SLIDING FRICTION PERFORMANCE OF DRY AND OIL IMPREGNATED PALM KERNEL ACTIVATED CARBON POLYMERIC COMPOSITE

HALIZA BINTI HASAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SLIDING FRICTION PERFORMANCE OF DRY AND OIL IMPREGNATED PALM KERNEL ACTIVATED CARBON POLYMERIC COMPOSITE

HALIZA BINTI HASAN

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

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this project report entitled “Sliding Friction Performance of Dry and Oil Impregnated Palm Kernel Activated Carbon Polymeric Composite” 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 of Mechanical Engineering.

Signature :..................................

Name of Supervisor :..................................

Date :..................................

DEDICATION

To my beloved parents, family and friends

ABSTRACT

Management of organic waste is one of the main problem in this era. A lots of study had been done to reuse the organic waste in order to reduce the cost to dispose the waste. At the piston ring also have a high energy losses due to the friction which is 20% of losses. This thesis is about the coefficient of friction performance of palm kernel activated carbon polymeric composite during dry and oil impregnated condition. The composite will have 3 different composite that will undergo three different sets of test. The composites will be test at original state, impregnated into oil which is mineral oil, semi-synthetic oil and fully synthetic oil for a day, and then the composite will be leave inside the box for a day without further impregnation. This test to see any changing of coefficient of the composite if the composite undergo three different condition. The ball-on-disc tribometer test will be used in this study. Basically, the composite were formed into disc shaped using hot compaction technique. When the composite were ready, basic mechanical test were done. Then the composite were tested through ball-on-disc tribometer. The results show that the coefficient of friction of mineral oil and semi-synthetic oil one day without further soaking composite gives the lowest value. This behaviour shows that the effect of coefficient of friction is also depend on the viscosity of lubricants and any others. In addition, the effect of impregnation time are not really significant in friction. The lubricant quickly fully absorb when the composite impregnated for a long time. In conclusion, the result of coefficient of friction of PKAC-E composite that one day left without further soaking gives the lowest result which is between 0.115 to 0.118.

ABSTRAK

Pengurusan sisa organik adalah salah satu masalah utama dalam era ini. Banyak kajian telah dilakukan untuk menggunakan semula sisa organik untuk mengurangkan kos untuk membuang sampah. Di cincin omboh juga terdapat kerugian tenaga yang tinggi akibat geseran yang 20% kerugian. Tesis ini adalah tentang pekali prestasi geseran polimer karbon polimer diaktifkan kernel sawit semasa keadaan kering dan minyak. Komposit akan mempunyai tiga komposit yang berbeza yang akan menjalani tiga ujian yang berlainan. Komposit-komposit akan diuji pada keadaan asal, dirombinasikan ke dalam minyak iaitu minyak mineral, minyak semi-sintetik dan minyak sintetik sepenuhnya selama satu hari, dan kemudian komposit itu akan meninggalkan di dalam kotak selama satu hari tanpa penomboran lanjut. Ujian ini untuk melihat apa-apa perubahan koefisien komposit jika komposit itu menjalani tiga keadaan yang berbeza. Ujian tribometer akan digunakan dalam kajian ini. Pada asasnya, komposit itu terbentuk ke dalam cakera berbentuk menggunakan teknik pemadatan panas. Apabila komposit telah siap, ujian mekanikal asas telah dilakukan. Kemudian komposit itu diuji melalui tribometer. Keputusan menunjukkan bahawa pekali geseran minyak mineral dan minyak semi-sintetik pada suatu hari tanpa komposit rendaman terus memberikan nilai terendah. Tingkah laku ini menunjukkan bahawa kesan pekali geseran juga bergantung kepada kelikatan pelincir dan mana-mana yang lain. Di samping itu, kesan masa impregnasi tidak begitu penting dalam geseran. Pelincir dengan cepat menyerap sepenuhnya apabila komposit itu diresapi untuk masa yang lama. Kesimpulannya, hasil koefisien geseran komposit PKAC-E yang satu hari ditinggalkan tanpa perendaman lanjut memberikan hasil yang paling rendah antara 0.115 hingga 0.118.

ACKNOWLEDGEMENT

I am grateful and would like to express my sincere gratitude to my supervisor Associate Professor Dr Mohd Fadzli Bin Abdollah for his invaluable guidance, continuous encouragement and constant support in making this research possible. I really appreciate his guidance from the initial to the final level that enabled me to develop an understanding of this research thoroughly. Without his advice and assistance it would be a lot tougher to completion. I also sincerely thanks for the time spent proofreading and correcting my mistakes.

My sincere thanks go to all lecturers and members of the staff of the Fakulti Kejuruteraan Mekanikal, UTeM, who helped me in many ways and made my education journey at UTeM pleasant and unforgettable. Many thanks go to my classmates for their excellent co-operation, inspirations and supports during this study. This three year experience with all you guys will be remembered as important memory for me to face the new chapter of life as an engineer.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I am really thankful for their sacrifice, patience, and understanding that were inevitable to make this work possible. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams.

Lastly I would like to thanks any person which contributes to my final year project directly or indirectly. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

FRP	Fiber Reinforced Polymer
PKAC	Palm Kernel Activated Carbon
MMC	Metal Matrix Composites
CMC	Ceramic Matrix Composites
PMC	Polymer Matrix Composites
PRP	Particle Polymer Reinforced
IUPAC	International Union of Pure and Applied Chemistry
COF	Coefficient of Friction
PRC	Particulate Reinforced Composite
SAE	Society of Automotive Engineers

LIST OF SYMBOL

wt%	=	Weight Percentage of Fiber Composition
COF	=	Coefficient of Friction
W	=	Weight
F	=	Frictional Force

CHAPTER 1

INTRODUCTION

1.1 Background

A lot of studies about the solid lubricant had been done for the tribological application purpose (Donnet & Erdemir, 2004). Due to the global demand for light weight, simpler process, environment sustainability, high performance, eco-friendly and cost, a lot of research had been done for the composite material (Chin & Yousif, 2009; Friedrich et al., 2018; Tahir et al., 2018). Natural resources are easy to get such as palm kernel and palm wood and the price also not expensive, it will be reducing the cost and lead to zero waste. That is why natural resources reinforced composite had been studied.

Natural resources have potential for self-lubricating. Not only that, it shows that natural resources have low density, higher stiffness and high wear resistance. Besides, it is renewable and sustainable (Gomes et al., 2001). Fibre-reinforced polymer (FRP) composite is used in the mechanical component such as gears, cams and seals. These components are used in aerospace and automotive application. These components are safe to be use because it is not harmful and will not cause pollution. There are two types of composite which is dry and wet condition. Composite that soak into oil can produce longer durability compared to the dry condition (Akpan et al, 2018). This is because more absorption of the composite the due to the pore content in the composite. The highest amount of pore the higher the absorption and the durability will higher.

1.2 Problem Statement

Management of solid waste is one of the biggest problems in this era. Since the population keep increasing year by year, waste product also keeps increasing. Waste product need to be disposed according to the law that state by the country, but this also gives a big problem because some of the waste need to be pays in order to dispose it. This causes a lot of open burning. A research shows that the organic waste gives the highest percentage of waste product which is 48.26% to be dispose (Pokhrel & Viraraghavan, 2005). In order to reduce the waste product, a few researches had been done to replace the ceramic and metal-based and metal material to the natural resources. This is because it will reduce the organic waste and also it is renewable and sustainable (Chin & Yousif, 2009; Friedrich., 2018)

There are two types of natural resources which are renewable such as tree and non-renewable are fuels and petroleum. Carbon is one of the products from the natural resources. Tree also can be transforms into carbon after undergoing certain processes. Carbons are used for filtration and purification. Palm kernel also changed into carbon which is PKAC for the same purpose. In order to enlarge the usage of the PKAC, a few researches had been done regarding to the PKAC. The effect of operating conditions on tribological had been researched before. However, for the palm kernel activated carbon, not so many researches had been done and there is not research about the palm kernel activated carbon impregnated to the car engine oil.

1.3 Objective

The objective in this project is to determine the friction performance of dry and oil impregnated palm kernel activated carbon.

1.4 Scope of Project

In this study, the materials that going to be use are PKAC, PKAC as reinforcement, 206 Hardener and West System 105 Resin as Epoxy. The test will use load at 49.05 N (5 kg), speed at 500 rpm, temperature at 27°C and time at 30 minutes. The material will transform into disc and the disc will be test under ball bearing SKD-11 using ASTM G99-95a. The disc will be soaking for one day into three different type lubricants which are Semi-synthetic Car Engine Oil Fully Synthetic Car Engine Oil and Mineral Engine Oil.

1.5 General Methodology

To achieve the objective of the study, actions need to be carried out as listed below. Figure 1.1 shows the flowchart of the methodology.

1) Literature Review

   Articles, books or any material that related to the study will be review.

2) Design of Experiment

   The experiment that will be conduct later must be design based on the objective. Tables will be used because of the a few types of data will be collect.

3) Sample Preparation

PKAC will be mix well with the epoxy before putting it in the mould. After that, the composite will be compress using hot pressed machine at certain temperature to get a disc shape of composite. The composite will be cure for a week before soak into oil for a day.

4) Tribology Test

Composite that ready to be test will be place at the ball-on-disc tribometer. Ball bearing will slide on the disc for certain time. If the test shows a bad result while doing the test, the test will be carrying out again.

5) Data Analysis

Data output from the test will be analysed.

6) Discussion

Data taken must be discuss and compare and come out with the conclusion.

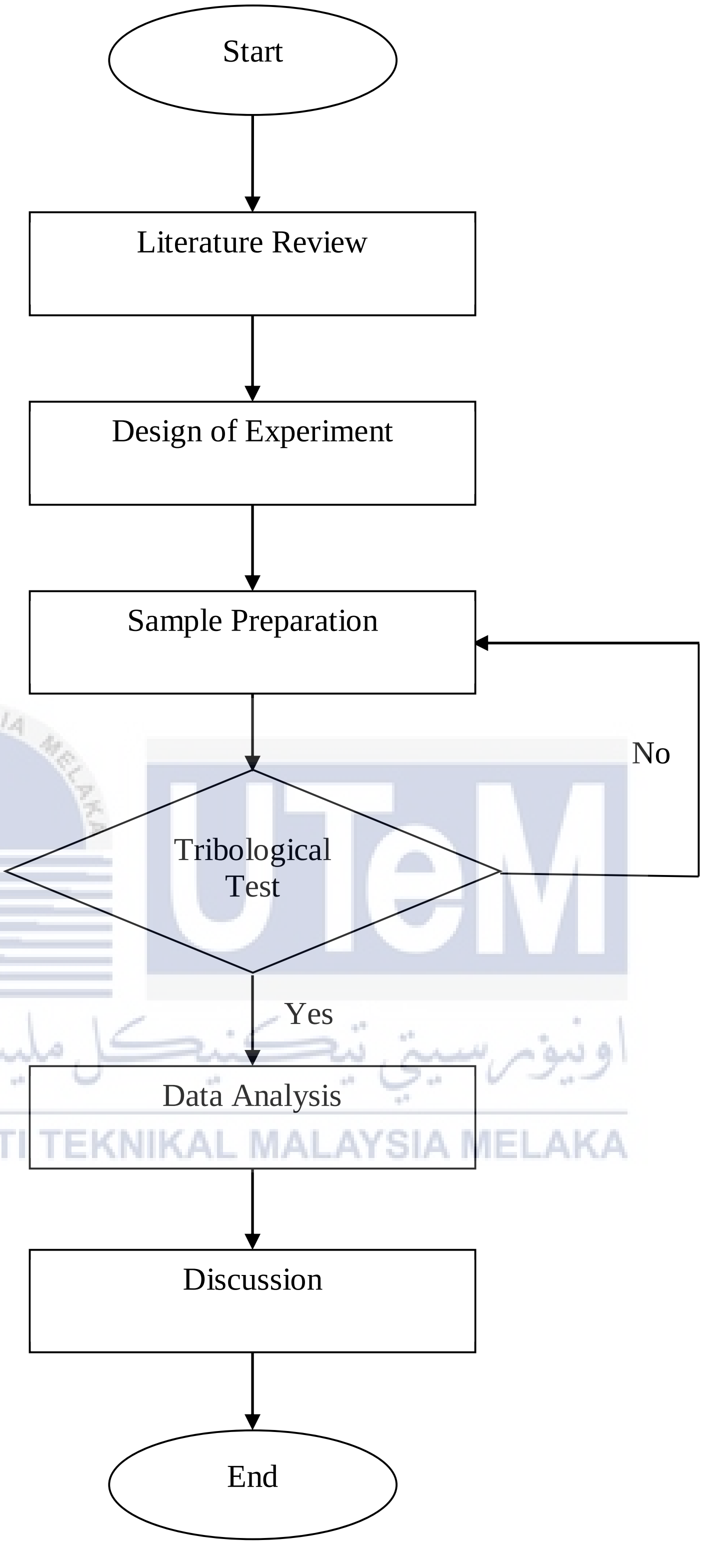

Figure 1. 1 Flow Chart of the Study.

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Kernel Shell

Palm oil became the most sought-after commodity during the industrial revolution because it was used as an industrial lubricant for machinery. Palm oil was widely used in the production of soap and the first pioneers were the brothers Lever, now known as the Unilever (Sawe, 2018). Table 2.1 shows the top 6 palm oil producing countries in the world.

Table 2. 1 Top 6 Countries Producing Oil Palm.

Rank	Country	Production (in metric tons)
1	Indonesia	36,000,000
2	Malaysia	21,000,000
3	Thailand	2,200,000
4	Colombia	1,320,000
5	Nigeria	970,000
6	World	58,800,000

Table 2.1 shows that Malaysia is one of the world's top palm oil producers with a current planting area of about 4.5 million hectares. This proved that the abundance of palm oil produces a large amount of palm oil biomass. The biomass of the oil palm can be reused

by adding additive that produces seven good added value products. The oil palm core shell (endocarp) is an example of oil palm biomass.

The oil palm core shell can be used for activated carbon production. The selection of the oil palm kernel shell for the activated carbon must be based on the shell thickness; endocarp. The oil palm kernel shell must also be obtained from 8-year - old palm oil trees to ensure that the endocarp is sufficiently thick. The thickness of the endocarp varies with dura types with thick endocarp and less mesocarp shows in Figure 2.2, and Tenera types the opposite shows in Figure 2.1. The activated carbon can be better in quality by choosing the Dura types of the oil palm kernel shell. By using this palm oil biomass, the profits for the oil palm sector can be doubled and the Malaysian economy can directly be generated. Table 2.2 and 2.3 shows the oil palm origin characteristics which contribute to the selection of the oil palm kernel shell.

Table 2. 2 Characteristic of Tenera Oil Palm.

Features	Percentage
Mesocarp	60-96%
Thickness of the Shell	3-20%
Thickness of the Seed	3-15%

Table 2. 3 Characteristics of Dura Oil Palm.

Features	Percentage
Mesocarp	20-65%
Thickness of the Shell	20-50%
Thickness of the Seed	4-20%

Figure 2. 1 Tenera Oil Palm Fruit.

Figure 2. 2 Dura Oil Palm Fruit.

2.2 Overview of the Composite

The composite material is produced by mixing two or more different elements to make the resulting material with superior parental properties. There are two composite parts, matrix and filler / fibre which is reinforcing phase. We can be strengthened in the form of fibres, sheets or particles at different phases. It is surrounded by the matrix phase of other materials. Metal, ceramic, non-metal and polymer material may be used in the development of composites as a reinforcing element and matrix material. The fibre / filler used in the composite is more rigid and stronger than the matrix material (continuous phase), which acts as load carrying elements. Continuous phase (matrix) of the composite acts as a means of transferring the load between fibres. The matrix has ductile properties over the fibres and therefore acts as a source of composite strength (Mathur & Bairwa, 2017).

2.1.1 Classification by matrix material type

The composites are made of individual materials as ingredients. The material is divided into two categories, such as matrix and reinforcement. The matrix encloses and sustains the Reinforce materials by keeping their relative positions while the Reinforcements convey their mechanical and physical special properties in order to improve matrix properties. The following additional classifications of composites.

a) Metal Matrix Composites (MMCs)

Some properties such as higher strength, fracture toughness and rigidity are provided with composite material based on metal matrices. Compared with polymer composites, the metal matrix can have a high temperature in the corrosive atmosphere. Titanium, aluminium and magnesium are currently the most high demand matrix metals used in aviation applications (Rout & Sahoo, 2014). These metal matrix composites are considered for a wide range of applications such as housings for combustion chamber nozzles, tubing, cables, and heat exchangers.

b) Ceramic Matrix Composites (CMCs)

This type of composite material consists of ceramic fibres / fillers with a ceramic matrix reinforcement. Examples are silicon carbide fibres fixed in a borosilicate glass matrix. One of the main objectives in the production of ceramic matrix composites is to improve the strength of the material. Moreover, it is expected and definitely found that the strength and stiffness of ceramic matrix composites is simultaneously improved (Ramadan et al., 2017).

c) Polymer Matrix Composites (PMCs)

Generally, the mechanical properties of polymers are insufficient in many structural determinations. Their strength and rigidity are particularly low compared with metals and ceramics. These complications are overwhelmed by the strengthening of other polymers. Second, polymer matrix composite processing does not require a high-pressure temperature. Equipment is also essential for the production of polymer matrix composites. Therefore, polymer matrix composites are rapidly developing and soon becoming popular in structural applications. There are two types of polymer matrix composites. First FRP and the other one is PRP. In the first type, fibres are the most powerful source and reinforcement, as the matrix collects all the fibres and transfers stresses between the fibres. In the second type, particles are used to strengthen and increase modules and reduce the matrix ductility. Ceramics and glasses are used for reinforcement, such as small mineral particles, metal particles, such as aluminium and amorphous materials, including polymers and carbon black. These types of composites are used in the manufacture of aircraft, in the space industry, in the production of sports goods, etc. (Karaduman et al., 2014; O'Brien et al., 2014; Prakash et al., 2015).

2.1.2 Classification by Type of Reinforcement Material

Reinforcement is a strong, inert woven and non-woven fibrous material incorporated into the matrix to enhance its metal glass and physical properties. Composites are classified into two types of reinforcement material.

a) Composite particulate

In such composites, the reinforcement is of a particle nature in various forms, such as, tetragonal, platelet or of a regular or irregular form. They improve to a limited extent the rigidity of the composite, used to improve the properties of matrix materials such as thermal and electrical conductivity, improved performance at high temperatures, reduced friction, increased resistance to wear and abrasion, improved machinability, increased hardness of the surface and reduced shrinkage (O'Brien et al., 2014).

b) Fibrous Composites

A fibre is characterized by a much larger length than the cross - sectional dimension. The size of the reinforcement determines its ability to contribute its composite properties. Fibres are very helpful in improving the resistance of the matrix to fractures, as a long-dimensional reinforcement prevents the growth of incipient cracks that are normal to the reinforcement, which could otherwise lead to failure, especially with cracked matrices.

There are two group of fibre which is synthetic fibres and natural fibres. Synthetic fibres are man - made fibres that scientists have researched to improve natural plant and animal fibres. Nylon was the first synthetic fibre. Plant, animal and mineral fibres are referred to as natural fibres. It can also be classified by origin, such as fruit fibres, bast fibres, and leaf fibres. Fruit fibres are extracted from plant fruits, are light, hairy and it is helpful to fly the seeds to another place. Bast fibres are found in the plant stems. Leaf fibres extracted are rough and robust, called leaf fibres (Mathur & Bairwa, 2017).

Since the naturally derived fibres are low - cost, renewable and biodegradable in nature, the field of engineering and research has shifted to the use of these fibres as a strengthening material in the polymer matrix since the last few decades. In recent decades, several studies have carried out on the mechanical properties of natural fiber-Polymer composites based on wood / polymer composites with a special emphasis. A detailed literature study is conducted to determine the composite scope of the current work.

2.1.3 Reinforcement

Reinforcement is the component which gives its special mechanical and physical characteristics to improve the matrix properties in the discontinuous phase. Reinforcement, generally in the form of fibres or particles, the composite provides tensile strength and shear strength.

2.3 Epoxy Resin

Epoxy resins are characterized by the presence of epoxy groups before cure and may also contain in the backbone aliphatic, aromatic or heterocyclic structures. Epoxy resins are expensive but have a long service of life and good physical properties often contribute to a favourable cost-performance ratio compared to other thermosets. Electronics (printed wiring boards and semiconductor encapsulation) and transport in composite structural and furnishing elements are the main areas where fire retardation of epoxy resins is required. Epoxy resins, like other thermoset resins, fire retardants can be made either by incorporating fire retardant additives or by copolymerizing reactive fire retardants. Fire retardants of an additive type are mainly used in coating or encapsulation, while reactive flame retardants in printed circuit boards and composites are preferable to avoid the risk of deterioration of physical properties (Levchik & Weil, 2004).

Epoxies are polymerizable thermosetting resins in liquid, solid and semi - solid forms available in a variety of viscosities. A variety of reinforcing fibres such as glass, carbon, aramid and boron are used for liquid epoxies. Epoxies can work well at high temperatures which is 200 ºF to 250 ºF, but the cost is increased together. Epoxies can perform up to 400 ºF, but they use good chemical and corrosion resistance. In this research, epoxy resin is selected since the use of epoxy-based composites provided good performance at room temperature in this study. Compared to the thermoplastic resin, epoxy resin processes very good mechanical properties and produces excellent bonding with the material. Previous research has shown that the strengthening of epoxy with natural fibre increases the composite's flexural strength (Yousif et al., 2012).

2.4 Compression Moulding

The production rate is dramatically increased in this process by applying heat to the mould surface to accelerate the healing process. Hot press moulding can be done with liquid resins in the same way as the cold press. However, it is normal to use prepare strengthening nowadays. These 25 processes enable the moulding of complex details from a simple material package. Very high stability and precision are possible but mechanical variability can still be a problem. The effect of moulding parameters on the tensile and flexural properties of the compression moulded parts has been found to increase the tensile module as the mould temperature and speed decreased, although the flexural modulus values have been dispersed (Tanaka et al., 1999). This production process is suitable for composites of natural fibres, as the fibres can be easily placed inside the mould and no shear stress and vigorous movement are applied. Figure 2.3 shows the hot press machine that used in this research.

Figure 2. 3 Hot Press Machine.

2.5 Natural Fibre Composites

Enhancing awareness of the environment around the world has had a major impact on materials engineering and design. Natural materials address environmental problems such as can be renew, recycle and safety in the environment. Currently, synthetic fibres such as glass, carbon and aramid are widely used in polymer - based composites because of their high strength and rigidity (Düpont et al., 2005). However, these fibres have serious disadvantages in terms of biodegradability, initial costs of processing, recyclability, energy consumption, abrasion of machines, health risks, etc. (A.K. Bledzki & Gassan, 1996). Most importantly, adverse environmental effects change the focus from synthetic fibres to natural / renewable fibres. The introduction of natural fibres as reinforcements in the polymer matrix has received considerable attention. The interest of scientists and engineers in using plant fibres as efficiently and economically as possible to produce fibre - reinforced polymer composites of good quality for structural, building and other requirements. Due to its high availability, it has led to the development of alternative materials rather than conventional or man - made materials. Many types of natural fibres, such as wood fibre, sisal, kenaf pineapple, jute, banana and straw, have been investigated for use in polymers (Kamel et al., 2011). Figure 2.4 shows the natural and synthetic fibre classification (Jawaid & Abdul Khalil, 2011).

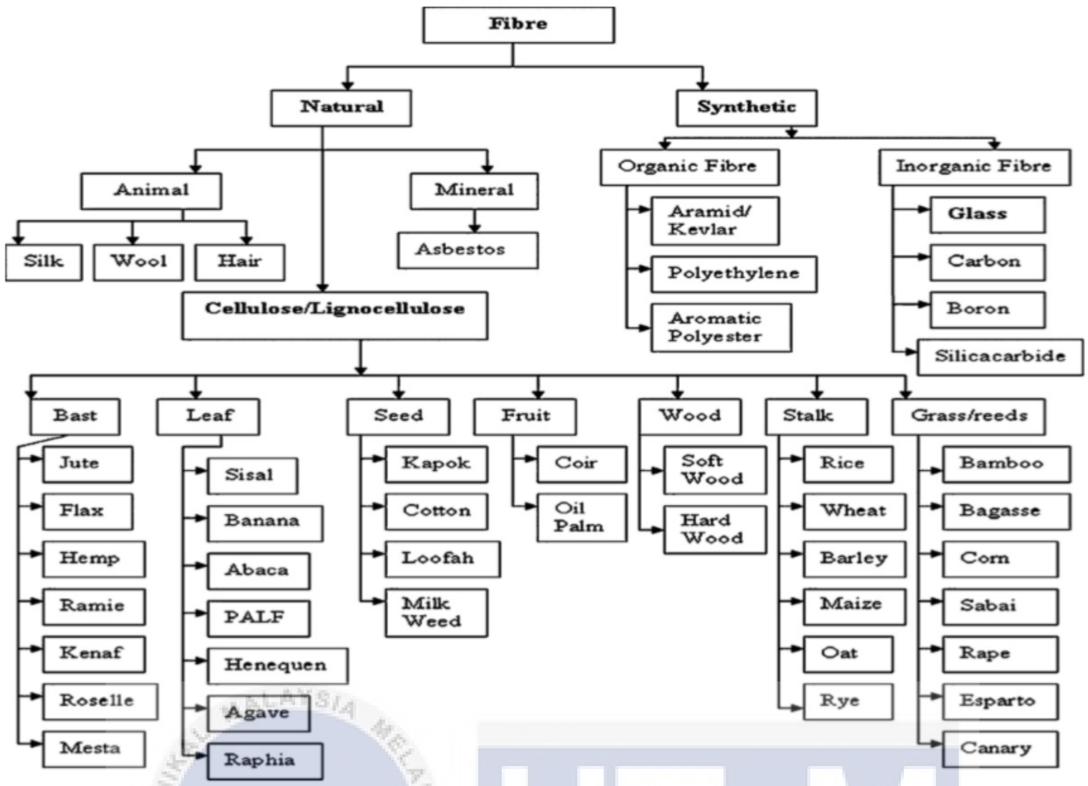

Figure 2. 4 Classification of Natural and Synthetic Fibre. (Jawaid & Abdul Khalil, 2011).

The impact of lignin content on the mechanical behaviour of jute has been investigated and a rapid decrease in fibre strength and rigidity with the removal of lignin has been observed. Further research shows, however, that the physical properties of natural fibres and the physical properties of natural fibres depend primarily on the plant's nature, the location in which it is grown, the age of the plant and the method of extraction used (Collier, B. J., Collier, J. R., Agarwal, P., & Lo, 1998). Various natural organic fibres and provides information on natural fibre composition and physical properties. Factors that affect agrofibres and determined that the chemical composition and physical properties of agrofibres depend on the part from which fibres are extracted.

2.2.1 Activated Carbon

Activated carbon forms a large and important class of porous solids found in a wide variety of technological applications. The porous structures and adsorption of gases, vapours and liquids of these materials have been extensively studied this section examines the microstructural and porous characteristics of the main active carbon classes. Detailed consideration of a large number of industrial applications and processes using activated carbon is beyond the scope of this contribution.

Activated carbons have been explained in different ways by several authors, which gives a basic understanding of activated carbons as solid carbon materials. An appreciation of the fine structure of activated carbons leads to a consideration of the surface forces in pores that give rise to the strong absorbing properties of activated carbons. They can be prepared from a large number of raw materials, in particular agro- industrial by- products such as palm kernel shells, physical reactivation and chemical activation by one of the following processes.

Activated carbons have a number of unique features, such as large internal surfaces, chemical properties and good internal pores accessibility. Three groups of pores can be identified according to IUPAC definitions which is the sizes are above 50nm diameter, 2-50 nm diameter and under 2 nm diameter. In general, micropores contribute to a large part of the inner surface. Macro and micropores can generally be considered the roads into the carbon particle and are crucial for cinematics. The desired porous structure of an activated carbon product is achieved through the combination of the right raw material and the appropriate activation.

2.2.2 Palm Kernel Activated Carbon

The raw palm shell characteristics are described in Table 2.4. The palm shell is suitable for adsorption because it can be modified and therefore becomes highly porous carbon (Fuadi et al., 2012). The basic analysis shows that the weight percentage of carbon is the highest. Due to the composition of the gasses, other elements can be removed at high temperature, thus increasing the carbon content. In addition, high lignin content and low cellulose content, causing short - term palm shell activation due to a less fibrous structure (Daud & Ali, 2004). However, after carbonisation, the palm shell suffers a high weight loss of about 75%. The carbon ash content is the residue when carbon material is burned off. Since activated carbon contains inorganic components derived from the source materials and active agents added during production, the total amount of inorganic components varies from grade to grade. Inorganic carbon components generally appear in the form when the carbon is ash. Ash content can lead to hydrophilicity and catalytic effects, resulting in processes of restructuring during regeneration of used carbon. The active carbon inorganic material is measured as an ash concentration.

Table 2. 4 Palm Shell's textural characteristics, proximate and final analysis.

Properties	Value	References
Solid density (g / cm3)	1.53	Guo and Lua (2002)
Apparent density (g / cm3)	1.47	
Porosity (%)	3.9	
BET surface area (m2/g)	1.6	
Micropore surface area (m2/g)	0.2	
Proximate analysis (wt %)		Daud and Ali (2004)
Carbon	18.7	
Moisture	7.96	
ash	1.1	
Volatile	0.1	
Elemental Analysis (wt %)		
Carbon	50.01	
Hydrogen	6.85	
Nitrogen	1.9	
Sulphur	-	
Oxygen	41.15	
Cellulose (%)	29.7	
Halocellulose (%)	47.7	
Lignin (%)	53.4	

The activated carbon of the palm kernel is one of the potential self-lubricating materials. Therefore, the effect of the activated carbon composition of the palm kernel on the physical-mechanical properties of the activated carbon-reinforced polymer composite of the palm kernel has been investigated. The activated carbon of the palm kernel was characterized on the basis of proximate and ultimate analyses, thermal stability, chemical function and area. The palm kernel shell is a suitable material for the production of activated charcoal due to its low ash content (2.3 wt%), but high carbon and volatile content (23 wt% and 61.7%). The Maximum thermal stability for palm kernel activated carbon and raw palm kernel shell up to 700ºC was observed, but for palm kernel charcoal up to 600ºC (Rugayah et al., 2003).

2.6 Application of Natural Fibre Composite

Natural fibres fortified composites emerge very quickly as a potential substitute for metal or ceramic materials in applications including automotive, aerospace, marine, sporting goods and electronics (Thakur & Thakur, 2014). Natural fibres fortified composites quickly become a potential substitute for metal or ceramic materials for automotive, aerospace, marine, sports and electronics applications. Their individual properties should provide a solid basis for new applications and opportunities for biocomposites or natural fibre composites in the green environment of 21st century materials. The use of natural fibre composites in various applications has opened up new possibilities for both academics and industry to produce a sustainable module for the future use of natural fibre composites (Gurunathan, Mohanty, & Nayak, 2015).

Composite building materials are made of straw in the United States. Straw bales are used in building the buildings. Many automotive components are already made from natural composites based mainly on polyester or polypropylene and fibres such as flax, hemp or sisal. In this industry, the adoption of natural fibre composites is driven by reasons of price, weight reduction and marketing rather than technical demands (Saravana Bavan & Mohan Kumar, 2010).

Germany is a leader in the application of natural fibre composites. The German automotive manufacturers Mercedes, BMW, Audi and Volkswagen took the initiative to introduce natural fibre composites for indoor and outdoor use. The first commercial example is the 1999 S-Class Mercedes-Benz inner door panel made in Germany with a 35% Baypreg F semi-rigid (PUR) elastomer from Bayer and a 65% flax, chanvre and sisal blend. It should be emphasised that luxury car manufacturers are on board, which can be seen as proof that natural fibre composites are used for environmental purposes and do not reduce costs.

In 1996, Mercedes - Benz used an epoxy matrix with the addition of jute in its E - Class vehicles in the door panels. Another paradigm of the application of natural fibre composites appeared commercially in 2000. Audi has launched the A2 midrange car: the door trim panels have been made of polyurethane with a mixed flax / sisal material. Toyota has developed and used an eco-plastic made of sugar cane to line the car interiors (Koronis et al., 2013).

Biodegradable bark tissue reinforced green epoxy composites are developed for use in automotive device panels (Rwawiire et al., 2015). The coir / polyester composites were used to manufacture mirror housing, paper weights, projector cover, voltage stabilizer cover, mailbox, helmet and cover. Natural fibre composites have been used in structural applications and infrastructure applications to develop load - bearing elements such as beams, roofs, multi - purpose panels, water tanks and footbridges. Green composites based on jute would be suitable for even primary structural applications, such as indoor elements in housing, temporary outdoor applications such as low-cost housing for defence, rehabilitation and transport. Because of its insulating properties, jute can be used in automotive door / ceiling panels and panels that separate the engine and passenger compartments.

2.7 Tribology Behaviour of Natural Fibre Composite

The main factor affecting the porosity of a composite is moisture that affects tribological properties, but experiments are carried out without considering moisture. Most experiments are conducted in dry conditions, but lubrication can be applied in actual practice (Karthikeyan et al., 2017).

2.7.1 Particle Size

The force of a composite material depends on the size of the particle. Smaller particles are between 0.001 and 0.1 mm and the remainder are referred to as larger particles. Small particles have more surface area than large particles per unit mass or greater volume. When the particle content is increased, and the particle size of the reinforcement is reduced, the wear rate is low and the friction coefficient (COF) is increased (Shakuntala, Raghavendra, & Samir Kumar, 2014). The increase in reinforcement particles to more than 30% increases the COF of composites. The peak erosion rate was found to be at an impingement angle of 45º–60º Euros. It shows that with the reduction of particle size the mechanical and tribological properties increase. Less grit size (0.15) and the highest composition (15%) give better tribological performance than others.

2.7.2 Volume Fraction

The volume fraction is the percentage of the particle volume in the whole resin impregnated particle volume, PRC. The sample hardness is increased by increasing the volume fraction and by increasing the volume fraction the weight loss is reduced. Increased mechanical and wear properties with an increased wt% reinforcement. Increasing the fibre content at lower normal load and sliding speeds improves the tribological properties of composite materials (Dadkar, Tomar, & Satapathy, 2009). A maximum surface roughness value of 10 mm, 10 wt% of fibre content and 15 wt% of hybrid particles is obtained at coir length; a minimum surface roughness value of 30 mm, 10 wt% of fibre content and 15 wt% of hybrid particles is obtained at coir length (Bashir et al., 2015).

2.7.3 Surface Treatment

Weak adhesion and low interlaminary shear strength between the particles and the matrix are present in a composite material. Treatments increase the functional surface area and surface acid groups and thus improve the bonding strength between the particles and the matrix. Composite immersed in lighter liquids with better results compared to high viscosity liquids and observed that particles may weaken and deboned at the time of the aging process, thus reducing the wear performance of the samples (Yousif & Nirmal, 2011).

2.8 Motor Oil

Motor oil is a lubricant used in cars, motorcycles, lawnmowers, engine generators and many other machines. There are parts in motors that move against each other and the friction wastes useful power by converting the kinetic energy into heat. It also removes those parts that could lead to less efficiency and less engine degradation. This increases fuel consumption, reduces power output and can lead to failure of the engine. A low viscosity index represents a significant change in viscosity with temperature change. Such oils are very viscous at low temperatures and at high temperatures are rather thin. The opposite means a high viscosity index: a small change in viscosity over a wide temperature range.

When selecting oil for a special purpose for lubrication in an internal combustion engine, the temperature - related viscosity change must be taken into account as it differs between oil types. Oils with the same viscosity at 40°C can have very different characteristics at 100°C (Paar, 2018). In order to achieve the required temperature - related viscosity properties of the oil, viscosity index improvers are added to the base oil, also known as viscosity modifiers. The maximum achievable viscosity index depends on the type of base oil used and the type and concentration of the oil's improved viscosity index. The viscosity index of common oil types varies between -60 and more than 400. The viscosity modifier content is approximately 5% to 20%.

The Society of Automotive Engineers (SAE) determines the level of viscosity of a lube oil. Oils may be broken down into multigrade oils and monograde oils. Multigrade oils must meet two viscosity requirements, their viscosity level is composed of two numbers. 10W-40: 10W, for example, refers to low - temperature viscosity (" Winter "), 40 to high - temperature viscosity (" Summer "). Most automotive engine oils are currently multigrade oils, while oils for limited use. Monograde oils are often used for seasonally used engines such as lawn mowers. While the two numbers specify the SAE viscosity grade, the viscosity index shows the change in viscosity due to the temperature (Paar, 2018). The kinematic viscosity is measured by the time a standard quantity of oil flows through a standard orifice at standard temperatures. The longer it takes, the greater the viscosity and therefore the higher the SAE. Numbers bigger are thicker. Table 2.4 show the properties of the motor oil.

Table 2. 5 Properties of the Motor Oil.

SAE Viscosity Grade (ºC)	Min. Viscosity $((mm^2/s)$ at 100ºC	Mix. Viscosity $((mm^2/s)$ at 100ºC	High Sheer Rate Viscosity (mPa.s) at 150ºC	Cranking Viscosity (mPa.s) Max at (ºC)	Pumping Viscosity (mPa.s) Max at (ºC)
0W	3.8	--	--	6200 at -35	60 000 at -40
5W	3.8	--	--	6600 at -30	60 000 at -35
10W	4.1	--	--	7000 at -25	60 000 at -30
15W	5.6	--	--	7000 at -20	60 000 at -25
20W	5.6	--	--	9500 at -15	60 000 at -20
25W	9.3	--	--	13 000 at -10	60 000 at -15
20	5.6	<9.3	2.6	--	--
30	9.3	<12.5	2.9	--	--
40	12.5	<16.3	2.9*	--	--
40	12.5	<16.3	3.7**	--	--
50	16.3	<21.9	3.7	--	--
60	21.9	<26.1	3.7	--	--

2.9 Piston Ring in Engine

In internal combustion engine, around 20% of losses due to the piston ring friction (Bedajangam & Jadhav, 2013). The purpose of the piston ring in the engine is to seal the combustion chamber so that the crankcase has minimal gas loss, improve heat transfer to the cylinder wall from the piston, maintaining the correct oil quantity between the piston and the cylinder wall and regulate engine oil consumption by scrapping oil back to the sump from the cylinder walls. Basically, the piston ring is made up of three circular rings in the piston grooves. During engine operation, the rings move along the cylinder liner with the piston. Table 2.6 shows the suggested operating conditions for various materials (B.V., 2019). It is show the average coefficient of friction of the piston ring.

Table 2. 6 Suggested operating conditions for various materials.

Matrix	**Filler**	**Terminal pressure bars**	**Maximum speed m/s**	**Maximum temp. °C**	**Average coefficient of friction (dry)**
PTFE	Carbon	200	6.0	250	0.1/0.15
	Glass	200	6.0	200	0.1/0.15
	Graphite/ MoS_2	200	6.0	200	0.12/0.18
	Bronze	100	4.0	200	0.15/0.2
Resin-bonded PTFE		200	4.0	200	0.15
Resin-bonded fabric		100	3.0	150	0.15/0.2
Carbon		60	3.8	350	0.2/0.25
Resin-bonded carbon		100	4.5	180	0.2

CHAPTER 3

METHODOLOGY

3.1 Experimental Flow

This chapter describes the methodology for obtaining data input for this project. The Figure 3.1 shows that project start with the factor selection which is choosing the types of oil that going to be used in this project. Oil that had been chosen are mineral engine car oil, semi-synthetic engine car oil and fully synthetic engine car oil from the same brand for each type of oil. Second is come out with the design of experiment. For this project, it is consisting of three specimens and two types of condition which is dry and wet condition. Using the same specimen, it is tested in both conditions to compare the friction and the changing of the friction.

Next is the sample preparation which is disc making. The PKAC is mixed with the epoxy and the mixing is put in the mould to get the disc shape and put in under the hot press machine. After the specimen is cure for a week, the specimen is ready to be used and it is tested under the ball-on-disc tribometer as planned in design of experiment. For the first test is using one specimen and test it under the ball-on-disc tribometer in dry condition. After that, use the same disc and soak it in the mineral oil for a day. After a day, the disc is tested again. After getting the result, the same specimen will be left in the covered box without further soaking and left it for a day and test it and get the result. The test is repeated using the other specimen with a different type of the oil. The test is repeated if the result is showing the unexpected graph. Data taken must be discuss and compare and come out with the conclusion.

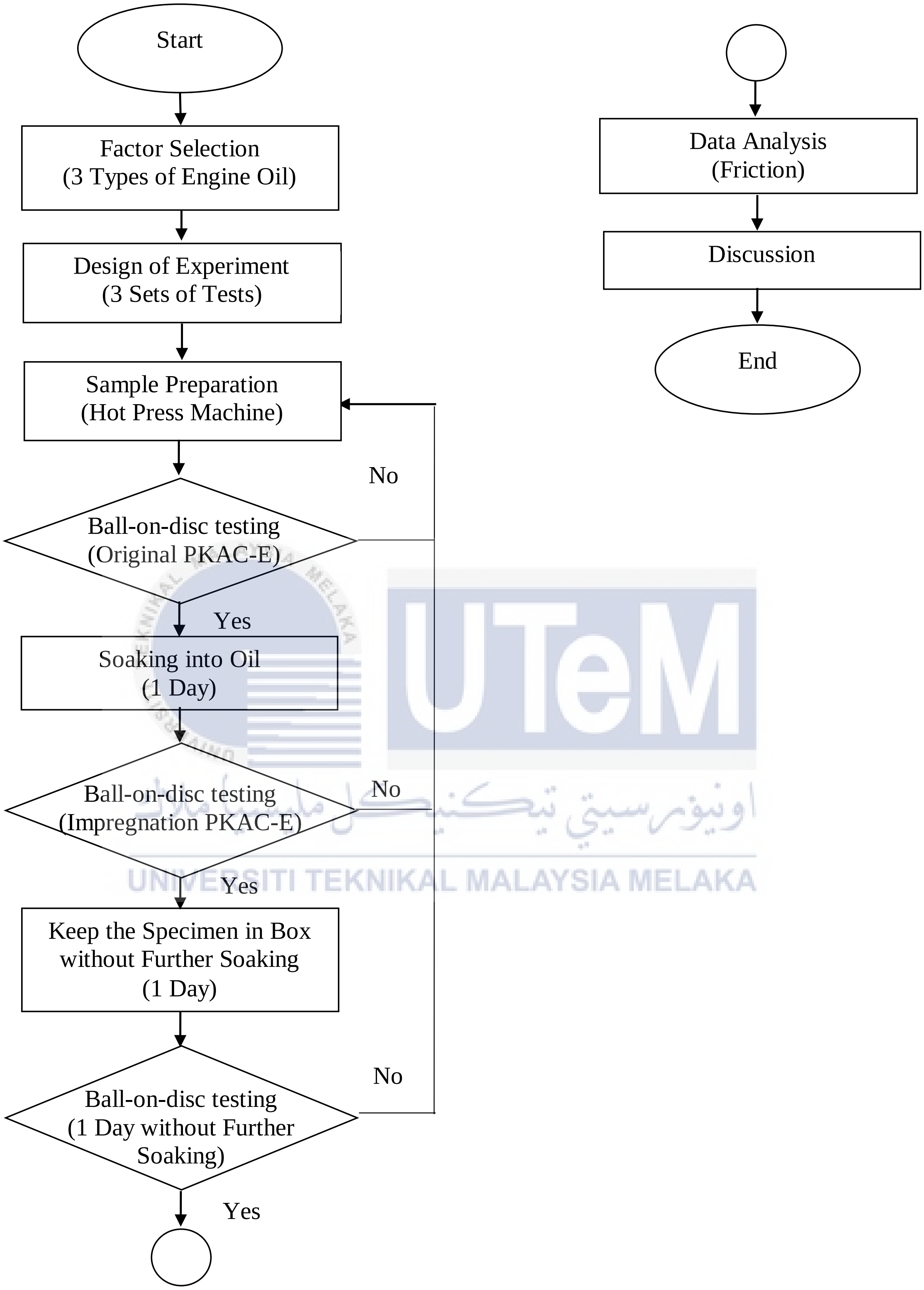

Figure 3. 1 Flow Chart of the Methodology.

3.2 Material Preparation

PKAC is crush using the crusher machine as shown in Figure 3.2 to make the size of carbon to be small (almost looks like powder) in order to make the composite. PKAC need to be in smaller size before combine with the hardener and epoxy. After the PKAC is crushed, it's placed in the sieve machine to separate the size of the PKAC. The PKAC need to be sieve for 2 hours to make sure it is separated according to the size. Figure 3.3 shows the sieve machine that used to separate the PKAC. After sieved it, PKAC need to be left for a day to make let it down because the small size of it will fly. To make sure that is not going to happened, it is needing to leave it for a day to make all the particle become passive. Size that used is 125 µm.

Figure 3. 2 Crush Machine.

Figure 3. 3 Sieve Machine.

3.3 Sample Fabrication

For the composite preparation, PKAC with size 125 μm is mixed with the high-density epoxy [West system 105 epoxy resin (105-B) and West system 206 hardener (206-B)]. The epoxy has been chosen because of its high processing characteristics, superior strength, excellent performance at high temperatures and high solvent resistance commonly used in the composite manufacturing industry. Epoxy in moulded or cast form also has excellent dimensional stability and low shrinkage, while in PMCs, creep resistance, rigidity and compressive strength are generally improved, and wear resistance is improved (Mohan et al., 2011). A mould has design with diameter of 75mm for the purpose of disc composite.

Before fabrication, the internal surface of the mould was greased with was as a release agent, so the composite will not be stuck in the mould. Following the previous publication (Mohmad et al., 2016), the PKAC of 60 wt.% in size 125 μm was mixed with the epoxy (at resin to hardener ratio 4:1) due to better mechanical properties. The mixing was performed by hand using spatula. Composite weight was set at 25 g and divided by percentage in order to facilitate the weighting and sample manufacturing process. The calculated weight of PKAC is 15g, resin is 8.33g and hardener is 1.67g.

Mixed materials have been put into the mould. The compression moulding method was selected to compress a component using the hot press. The compression process parameters such as temperature, pressure, pressure time and cooling time have been set. The temperature was set to 80ºC before the process of compression began and after the mould was placed. For 10 minutes, the pressure was set to 50 kg / cm. The mould was then left to cool at room temperature for about 10 minutes before it was pressed out of the mould. The composite disk was cured at room temperature for approximately seven days and the surface of the disk was polished with sand paper to make the surface smooth. The laser cutter was then used to make a hole on the disk. Figure 3.4 shows the composite disk used for this test.

Figure 3. 4 PKAC-E Disc Composite.

3.4 Tribological Test

Figure 3.5 and Figure 3.6 shows the experiment of the ball-on-disc tribometer. In this experiment, there is one monitor to show and set the speed and the distance of the testing, computer to show the graph and the result after the test is finish and the ball-on-disc test are where the disc and the ball bearing placed on it. Once the disc is ready to be test, the disc is placed on the rotating disc and the ball bearing placed on the holder provided. 49.05 N of load is placed at its place, the monitor sets at 30 minutes. The experiment then conducted by conducting the computer in case there is unexpected result occur during the test. The test will be stop immediately once the result is showing the unstable graph.

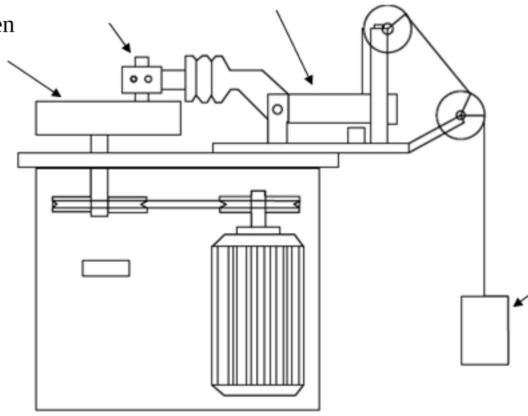

Figure 3. 5 Ball-on-disc Experiment Setup.

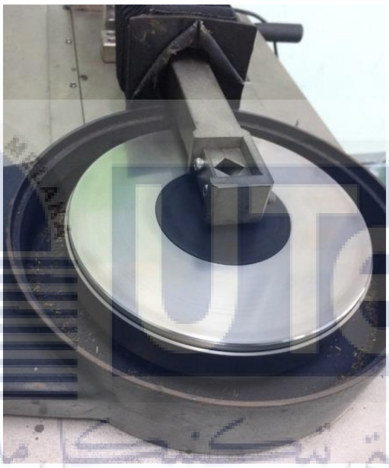

Figure 3. 6 Actual Set up of Ball-on-disc Test.

Before that, the ball bearing immersed into acetone using ultrasonic bath for 5 minutes to remove any oil or any dirt. Then the ball bearing wiped dry before starting the test. The properties of ball bearing as shown in the Table 3.1.

Table 3. 1 Properties of SKD-11.

Type	Chemical	Composition (%)	Hardness
SKD-11 (AISI D2)	Carbon	2.00-2.30	7.35 GPa
	Silicon	0.10-0.40	
	Phosphorus	Max. 0.03	
	Manganese	0.30-0.60	
	Sulphur	Max. 0.03	
	Chromium	11.0-13.0	
	Tungsten	0.60-0.80	

The test was perform using a different type of engine oil for car which is mineral oil (SAE 10w-30), semi-synthetic oil (SAE 5W-30) and fully synthetic oil (SAE 0W-20). Table 3.2 shows the parameter that used in this test.

Table 3. 2 Sliding Test Operating Parameter.

Test Parameter	Value
Weight Percentage of PKAC (%)	60
Load (N)	49.05
Sliding Speed (rpm)	500
Temperature (°C)	25
Time (s)	1800

The ball bearing was fixed and the PKAC-E disc was rotated during this experiment. The mass loss in the disc after each test was estimated by measuring the weight of the disc before and after each testing using an electronic balance with an accuracy of ± 0.001 mg. every changing of disc is measured to observe the different of the disc before and after. The result is shown on the monitor and the value of the given friction is changed to a friction coefficient (COF). The COF is calculated using the equation 3.1.

$$COF = \frac{F}{W} \tag{3.1}$$

Where F is the frictional force and W is the applied load. Both unit in N.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Effect of Coefficient of Friction

4.1.1 Effect on COF at Mineral Oil

Figure 4.1 shows the graph of COF against sliding distance. The graph shows the result COF of composite after test of original composite, soaked into mineral oil for one day and 1 day without further soaking composite after a day. From the graph, it shows the original PKAC-E is takes time to stable. COF for the soaked composite reduce 13.56% and for the 1 day without further soaking composite is 17.12%. This shows that the mineral oil helps the composite to reduce the COF. For the soaked and 1 day without further soaking composite shows that the composites start to stable at 500m.

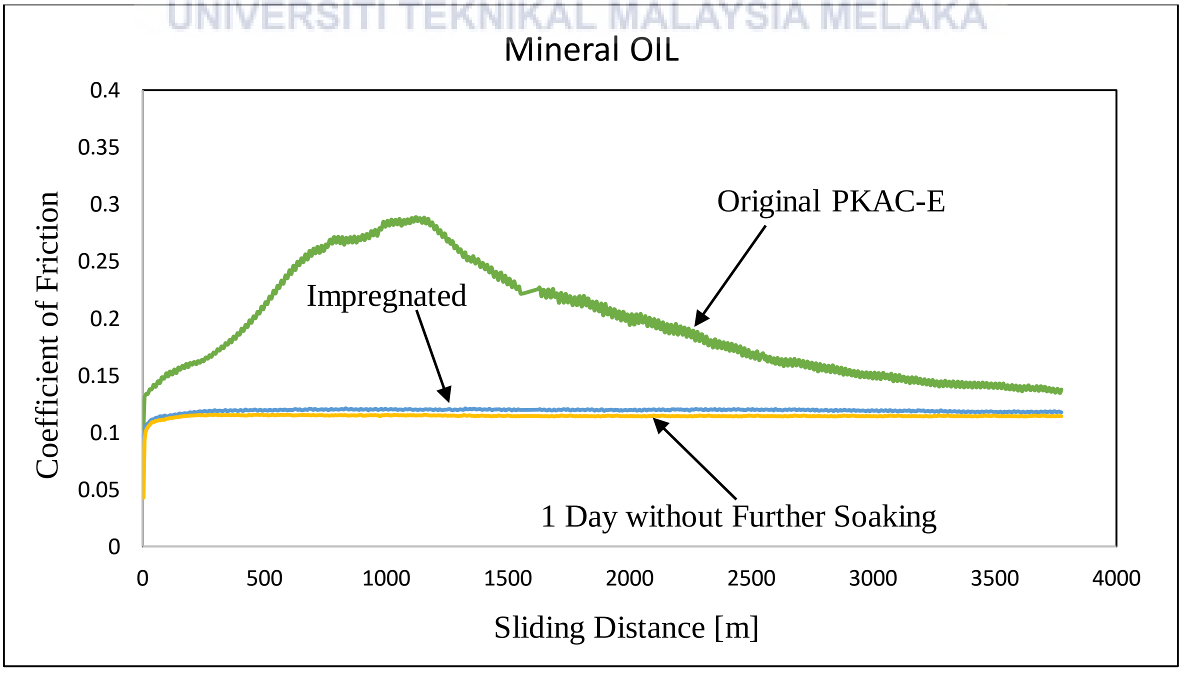

Figure 4.1 Graph of COF against sliding distance of Original PKAC-E, 1 day after test with lubricant and 1 day after test without further lubricant using mineral oil.

4.1.2 Effect on COF at Semi-Synthetic Oil

Figure 4.2 shows the graph of COF against sliding distance. The graph shows the result COF of composite after test of original composite, soaked into mineral oil for one day and 1 day without further soaking composite after a day. From the graph, it shows that the second composite for original PKAC-E test has almost the same value of average of COF. But the value of COF for the soaked composite reduce 4.02% and for the 1 day without further soaking composite is 4.36%. This shows that the semi-synthetic oil help to reduce the COF even the value is slightly different.

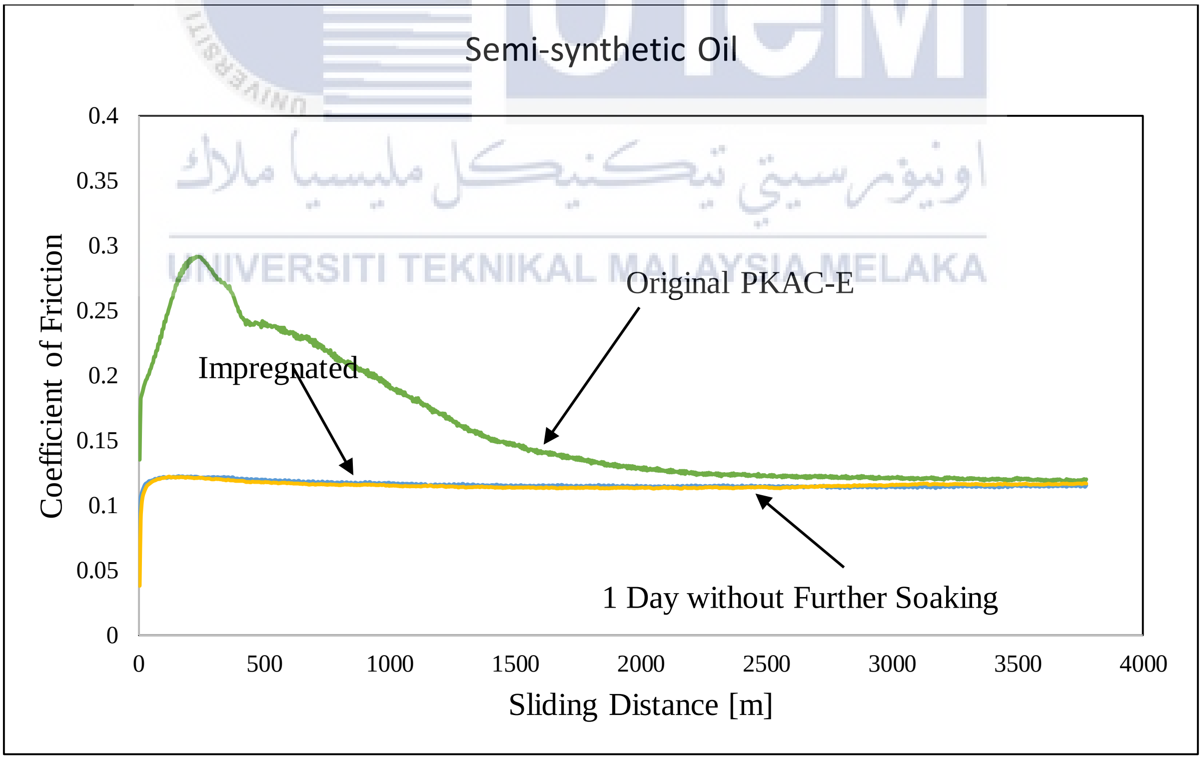

Figure 4.2 Graph of COF against sliding distance of Original PKAC-E, 1 day after test with lubricant and 1 day after test without further lubricant using semi-synthetic oil.

4.1.3 Effect on COF at Fully Synthetic Oil

Figure 4.3 shows the graph of COF against sliding distance. The graph shows the result COF of composite after test of original composite, soaked into fully synthetic oil for one day and 1 day without further soaking composite after a day for fully synthetic oil. From the graph, it shows that the third composite for soaked and 1 day without further soaking test has the same value of average of COF but at the beginning of the test, the value of COF of 1 day without further soaking composite is lower than the soaked composite. The value of COF for the soaked composite reduce 19.29% and for the 1 day without further soaking composite is 18.89%. The value COF at 1 day without further soaking composite start to increase at the 2600m this is due to the evaporation occur. The lubricant helps the composite to reduce the COF but when the lubricant start to evaporate, the COF will increase. This shows that the semi-synthetic oil help to reduce the COF even the value is slightly different.

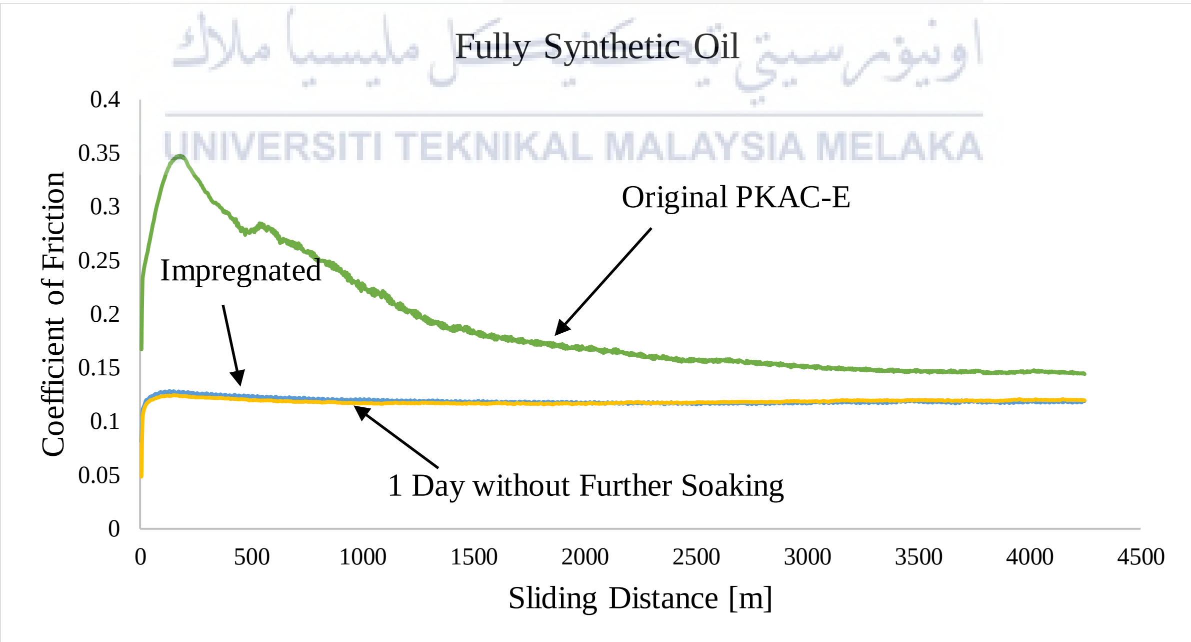

Figure 4.3 Graph of COF against sliding distance of Original PKAC-E, 1 day after test with lubricant and 1 day after test without further lubricant using fully synthetic oil.

4.2 Average Coefficient of Friction

Figure 4.4 shows the value of COF for each test of original PKAC-E, impregnated and 1 day without further soaking of mineral oil, semi-synthetic oil and fully synthetic oil. The bar chart shows that the impregnated composite of semi synthetic oil is the lowest value among the impregnated composite and for 1 day without further soaking composite, mineral oil and semi-synthetic oil gives the same value of COF.

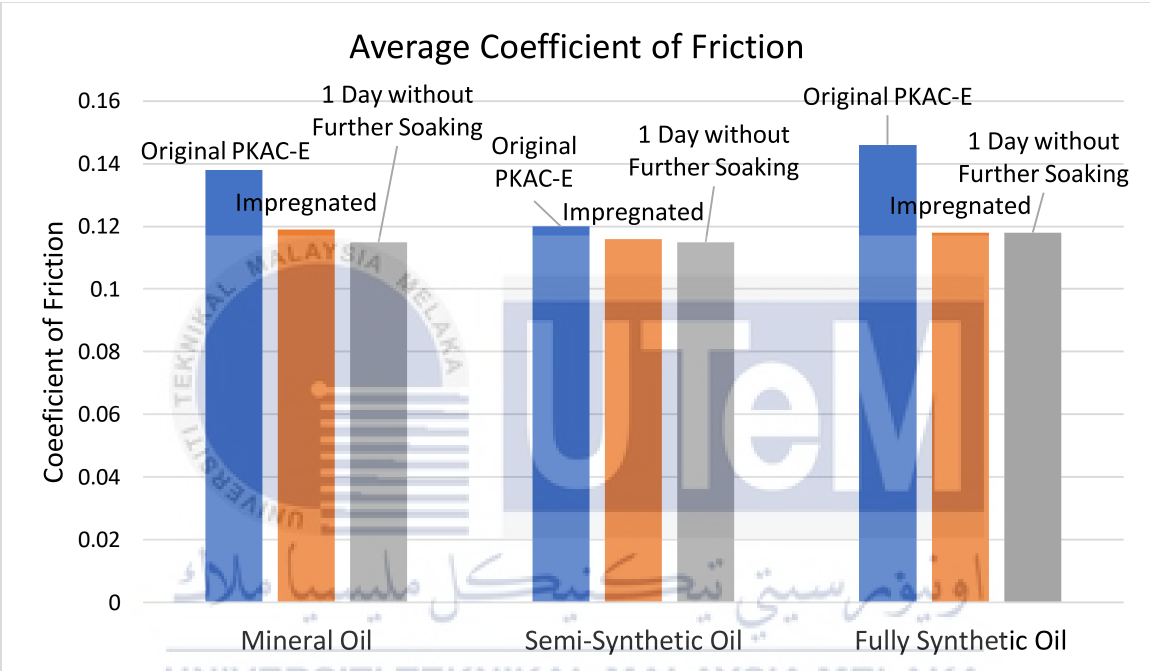

Figure 4.4 Average of Coefficient of Friction of original PKAC-E, impregnated and 1 day without further soaking of mineral oil, semi-synthetic oil and fully synthetic oil.

4.3 Effect of Coefficient of Friction

A good lubricant characteristics should have a high boiling point and low freezing point to keep the liquid within a wide temperature range. Lubricant also must have high index of viscosity, hydraulic stability and thermal stability, demulsibility, prevention of corrosion and high oxidation resistance.

4.3.1 Effect of Coefficient of Friction at Different Lubricant

A friction coefficient is a value showing the relationship between the friction force between two objects and the normal reaction between the involved objects. Equation 3.1 is used to calculate the value of COF.

The composite was impregnated by mineral oil, semi-synthetic oil and fully synthetic oil is better than original composite because the impregnated composite have lower COF by 4% to 19% from the original composite. The range of COF of composite that impregnated by these three different oil in between 0.115 to 0.119. Even though mineral oil and semi-synthetic oil has the same value if viscosity index, the value of COF impregnated composite of semi-synthetic in lower than impregnated composite of mineral oil. This is shows that the impregnated composite of semi-synthetic oil is better than mineral oil. Impregnated composite of fully synthetic oil also high from the COF impregnated composite of semi-synthetic even though the viscosity index of fully synthetic oil is lower from the semi-synthetic. This is because of the different type of specimen used. The original composite of semi-synthetic oil give the lowest value of COF compared to the original composite of fully synthetic. This is the cause of why impregnated composite of fully synthetic is higher than the semi-synthetic.

4.3.2 Effect of Coefficient of 1 Day without Further Soaking Composite

The 1 day without further soaking composite of semi-synthetic oil and mineral oil are decreased because it has high viscosity index and it makes the oil keep remain in the composite and experience small losses of oil but for the fully synthetic oil is also decreased but the COF starts to increase during the experiment. The change is slightly different from the impregnated composite. This is due to the humidity and the time different is short which is one day only. The oil contain in the composite start to decrease when running the test since the viscosity index also low. The oil might be lost due to evaporation and also may be due to the dust at the surrounding because the test at the open area since the value of COF of 1 day without further soaking fully synthetic oil increased at 2200 m. this is shows that the composite easily lost the oil when the experiment is run at the open area and the viscosity index of the oil also low.

4.4 Total Weight Loss

The total weight of the composite must be taken before the experiment and after to get the weight loss of the composite for each test. The Figure 4.4 shows the total weight loss for all the test. The purpose is to find the total weight of lubricant loss after the tribology test. The result shows that the highest weight loss is composite impregnated by fully synthetic oil. As the viscosity is low, the movement of the oil inside and out of the composite become easier. After the tribology test, it can be seen the fully synthetic oil is left out at the machine. This is because the oil have low viscosity index, so during the test, the oil is coming out from the composite and leave the composite. Evaporation also one of the reason of reducing of weight of lubricant. This also cause the changing of COF and become higher.

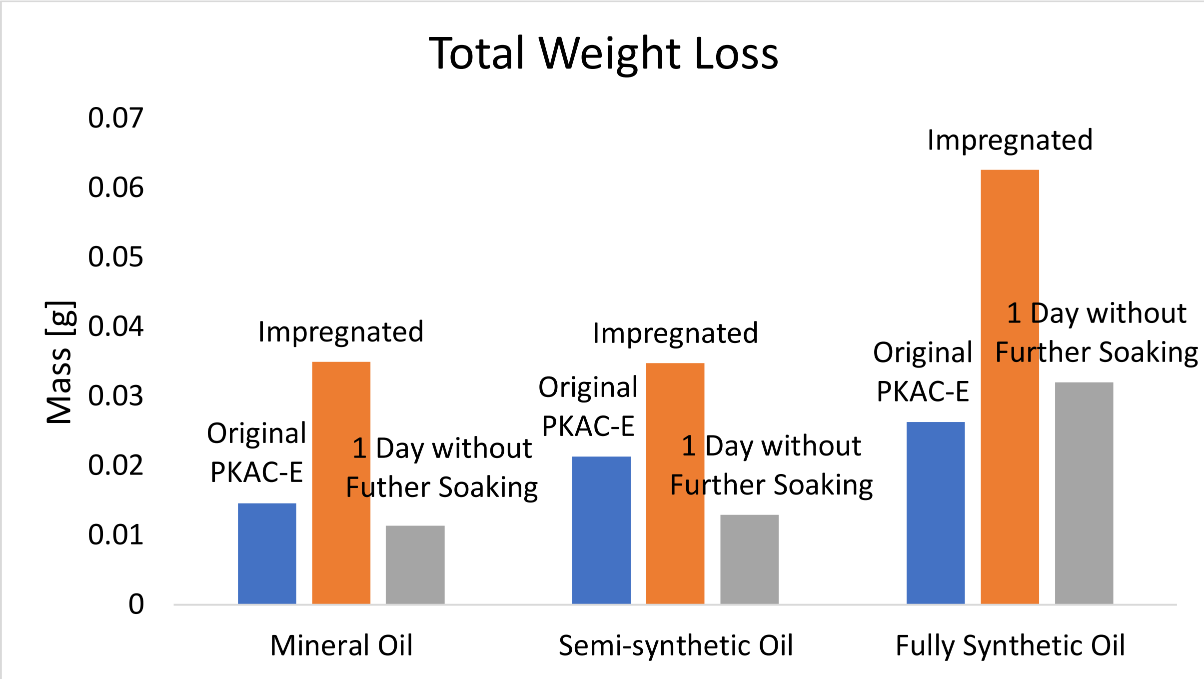

Figure 4.5 Total weight loss of the PKAC-E of original, impregnated and 1 day without further soaking for mineral oil, semi-synthetic oil and fully synthetic oil.

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATION

This study is about to get a better result of friction performance of PKAC-E when impregnated by lubricants and when it is not undergo further soaking for a day obtained by ball-on-disc tribometer test. This shows that the friction improvement can reduce the total organic waste because the waste can be transform into composite that very useful. This can reduce the cost, energy and money because organic waste is not expensive and biodegradable that will lead to environment saving.

I day without further soaking of mineral oil gives the best result where it has low coefficient friction and less total weight lost compared to the other composite. the oil contain inside of the mineral oil composite shows that the oil can keep stay inside the composite and keep remain in the composite even though has test under the 500 rpm which fully synthetic cannot remain the oil inside the composite and gives the highest total weight lost. The oil is very significant to the composite to make sure that the composite can remain at low coefficient of friction. When the composite experience high total loss of oil, it is shows that the oil did not protect the surface of the composite and will gives high coefficient of friction.

As shown in the Figure 4.1, Figure 4.2 and Figure 4.3, it shows clearly that the lubricant helps the composite achieve stable state faster compare to the original PKAC-E. the original PKAC-E is not stable at the beginning and start to stable at the certain period.

But the PKAC-E still give a low COF when the composite start to stable because due to its characteristic which is it has self-lubricating.

By referring to the result of coefficient of friction of all the composite, it shows that the coefficient of friction is at the range of piston ring coefficient of friction. This prove that the PKAC-E is suitable to replace or to coat the piston ring with a thin layer of PKAC-E in term of coefficient of friction.

For the future recommendation, this project can continued using the same lubricants which is mineral oil, semi-synthetic oil and fully synthetic oil but, use the same range of temperature inside the engine and get the maximum time of the PKAC-E can remain in the engine.

REFERENCE

A.K. Bledzki, & Gassan, J. (1996). Composities Reinforced with Cellulose Based Fibers. *Progress in Polymer Science*, *24*(2), 221–274.

Akpan, E. I., Wetzel, B., & Friedrich, K. (2018). A fully biobased tribology material based on acrylic resin and short wood fibres. *Tribology International*, *120*, 381–390. https://doi.org/10.1016/j.triboint.2018.01.010

B.V., E. (2019). Piston Ring. Retrieved May 19, 2019, from ScienceDirect website: https://www.sciencedirect.com/topics/engineering/piston-rings

Bashir, M., Saleem, S. S., & Bashir, O. (2015). Friction and Wear Behavior of Disc Brake Pad Material Using Banana Peel Powder. *International Journal of Research in Engineering and Technology*, *4*, 650–659.

Bedajangam, S. K., & Jadhav, N. P. (2013). *Friction Losses between Piston Ring-Liner Assembly of Internal Combustion Engine : A Review*. *3*(6), 2–4.

Chin, C. W., & Yousif, B. F. (2009). Potential of kenaf fibres as reinforcement for tribological applications. *Wear*, *267*(9–10), 1550–1557. https://doi.org/10.1016/j.wear.2009.06.002

Collier, B. J., Collier, J. R., Agarwal, P., & Lo, Y.-W. (1998). Extraction and evaluation of fibers from sugar cane. *American Journal of Cardiology*, *81*(6), 772–775. https://doi.org/10.1016/S0002-9149(97)01035-7

Dadkar, N., Tomar, B. S., & Satapathy, B. K. (2009). Evaluation of flyash-filled and aramid fibre reinforced hybrid polymer matrix composites (PMC) for friction braking applications. *Materials and Design*, *30*(10), 4369–4376. https://doi.org/10.1016/j.matdes.2009.04.007

Daud, W. M. A. W., & Ali, W. S. W. (2004). Comparison on pore development of activated carbon produced from palm shell and coconut shell. *Bioresource Technology*, *93*(1), 63–69. https://doi.org/10.1016/j.biortech.2003.09.015

Donnet, C., & Erdemir, A. (2004). Historical developments and new trends in tribological and solid lubricant coatings. *Surface and Coatings Technology*, *180–181*, 76–84. https://doi.org/10.1016/j.surfcoat.2003.10.022

Düpont, A., Lobo, E. A., da Costa, A. Ben, & Schuch, M. (2005). Avaliação Da Qualidade Da Água Do Arroio Do Couto, Santa Cruz Do Sul, Rs, Brasil. *Caderno de Pesquisa, Série Biologia*, *19*(1), 56–74. https://doi.org/10.4103/0970-9185.155206

Gomes, J. R., Silva, O. M., Silva, C. M., Pardini, L. C., & Silva, R. F. (2001). The effect of sliding speed and temperature on the tribological behavior of carbon-carbon composites. *Wear*, *249*(3–4), 240–245. https://doi.org/10.1016/S0043-1648(01)00554-3

Gurunathan, T., Mohanty, S., & Nayak, S. K. (2015). A review of the recent developments in biocomposites based on natural fibres and their application perspectives. *Composites Part A: Applied Science and Manufacturing*, *77*, 1–25. https://doi.org/10.1016/j.compositesa.2015.06.007

Jawaid, M., & Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate Polymers*, *86*(1), 1–18. https://doi.org/10.1016/j.carbpol.2011.04.043

k. friedrich, e.i. akpan, b. wetzel. (2018). *sliding wear performance of dry and oil impregnated black-fiber palm wood - a brief report*.

Kamel, M. M., Abdelghaffar, F., & El-Zawahry, M. M. (2011). Eco-friendly Dyeing of Wool with a Mixture of Natural Dyes. *Journal of Natural Fibers*, *8*(4), 289–307. https://doi.org/10.1080/15440478.2011.627114

Karaduman, Y., Sayeed, M. M. A., Onal, L., & Rawal, A. (2014). Viscoelastic properties of surface modified jute fiber/polypropylene nonwoven composites. *Composites Part B: Engineering*, *67*, 111–118. https://doi.org/10.1016/j.compositesb.2014.06.019

Karthikeyan, S., Rajini, N., Jawaid, M., Winowlin Jappes, J. T., Thariq, M. T. H., Siengchin, S., & Sukumaran, J. (2017). A review on tribological properties of natural fiber based sustainable hybrid composite. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, *231*(12), 1616–1634. https://doi.org/10.1177/1350650117705261

Koronis, G., Silva, A., & Fontul, M. (2013). Green composites: A review of adequate materials for automotive applications. *Composites Part B: Engineering*, *44*(1), 120–127. https://doi.org/10.1016/j.compositesb.2012.07.004

Levchik, S. V., & Weil, E. D. (2004). Thermal decomposition, combustion and flame-retardancy of epoxy resins - A review of the recent literature. *Polymer International*, *53*(12), 1901–1929. https://doi.org/10.1002/pi.1473

Mathur, N. M., & Bairwa, K. (2017). *A literature review on Composite material and scope of Sugar cane Bagasse*. *5*(4), 125–133.

Mohmad, M., Abdollah, M. F. B., Tamaldin, N., Amiruddin, H., & Jaharah, A. G. (2016). Tribological Characteristics of Surface Textured PKAC-E Created by Laser Surface Texturing under Boundary Lubrication. *Mohdfadzli.Com*, (August), 79–80. Retrieved from http://www.mohdfadzli.com/doc/p79-80.pdf

noor ayuma tahir, mohd fadzli bin abdollah, hilmi amiruddin. (2018). *friction improvement of palm kernel activated carbon by palm oil impregnation*.

Nur Azreen Bt Fuadi*, Ahmmed Saadi Ibrahim, K. N. I. (2012). *Review study for activated carbon from palm shell used for treatment of waste water*. *1*(5), 252–266.

O'Brien, D. J., Chin, W. K., Long, L. R., & Wetzel, E. D. (2014). Polymer matrix, polymer ribbon-reinforced transparent composite materials. *Composites Part A: Applied Science and Manufacturing*, *56*, 161–171. https://doi.org/10.1016/j.compositesa.2013.09.015

Paar, A. (2018a). SAE Viscosity Grades. Retrieved November 27, 2018, from Anton Paar

Paar, A. (2018b). Viscosity index. Retrieved November 27, 2018, from https://wiki.anton-paar.com/en/viscosity-index/

Pokhrel, D., & Viraraghavan, T. (2005). Municipal solid waste management in Nepal: Practices and challenges. *Waste Management*, *25*(5), 555–562. https://doi.org/10.1016/j.wasman.2005.01.020

Prakash, A., Sarkhel, G., & Kumar, K. (2015). Study of mechanical properties of kaolin reinforced epoxy composite. *International Journal of Applied Engineering Research*, *10*(11), 10080–10084. https://doi.org/10.1016/j.mspro.2014.07.070

Ramadan, N., Taha, I., Hammouda, R., & Abdellatif, M. H. (2017). Behaviour of hybrid SiC/jute epoxy composites manufactured by vacuum assisted resin infusion. *Polymers and Polymer Composites*, *25*(5), 333–344.

Rout, A. K., & Sahoo, S. S. (2014). *Study on Erosion Wear Performance of Jute-Epoxy Composites Filled With Industrial Wastes Using Taguchi Methodology 1 Arun Kumar Rout, 2 Sucharita Sanghamitra Sahoo*. *30*, 978–993.

RUGAYAH, A F*; ASTIMAR, A A** and NORZITA, N. (2003). Preparation and characterization of activated carbon from palm kernel shell by physical activation with steam. *Clinical Risk*, *9*(1), 18–22. https://doi.org/10.1258/135626203762301869

Rwawiire, S., Tomkova, B., Militky, J., Jabbar, A., & Kale, B. M. (2015). Development of a biocomposite based on green epoxy polymer and natural cellulose fabric (bark cloth) for automotive instrument panel applications. *Composites Part B: Engineering*, *81*, 149–157. https://doi.org/10.1016/j.compositesb.2015.06.021

Saravana Bavan, D., & Mohan Kumar, G. C. (2010). Potential use of natural fiber composite materials in India. *Journal of Reinforced Plastics and Composites*, *29*(24), 3600–3613. https://doi.org/10.1177/0731684410381151

Sawe, B. E. (2018). Top Palm Oil Producing Countries In The World. Retrieved November 27, 2018, from https://www.worldatlas.com/articles/top-palm-oil-producing-countries-in-the-world.html

Shakuntala, O., Raghavendra, G., & Samir Kumar, A. (2014). Effect of filler loading on mechanical and tribological properties of wood apple shell reinforced epoxy composite. *Advances in Materials Science and Engineering*, *2014*. https://doi.org/10.1155/2014/538651

Tanaka, H., Nagashima, T., Sato, T., & Kawauchi, S. (1999). Effect of 0W-20 Low Viscosity Engine Oil on Fuel Economy. *HONDA R&D Technical Review*, *11*(2), 143–148. https://doi.org/10.4271/1999-01-3468

Thakur, V. K., & Thakur, M. K. (2014). Processing and characterization of natural cellulose fibers/thermoset polymer composites. *Carbohydrate Polymers*, *109*, 102–117. https://doi.org/10.1016/j.carbpol.2014.03.039

Yousif, B. F., & Nirmal, U. (2011). Wear and frictional performance of polymeric composites aged in various solutions. *Wear*, *272*(1), 97–104. https://doi.org/10.1016/j.wear.2011.07.006

Yousif, B. F., Shalwan, A., Chin, C. W., & Ming, K. C. (2012). Flexural properties of treated and untreated kenaf/epoxy composites. *Materials and Design*, *40*, 378–385. https://doi.org/10.1016/j.matdes.2012.04.017