TRIBOLOGICAL BEHAVIOUR OF PALM OIL BY MIXING FLY ASH MICROPARTICLES AS A BIO-BASED LUBRICANT FOR MACHINING PROCESSES

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

TAY HOCK SENG
B051720029
970605-04-5197

FACULTY OF MANUFACTURING ENGINEERING
2021

UTeM

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **TRIBOLOGICAL BEHAVIOUR OF PALM OIL BY MIXING FLY ASH MICROPARTICLES AS A BIO-BASED LUBRICANT FOR MACHINING PROCESSES.**

Sesi Pengajian: **2020/2021 Semester 1**

Saya **TAY HOCK SENG (970605-04-5197)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

☑ √ TIDAK TERHAD

Disahkan oleh:

______________________ ______________________

Alamat Tetap:
No. 36, Jalan LP 12,
Taman Limbongan Permai,
75200 Melaka, Malaysia

Tarikh: 8/2/2021

Cop Rasmi:
ASSOC. PROF. DR. LIEW PAY JUN
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

Tarikh: 8/2/2021

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled "Tribological Behaviour of Palm Oil by Mixing Fly Ash Microparticles As a Bio-based Lubricant for Machining Processes" is the results of my own research except as cited in reference.

Signature : ………………………………………

Author's Name : TAY HOCK SENG

Date : 8 February 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

………………………………………

(PM. DR. LIEW PAY JUN)

ABSTRAK

Cecair pelincir digunakan secara meluas semasa proses pemesinan bagi mengurangkan haba yang dijana daripada proses pemotongan. Walau bagaimanapun, terdapat isu bahawa kos cecair pelincir semasa adalah tinggi dan tidak terbiodegradasi. Untuk mengisi jurang penyelidikan, kajian ini bertujuan untuk menghasilkan satu cecair pelincir biodegradasi yang berkos rendah. Objektif kajian ini adalah untuk mengkaji kesan kepekatan zarah-zarah mikro abu terbang yang berbeza dalam bio-pelincir minyak sawit pada pekali geseran, diameter parut kehausan dan permukaan tercalar bola keluli. Dalam penyelidikan ini, pelincir berasaskan bio telah disediakan dengan menyebarkan zarah-zarah mikro abu terbang pada kepekatan 0.02% berat, 0.04% berat, 0.06% berat, 0.08% berat, 0.10% berat, 0.12% berat dan 0.14% berat bersertakan Span 85 sebagai surfaktan dalam minyak sawit dengan menggunakan teknik ultrasonikasi. Ujian tribologikal telah dijalankan dengan menggunakan Tribometer Empat Bola mengikut standard ASTM D 4172. Morfologi permukaan telah dianalisis dengan menggunakan Mikroskop Elektron Imbasan (JEOL6010PLUS). Zarah-zarah mikro abu terbang yang berbentuk sfera didapati telah memberikan kesan menggolek yang paling ketara semasa ujian kehausan sehingga menyebabkan pekali geseran yang paling rendah, diameter parut kehausan yang paling kecil, dan permukaan tercalar yang paling licin pada kepekatan optimum iaitu 0.12% berat.

ABSTRACT

Liquid lubricants are widely used during machining process to reduce the heat generated from cutting process. However, issue occurs as the current liquid lubricants are high cost and not biodegradable. To fill this research gap, this study aims to produce a low-cost biodegradable liquid lubricant. The objective of this study is to investigate the effect of different concentration of fly ash microparticles in palm oil bio-based lubricant on the coefficient of friction, wear scar diameter and worn surfaces of steel ball. In this research, bio-based lubricants were prepared by dispersing fly ash microparticles at 0.02 wt.%, 0.04 wt.%, 0.06 wt.%, 0.08 wt.%, 0.10 wt.%, 0.12 wt.% and 0.14 wt.% concentrations and Span 85 was used as surfactant in palm oil using ultrasonication technique. The tribological test was conducted using Four Ball Tribometer according to the ASTM D 4172 standard. The surface morphology was analysed using Scanning Electron Microscopy (JEOL6010PLUS). The spherical shape of fly ash microparticles was found to provide most significant rolling effect during wear test that caused lowest coefficient of friction, smallest wear scar diameter and smoothest worn surface in optimum concentration which is at 0.12 wt.%.

DEDICATION

Only
my beloved father, Tay Peng Swee
my appreciated mother, Cheong Seck Neo
my adored sister and brother, Tay Chai Lian, Tay Hock Lye and Tay Chai Hua
for giving me moral support, money, cooperation, encouragement and also understandings
Thank You So Much & Love You All Forever

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my respected supervisor, PM. Dr. Liew Pay Jun for the kindness, unwavering patience and great mentoring that was given to me to complete the project.

I would like to give a thousand thanks to Wong Kah Yan, Yap Ching Yee, and Maisarah binti Kursus as my senior under supervision of PM. Dr. Liew Pay Jun for their willingness to hear my problems and give suggestions during the period of final year project. Last but not least, I would like to give a special thanks to all my best friends who gave me much motivation and cooperation mentally in completing this report.

Finally, I would like to thank everybody who was important to this final year project report, as well as expressing my apology that I could not mention personally each one of you.

TABLE OF CONTENT

Abstrak		i
Abstract		ii
Dedication		iii
Acknowledgement		iv
Table of Contents		v
List of Tables		viii
List of Figures		ix
List of Abbreviations		xi
List of Symbols		xiii
CHAPTER 1: INTRODUCTION		
1.1	Background of Study	1
1.2	Problem Statement	2
1.3	Objectives	3
1.4	Scope	4
1.5	Significant of Study	4
1.6	Organization of Report	5
CHAPTER 2: LITERATURE REVIEW		
2.1	K-Chart	6
2.2	Classification of Lubricant	7
	2.2.1 Solid lubricant	7
	2.2.2 Semi-solid lubricant	9
	2.2.3 Gas lubricant	9
	2.2.4 Liquid lubricant	10
	2.2.4.1 Mineral based oil	10
	2.2.4.2 Synthetic oil	11
	2.2.4.3 Bio-based oil	12
2.3	Tribological & Rheological Behaviour	14

2.3.1 Coefficient of friction 17
2.3.2 Wear 20
2.3.3 Viscosity 21
2.4 Surface Morphology 23
2.4.1 Worn surface 24
2.4.2 Surface roughness 25
2.4.3 Wear scar diameter 26
2.5 Additive Materials 28
2.5.1 Fly ash 33
2.5.1.1 Elements of fly ash 34
2.5.1.2 Properties of fly ash 36
2.5.1.3 Application of fly ash 37
2.6 Parameters 38

CHAPTER 3: METHODOLOGY
3.1 Materials Selection 42
3.1.1 Characterization of fly ash 42
3.1.2 Palm oil 43
3.2 Preparation of Bio-Based Lubricant 44
3.3 Tribological Test 45
3.4 Surface Morphology Observation 48

CHAPTER 4: RESULTS AND DISCUSSION
4.1 Tribological Properties of Bio-Based Lubricants 50
4.1.1 Coefficient of friction of steel ball on different fly ash microparticles concentrations 50
4.1.2 Wear scar diameter of steel ball 52
4.2 Surface Morphology Analysis of Steel Ball 54
4.3.2 Observation by SEM 54

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS
5.1 Conclusions 57
5.2 Recommendations 58
5.3 Sustainability Element 58

5.4 Lifelong Learning and Basic Entrepreneurship Element 58
5.5 Complexity Element 59

REFERENCES 60

LIST OF TABLES

2.1	Examples of hard and soft solid lubricant coatings	8
2.2	Examples of mineral hydrocarbons and their viscosity, molecular mass and carbon number at 5% distillation point	10
2.3	Characteristics of synthetic and vegetable-based base oil	11
2.4	Applications of synthetic lubricant categories	12
2.5	Modification methods on vegetable oils	13
2.6	Parameters of Four Ball Tester used by the 5 studies	16
2.7	Coefficient of friction of additives mixed with base oils at different concentrations	18
2.8	Wear reduction of base lubricants with additives	21
2.9	Viscosity of base lubricant with additives	23
2.10	Surface roughness obtained by other researchers	26
2.11	General types of additives	29
2.12	Different types of additives mixed with different types of base oil	31
2.13	Physical properties of fly ash	37
2.14	Comparison between two lubricants on the coefficient of friction	38
3.1	Chemical composition of fly ash microparticles	43
3.2	Properties of Malaysia palm oil	44
3.3	Lubricants produced with different concentrations of fly ash and palm oil	45
3.4	Parameter used to run Four Ball Tribometer	47
3.5	Wear Scar Diameter	49
4.1	Coefficient of friction	50
4.2	Wear scar diameter	53

LIST OF FIGURES

2.1 Structure of K-chart research flow 6

2.2 Layered lattice crystal structures of (a) molybdenum disulfide, (b) graphite and (c) hexagonal boron nitride 8

2.3 Friction, wear and lubrication takes place when two surfaces in contact to each other 14

2.4 Pin-on-disk tribometer 15

2.5 Ball-on-disk tribometer 15

2.6 Diagram of Four Ball Tester 16

2.7 Dynamic viscosity of nano-green cutting fluid with MoS_2 23

2.8 Dynamic viscosity of nano-green cutting fluid with CaF_2 23

2.9 Morphology of worn surfaces produced during wear tests with (a) sunflower oil, (b) 26 sunflower oil with SiO_2 nanoparticles at 1.25 wt.% and (c) sunflower oil with TiO_2 nanoparticles at 1.0 wt.% 25

2.10 Surface roughness obtained by using different cutting fluid 26

2.11 Wear scar diameter with temperature for different concentration of biodiesel 27

2.12 Optical micrograph of wear scar diameter: (a) pure neem oil, (b) 0.25% GNPs-NO, (c) 0.50% GNPs-NO, (d) 0.75% GNPs-NO and (e) 1.0% GNPs-NO 28

2.13 Wear scar diameter for variety of particle size 31

2.14 Friction coefficient against CNTs concentration 31

2.15 Fly ash 33

2.16 Chemical composition of fly ashes: Major and minor elements 34

2.17 Chemical composition of fly ashes: Class C fly ash and Class F fly ash 35

3.1 Research flow chart 41

3.2 Particle size analysis (Malvern Mastersizer 2000) 42

3.3 X-Ray diffractometer (PANalytical X'Pert Pro) 42

3.4 SEM image of fly ash microparticles 43

3.5 Ultrasonic homogenizer 45
3.6 Four ball tribometer 47
3.7 Schematic diagram of four ball tribometer 47
3.8 Scanning Electron Microscopy (JEOL6010PLUS) 48
3.9 3D Non-contact Optical Profilometer 49

4.1 Coefficient of friction 51
4.2 Schematic diagram of lubrication mechanism 51
4.3 Wear scar diameter 54
4.4 SEM image of worn surface on steel balls 55

LIST OF ABBREVIATIONS

Ag	-	Silver
AISI	-	American Iron and Steel Institute
Al_2O_3	-	Aluminium oxide
ASEM	-	Automated Scanning Electron Microscope
ASTM	-	American Society for Testing and Materials
CaF_2	-	Calcium Fluoride
CaO	-	Calcium Oxide
CNTs	-	Carbon Nanotubes
Cu	-	Copper
Fe_2O_3	-	Iron (III) Oxide
GCFs	-	Green Cutting Fluids
GNPs	-	Graphene Nanoplatelets
hBN	-	Hexagonal Boron Nitride
JMG	-	Jabatan Mineral dan Geosains Malaysia
K_2O	-	Potassium Oxide
LOI	-	Loss on Ignition
MDD	-	Maximum Dry Density
MgO	-	Magnesium Oxide
MoS_2	-	Molybdenum disulfide
Na_2O	-	Sodium Oxide
OMC	-	Optimum Moisture Content
PAG	-	Polyglycols
PAO	-	Poly-alpha-olefin
PI	-	Plasticity Index
POFA	-	Palm Oil Fly Ash
P_2O_5	-	Phosphorus Pentoxide
XRD	-	X-Ray Diffractometer
SE	-	Synthetic Ester
SEM	-	Scanning Electron Microscopy

SiO_2	-	Silicon Dioxide
SO_3	-	Sulfur Trioxide
SrO	-	Strontium Oxide
TiO_2	-	Titanium Dioxide
WS_2	-	Tungsten Disulfide
XRF	-	X-Ray Fluorescence
ZDP	-	Zinc Dithiophosphate

LIST OF SYMBOLS

%	-	Percentage
wt	-	Weight
^oC	-	Degree Celcius
kPa	-	Kilopascal
GPa	-	Gigapascal
Vol	-	Volume
nm	-	Nanometer
µm	-	Micrometer
cP	-	Centipoise
cm/sec	-	Centimeter per second
N	-	Newton
RPM	-	Revolution per minute
kJ/kg^oC	-	Kilojoule per kilogram-degree Celcius
kg/m^3	-	Kilogram per meter cube
W/m^oC	-	Watts per meter-degree Celcius

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Lubricant is a substance that is applied in between two moving surfaces to reduce friction, heat and wear. Currently, the most common lubricants in the market are the mineral oils (Abdollah et al., 2020). This is due to its low cost and good tribological performance. However, these mineral oils demonstrated a destructive environmental effect because they are not biodegradable and harmful. This will further lead to a higher cost in waste management. Furthermore, there is increasing concern on the use of these mineral oil lubricants on environmental impact as they were consumed about 38 million metric tons worldwide (Abdollah et al., 2020).

Nowadays, strict environmental regulations have forced the market to move toward bio-based lubricants because of their biodegradable properties. Not only that, bio-based lubricant or specifically vegetable oils have many good properties such as low volatility, high viscosity, low toxicity, high flash point and high lubricity. The most common types of vegetable oils used as lubricants that currently being researched on are sunflower oil, neem oil, jatropha oil and coconut oil. However, researchers have not treated palm oil in much detail. Therefore, palm oil will be used as base oil in this study. Abdollah et al. (2020) stated that palm oils produced a higher wear rate than mineral oils due to its incomplete oxidation and thermal stability, solidified at low temperature and low viscosity. Although these are the disadvantages of palm oil other than the environmental advantages, it can be fixed by mixing up with additive materials through process called ultrasonication.

The physical properties of the lubricant such as wear and corrosion can be intensified by introducing additive materials into the lubricant (Chan et al., 2018). The aim is to have a longer tool life span, less coefficient of friction and better performance on machining process. The most commonly used additive materials in the lubricants are graphite, molybdenum disulfide, tungsten disulfide (WS_2), ester and zinc dithiophosphate (ZDP) (Kopeliovich, 2012). Fly ash is a by-product of coal thermal power plants. Hower et al. (2017) has predicted that about 750 million ton of coal ash are generated all over the world annually. Fly ash can cause environmental pollution if does not dispose properly. Therefore, efforts have been made to recycle fly ash and thus fly ash is extensively used in concrete and ceramic industry due to its large surface area. Although extensive research has been carried out on applications of fly ash, however, the application of fly ash as additive materials in lubricant is still scarce. Therefore, in this study, fly ash will be used as the additive material that will be mixed into palm oil to become an environmental-friendly lubricant. The effect of fly ash microparticles mixed into palm oil on the tribological behaviour especially on the coefficient of friction and wear will be investigated.

1.2 Problem Statement

Machining is one of the most crucial processes in the manufacturing industry which involve the removal of materials from the stock or billet with a cutting tool. In machining operation, the removal of materials from the workpiece only used about 40% of energy (Astakhov, 2006). The other 60% of energy is used at the tool-chip and tool-workpiece interfaces. Tool-chip and tool-workpiece interfaces are the contacts areas that directly involved in the cutting process. Furthermore, all the energy spent during cutting process will be converted into heat energy (Bhirud and Gawande, 2017). When machining low strength alloys, less heat is generated but high heat will be generated when high strength alloys are machined due to increasing in cutting speed. The generated heat, if does not dissipate successfully, will affect the wear rate of cutting tool thus affecting the surface finished quality (Ogedengbe et al., 2019).

Many techniques were introduced to help in reducing the heat generated from the cutting process. One of the techniques is by using lubricant during the machining process. There are a few types of lubricant such as solid, liquid, semi-solid and gas lubricant. Liquid lubricant contains bio-based oil such as sunflower oil, neem oil and coconut oil. The tribological behaviour of these oils in machining processes are currently being researched by many researchers. However, there has been little quantitative analysis of palm oil as lubricant for machining process. Palm oil is known for its immeasurably proficient yield, which create more oil per land ratio than other vegetable oil crop such as soybean oil or coconut oil (Abdollah et al., 2020). Not only that, palm oil as lubricants exhibits great tribological properties when mixed with additive materials.

Additive materials or lubricant additives are chemical components that helps to improve the physical properties of a lubricant in machining process (Corporation, 2018). At present, oil mixed with additive materials such as graphite, graphene nanoplatelets (GNPs), molybdenum disulfide, tungsten disulfide (WS_2), ester and zinc dithiophosphate (ZDP) are widely used as lubricant for machining process (Kopeliovich, 2012). Although these additive materials helped in reducing coefficient of friction and wear rate of cutting tools, but they are expensive (Cao and Xia, 2017). Therefore, attentions are now centred to fly ash. Fly ash is cheap and it also exhibits certain excellent properties such as low coefficient friction and low wear rate when integrated in automotive brake lining friction composites (Mohanty and Chugh, 2007). Furthermore, fly ash is widely available as it is a by-product produced from the combustion of pulverized coal.

Currently, annual world production of fly ash is predicted to be over 500 million tonnes where only less than 20% of it is recycled and used as pozzolan to produce cement (Amran et al., 2020). The rest is disposed of in landfills and ash ponds. This will lead to environment pollution where the toxic compounds leach into underground waterbed. Therefore, the study of tribological behaviour of fly ash microparticles mixed with palm oil as an environment friendly lubricant needs to be done to reduce the effect of environment pollution.

1.3 Objectives

The purpose of this study is to investigate the tribological behaviour of palm oil by mixing fly ash microparticles as a bio-based lubricant for machining process. Detailed objectives of this study are as follows:

1. To investigate the tribological performance (coefficient of friction and wear) of the palm oil blended with fly ash microparticles.
2. To investigate the surface morphology of worn surfaces on the steel balls after the tribological test.

1.4 Scope

To achieve the objectives, few scopes are set as shown below:

1. Producing an environment-friendly lubricant using palm oil and fly ash microparticles as additives.
2. Mixing palm oil and fly ash microparticles of concentration ranging between 0.02 and 0.14 wt.% using ultrasonic homogenizer.
3. Testing the tribological behaviour of environment-friendly lubricant using Four Ball Tester (ASTM D 4172).
4. Observing surface morphology of worn surfaces using 3D non-contact optical profilometer and scanning electron microscopy (SEM).

1.5 Significant of Study

There are some benefits that can be obtained when this study is completed. First is the production of bio-based lubricant which is an environment-friendly lubricant that means it does not have or produce less impact on the environment pollution when being disposed of. Next, the cost of producing this lubricant will be reduced due to the use of fly ash as recycle materials. This is because fly ash is abundant, can be obtained easily and 60% of them in the world is not being recycled.

1.6 Organization of Report

The overall organization of the study took the form of five chapters, including this introductory chapter. Chapter 1 discussed on the background of study and the problems that were identified through multiple researches of journals, articles and current news. It was then followed by objectives that were set to be achieved through scope which narrowed down the area of the study. The significant of the study to the machining industry was also disclosed.

Chapter 2 began by reviewing the classifications of lubricants and followed by the types of oil available in each lubricant. It was then continued reviewing on the types of vegetable oils that people normally researched on. After that, definition of additive materials and the most common additives materials that were being used as lubricant additives was mentioned. Not only that, the additive material that were used in this study were also discussed. Lastly, the methods for experimenting the lubricants and the parameters were described.

Chapter 3 described the methods and procedures to achieve the objectives mentioned in this study. The flow started from explaining the materials used to the methods used to mix up the materials into lubricant. This was followed by the analysis or experiments to determine the tribological behaviour of bio-based lubricant and the surface morphology of worn surface produced on the steel ball.

Chapter 4 analysed the information and data collected after conducting tribological behaviour of bio-based lubricant through Four Ball Tester. Then, the surface morphology of worn surface of the steel ball were also observed and discussed in this chapter.

Chapter 5 summarized the tribological behaviour of the fly ash microparticles mixed with palm oil as an environment-friendly lubricant.

CHAPTER 2

LITERATURE REVIEW

2.1 K-Chart

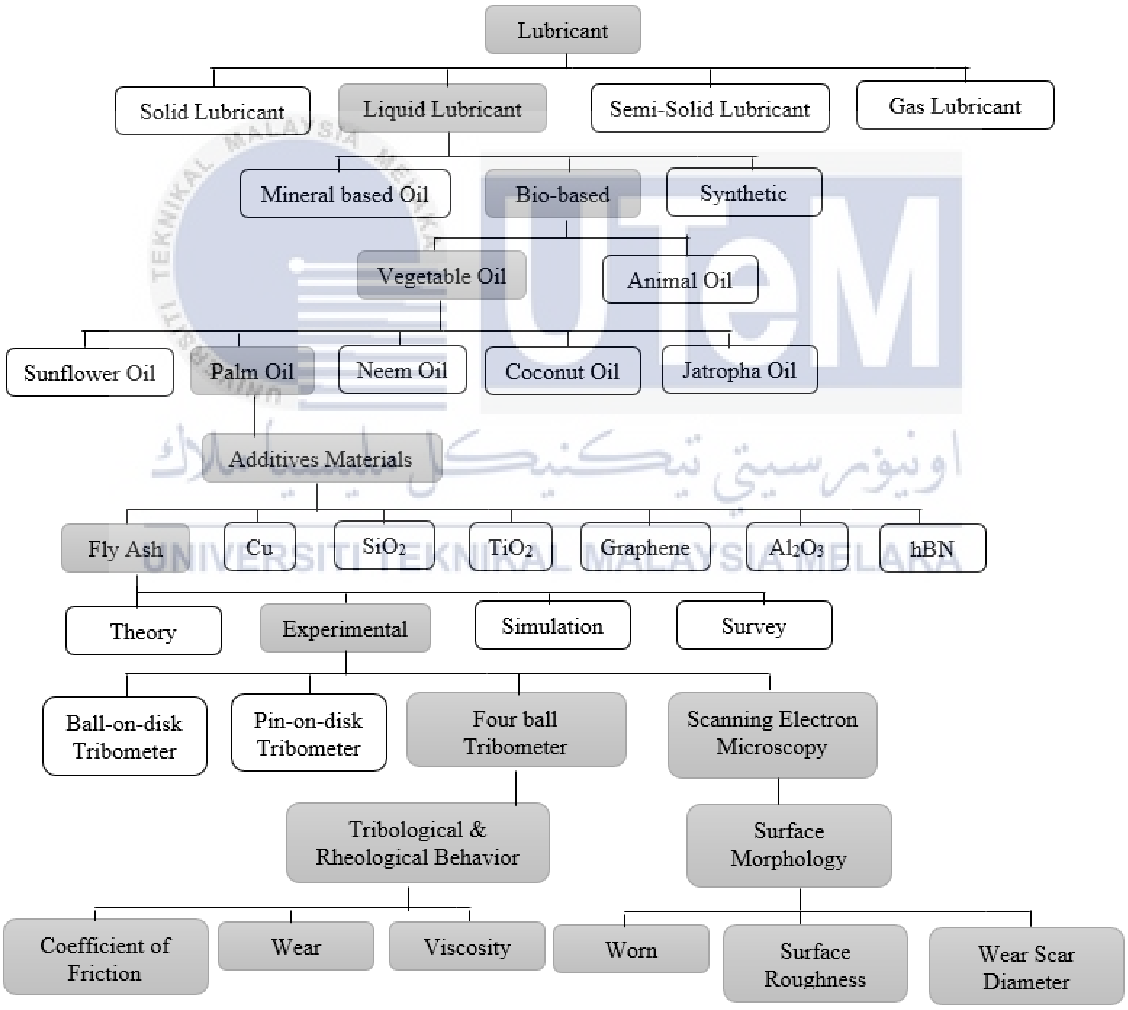

Figure 2.1: Structure of K-chart research flow

Figure 2.1 shows the structure of K-chart research flow for this study. K-chart is a tool that organizes the problems from the general ones to the specific ones within the area under study. K-chart consists of general title, issues layer, methods layer, results layer and timeline in the form of a tree diagram. The development of K-chart structure bases on the researcher requirement to achieve the objective in the study (Khazani et al., 2006). In this study, K-chart was developed to be used in this chapter and the next chapter, methodology.

2.2 Classification of Lubricant

Lubricant is an element that is used in between two surfaces to reduce friction, wear and tear. In machining processes, lubricants are used for heat transfer, lubrication and corrosion protection. In a high-level grouping of products, lubricant plays an important role in industry and transportation because there will be no energy transfer if no lubrication is available. According to Bart et al. (2013a), lubricants is classified into 4 groups which are solids, semi-solids, gas and liquids.

2.2.1 Solid lubricant

Solid lubricant is a material that able to reduce friction between two moving surfaces without requiring any other liquid substances. It is a material in the solid form. Bart et al. (2013a) mentioned in the article that solid lubricant is used as coating which can provide surfaces from being damaged by decreasing the friction, wear and tear of the two contacting surfaces. In another source, Bart et al. (2013b) stated that these solid lubricants are made up of solid, binder and additives. Solid lubricants are used during important cases where the lubricants had to stay in place. Usually have a temperature range where they are highly effective, these solid lubricants may degrade if they reach above their optimum temperature. For example, graphite as solid lubricants able to withstand temperature up to 650ºC before they start to degrade physically and chemically. According to Donnet and Erdemir (2006) and Campañá and Müser (2007), example of generally used solid lubricants are graphite, molybdenum disulfide, hexagonal boron nitride, boric acid and tungsten disulfide. Most of the solid lubricants have unique lubricating properties because they are associated with layered lattice crystal structure as shown in Figure 2.2.