimen thus the wear is dominated by the disc specimen (So, 1996). But still, the increment of PKS content led to an increase in the hardness of the composites compared to pure UHMWPE. It should be recalled that PKS has good thermal insulation and high impact strength. (Ndoke, 2006). As a result of PKS addition, the mechanical strength and thermal properties were enhanced which result in the reduction of specific wear rate (Aliyu et al., 2018)

The increase in hardness of the composites is attributed to the uniform dispersion of PKS in UHMWPE. The reduction of specific wear rate of the composites indicates the ability of carbon element in PKS to enhance the wear resistance of the polymer matrix of UHMWPE. It is functioning the same as nano-filler which can improve the wear resistance (Tai et al., 2012). Briefly, the increment of percentage content of PKS in the UHMWPE composites have increased the hardness and correspond to the reduction of specific wear rate. These findings are tallied with the previous researches done by (Aliyu et al., 2018) (Tai et al., 2012) (Mohammed., 2012) (Dangsheng, 2005).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results obtained from this study, the author can validate that the tribological properties of UHMWPE can be enhanced with the reinforcement of PKS in dry sliding state. The COF of UHMWPE composites is reduced with the increment of percentage content of PKS. Comparing wear rate, it follows the same trend. Between 4 composites that are used, the composites UHMWPE reinforced 15 wt% PKS have the lowest both COF and wear rate while vice versa for pure UHMWPE.

By conducting the analysis using the SEM and EDX, it was found that the counter surface that has been used in testing the composite UHMWPE reinforced 15 wt% PKS has the highest weight percentage of carbon element which mean high amount of carbon is transferred to the counter while forming the tribofilm which act to reduce the COF. Meanwhile, the hardness influenced the wear rate where the harden the composites with the reinforcement of PKS, the lower the wear rate.

It can be concluded that the PKS is suitable to be reinforced with the UHMWPE under dry sliding state in order to obtain a better tribological performance. Furthermore, a zero-waste strategy can be achieved by implementing the waste material as a new reinforcement to produce matrix composite.

5.2 Recommendations for future studies

The COF and wear rate obtained from this study shows variation between the different composites. However, this study only emphasizes on certain testing parameter and material composition. Palm kernel shell (PKS) is the material used to be reinforced with the UHMWPE to produce a new matrix composite. PKS is the by-product that obtained from the palm oil fruit which resulted a slightly better tribological performance to be a filler or reinforcement in self-lubricating material, mainly UHMWPE. Meanwhile, palm kernel activated carbon (PKAC) is the material derive from the raw PKS, which has been treated by specific method. It also can act as a self-lubricating material under dry condition.

To have a better performance in tribological properties of UHMWPE, the author recommends material PKAC as a new reinforcement for the future study. The PKAC will enhance the tribological performance of UHMWPE since it is proven from the past study where PKAC as main material reinforced with other material can improve the tribological performance. Besides, this study only focuses on the effect of the composition of reinforcement on the tribological performance. The other characteristics such as the effect of load applied, sliding distance and temperature should be consider for detail study in order to provide the benefits to various fields and industry.

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APPENDICES

Appendix A1: Project Gantt chart for PSM 1

No.	Topic	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Working time for PSM 1														
2	Topic selection														
3	Topic confirmation														
4	Literature review of Tribology														
5	Literature review of UHMWPE														
6	Literature review of PKS														
7	Material selection														
8	Acquire the material														
9	Methodology														

Appendix A2: Project Gantt chart for PSM 2

No.	Topic	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Working time for PSM 2														
2	Fabrication of composite														
3	Wear and friction test														
4	Data analysis														
5	Report writing														
6	Submission of report														

Appendix B1: Wear track of the composites

Specimen	Image
UHMWPE / 0 wt% PKS	
UHWMPE / 5 wt% PKS	
UHMWPE / 10 wt% PKS	
UHMWPE / 15 wt% PKS