TRIBOLOGICAL PERFORMANCES FOR PALM KERNEL ACTIVATED CARBON EPOXY COMPOSITES

NOOR AYUMA BINTI MAT TAHIR

MASTER OF SCIENCE
IN MECHANICAL ENGINEERING

2016

Faculty of Mechanical Engineering

TRIBOLOGICAL PERFORMANCES FOR PALM KERNEL ACTIVATED CARBON EPOXY COMPOSITE

Noor Ayuma Binti Mat Tahir

Master of Science in Mechanical Engineering

2016

TRIBOLOGICAL PERFORMANCES FOR PALM KERNEL ACTIVATED CARBON EPOXY COMPOSITE

NOOR AYUMA BINTI MAT TAHIR

A thesis submitted
In fulfilment of the requirements for the degree of
Master of Science in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitled “Tribological Performances for Palm Kernel Activated Carbon Epoxy Composite” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature	:	………..
Name	:	………………………………….......
Date	:	………………………………….......

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ……………………………………………..

Supervisor’s Name : …………………………………………….

Date : ……………………………………………

DEDICATION

To my beloved mother and father

ABSTRACT

Nowadays, it is expected that for most materials to be environmental friendly. Waste materials may be considered a secondary source of materials with an energetic advantage due to its high energy content. Consisting of a carbon material from agriculture wastes as new reinforcement substitutes in the fabrication of polymer matrix composites, are supposed to have large potential for a zero waste strategy in improving tribological properties at an affordable cost. Until today, based on our knowledge and from the literature review, there is no study regarding the potential of Palm Kernel Activated Carbon (PKAC) as solid lubricant in polymer matrix composites. Thus, a study on carbon materials from agriculture wastes has a great potential in tribological applications. The objectives of this study were to investigate the tribological performance of Palm Kernel Activated Carbon Epoxy composites and its wear mechanisms, and proposed wear and friction equations using Analysis of Variance (ANOVA). Basically, the composite were formed into pin shaped sizing of 30 mm height and 10 mm diameter using compaction technique. When the pin were ready, basic mechanical test were done. Then the pin were tested through pin-on-disc tribometer, then the surface morphology of the pin were studied through Scanning Electron Microscope (SEM) and Energy Dispersive Xray (EDX). The collected data were analysed through qualitative and quantitative approaches. From the study, it is interesting to find that the coefficient of friction and wear rate of the composite are highly affected by the composition and temperature due to the failure of the Epoxy bond. In addition, some traces of transfer layer were also found. Through comparison between friction and wear equations proposed with the experimental value, the equations shows average of 90.70% of reliability. Thus it can be said that the PKAC-E composite has high potential as the self-lubricating materials.

ABSTRAK

Bahan yang diguna pakai pada masa kini adalah sudah dijangkakan sebagai bahan mesra alam. Bahan buangan boleh diguna pakai sebagai bahan sumber kedua kerana bahan tersebut mempunyai kelebihan untuk beroperasi dengan kadar tenaga tambahan yang diperolehi dari kandungan tenaga yang tinggi. Bahan buangan agrikultur yang mengandungi karbon sebagai bahan penguat tambahan didalam komposit polimer adalah dijangkakan untuk mempunyai potensi yang besar sebagai bahan bebas pencemaran. Potensi bahan tersebut mempunyai kebaikan dalam menambah baik ciri-ciri tribologi dalam kadar yang berpatutan. Bedasarkan pengetahuan umum dan kajian sebelum ini, masih tiada lagi kajian berkaitan karbon aktif dari biji kelapa sawit sebagai pelincir keras didalam komposit polimer. Oleh yang demikian, kajian terhadap bahan karbon dari hasil buangan agrikultur mempunyai potensi besar terhadap aplikasi dalam bidang tribologi. Tujuan kajian ini adalah untuk mengkaji prestasi tribologi terhadap karbon aktif dari biji sawit bersama epoksi serta mekanisma haus komposit tersebut dan mengetengahkan model kehausan dan geseran menggunakan aplikasi ANOVA. Secara dasarnya, komposit dibentuk menjadi pin bersaiz 30mm tinggi serta 10mm diameter melalui teknik tekanan. Apabila pin tersebut telah siap, ujian mekanikal mudah dijalankan. Kemudian, pin diuji menggunakan ujian "pin-on-disc" lalu permukaan yang bercalar dan haus di analisis menggunakan "Scanning Electron Microscope" SEM dan "Electron Dispersive Xray" EDX. Data yang diperolehi dianalisis menggunakan pendekatan kualitatif dan kuantitatif. Berdasarkan hasil dapatan dari kajian, kadar tetapan geseran and kadar kehausan dari komposit tersebut adalah sangat dipengaruhi oleh kadar suhu dan komposisi berikutan kegagalan yang berpunca dari pegangan elemen epoksi. Selain dari itu, sebahagian kesan lapisan bahan yang terpindah juga berjaya dikesan. Melalui perbandingan antara persamaan kadar geseran dan kadar kehausan terhadap nilai kajian, model tersebut memaparkan purata sebanyak 90.70% kadar kebolehpercayaan. Oleh yang demikian, adalah wajar untuk mengatakan bahawa komposit PKAC-E berpotensi sebagai bahan pelincir sendiri.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere gratitude to my supervisor Assoc. Prof. Dr. Mohd Fadzli Bin Abdollah for his nonstop supervision, support, motivation, encouragement, and immense knowledge towards the completion of research and thesis writing.

I would also like to express my gratitude to Dr. Rafidah Binti Hassan as co-supervisor of this project for her unlimited advice and suggestions. Also to my deepest thanks to the Ministry of Education Malaysia for supporting this research by the grant (Grant No.: ERGS/2013/FKM/TK01/UTEM /02/04/E00016) and scholarship from MyBrain15.

Special thanks to the members of the Green Tribology and Engine Performance (G-TriboE) research group from CARe UTeM, and my colleagues especially Dr. Muhammad Ilman Hakimi Chua Bin Abdullah for his advices and guides. I would also like to express my deepest gratitude to Dr. Nor Azmmi Bin Masripan, for his contribution on giving ideas in every colloquium, Dr. Mohd Zulkefli Bin Selamat for giving ideas and solution on designing mould, all the technicians from the laboratory Faculty of Mechanical Engineering for their assistance and efforts in all the lab and analysis works.

Special thanks to my family and friends for their moral support in completing this project. Lastly, thank you to everyone who are not listed here who had been to the crucial parts of realization of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS AND SYMBOLS

θ	-	Angle (degree)
m	-	Mass
g	-	Gravity
nm	-	Nanometer
Σ	-	Summation
wt%	-	Weight Percent
µm	-	Micrometer
σ	-	Stress
ε	-	Strain
ρ	-	Density
T	-	Temperature
C	-	Composition
Ra	-	Surface Roughness
F	-	Applied Load
k	-	Specific Wear Rate
S/N	-	Signal to Noise Ratio
Cont %	-	Contribution Percent
COF	-	Coefficient of Friction
RPM	-	Rotation per Minutes
PKAC	-	Palm Kernel Activated Carbon
PKAC-E	-	Palm Kernel Activated Carbon reinforced Epoxy
SEM	-	Scanning Electron Microscope
EDX	-	Energy Dispersive Xray
DLC	-	Diamond Like Carbon
MMC	-	Metal Matrix Composite
PMC	-	Polymer Matrix Composite

LIST OF PUBLICATIONS

Article in Journals:

Mat Tahir, N.A., Abdollah, M.F.B., Hassan, R., Amiruddin, H. and Abdullah, M.I.H.C., 2016. Statistical Models for Predicting Wear and Friction Coefficient of Palm Kernel Activated Carbon-Epoxy Composite using the ANOVA. *Industrial Lubrication and Tribology*. ISI Q4 (Accepted for publication)

Mat Tahir, N.A., Abdollah, M.F.B., Hassan, R. and Amiruddin H., 2016. The effect of sliding distance at different temperatures on the tribological properties of a palm kernel activated carbon-epoxy composite. *Tribology International,* 94, pp. 352-359.
ISI Q1 (DOI: http://dx.doi.org/10.1016/j.triboint.2015.10.001).

Mat Tahir, **N.A.,** Abdollah, M.F.B., Hasan, R. and Amiruddin, H., 2015. The effect of temperature on the tribological properties of palm kernel activated carbon-epoxy composite. *Tribology Online*, 10. 6, pp. 428-433. SCOPUS (DOI: http://doi.org/10.2474/trol.10.428).

Chua, K.W., Abdollah, M.F.B., **Mat Tahir N.A.,** and Amiruddin, H., 2015. Frictional properties of palm kernel activated carbon-epoxy composite under various normal loads. *Jurnal Teknologi (Sciences and Engineering),* 76, pp. 1-4. SCOPUS
(DOI: http://dx.doi.org/10.11113/jt.v76.5783).

Conferences Attended:

Mat Tahir, N.A., Abdollah, M.F.B., Hassan, R. and Amiruddin, H., 2014. The effect on friction coefficient and wear rate of palm kernel activated carbon-epoxy (PKAC-E) composite at different temperatures. *Proceedings of 3rd Malaysia-Japan Tribology Symposium*, Kuala Lumpur, 12~14 November 2014.

Mat Tahir, N.A., Abdollah, M.F.B., Hassan, R. and Amiruddin, H., 2014. The effect of sliding distance on friction coefficient and Wear rate of palm kernel activated carbon-epoxy (PKAC-E) composites. *Proceedings of 2nd Advance Materials Conference*, Langkawi, 25~26 November 2014.

Competition Attended:

Mat Tahir, N.A., Abdollah, M.F.B., Hassan, R., Amiruddin, H., and Abdullah, M.I.H.C., 2016. Tribological performances for palm kernel activated carbon epoxy (PKAC-E) composites. *Tribology Poster Competition*, Universiti Malaya, Kuala Lumpur, 01 June 2016.

Awards:

Gold and Special Jury Award; Agro-waste for sustainable self-lubricating materials. UTeMEX2015 (Green Technology Category). *UTeM Research and Innovation Expo 2015,* Universiti Teknikal Malaysia Melaka, Melaka, 27~28 October 2015.

CHAPTER 1

INTRODUCTION

1.1 Background

Palm kernel activated carbon is actually the waste from palm oil extraction process. As shown in Figure 1.1, the palm oil is actually made up of exocarp, mesocarp, endocarp, and endosperm. After the extraction process, what is actually left to become activated carbon is the endocarp part, which is called the kernel. Through the extraction process, the potential of this kernel or endocarp is found through the ash content, the moisture content, and the physical condition—that is, high density, hardness, and volatile content.

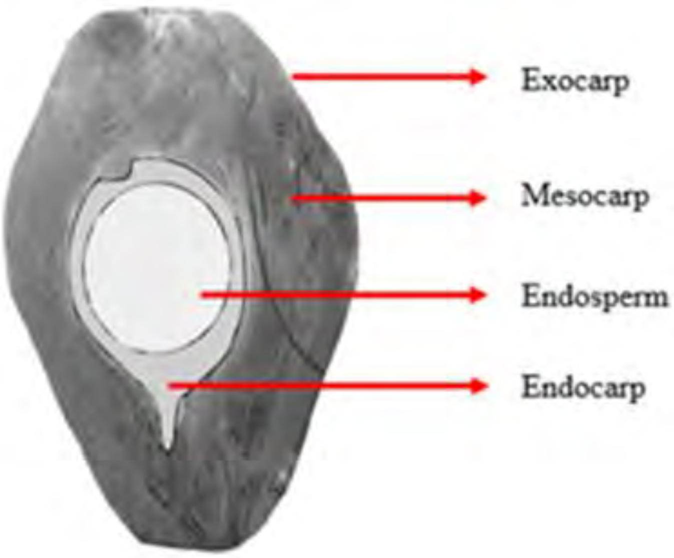

Figure 1.1 Components of palm oil fruit
[Source: http://www.bgrimmgreenpower.com/biodisel-sourcing.php]

Ash content can lead to increase hydrophilic ability and can have catalytic effects as well, causing restructuring process during regeneration of used activated carbon. The inorganic material contained in activated carbon is measured as ash content, generally in the range of 2 to 10%. Moreover, some activated carbons can absorb considerable moisture from over 25 to 30% for over a month under humid conditions, but maintain to appear dry. Although this obviously dilutes the carbon, sometimes, the moisture content does not affect the absorptive power of active carbons at all.

Recently, a significant shift to oil palm is an acknowledged emerging trend in the cooking oil industry. From Figure 1.2, it can be seen that Malaysia and Indonesia are leading other countries in the world's palm oil production. As global players in the palm oil market, it can be expected that there will be a huge abundance of palm oil waste or biomass in both countries. However, this waste may be reused in consideration that biomass can be recycled and transformed into potentially marketable value-added products with the help of additives and other materials.

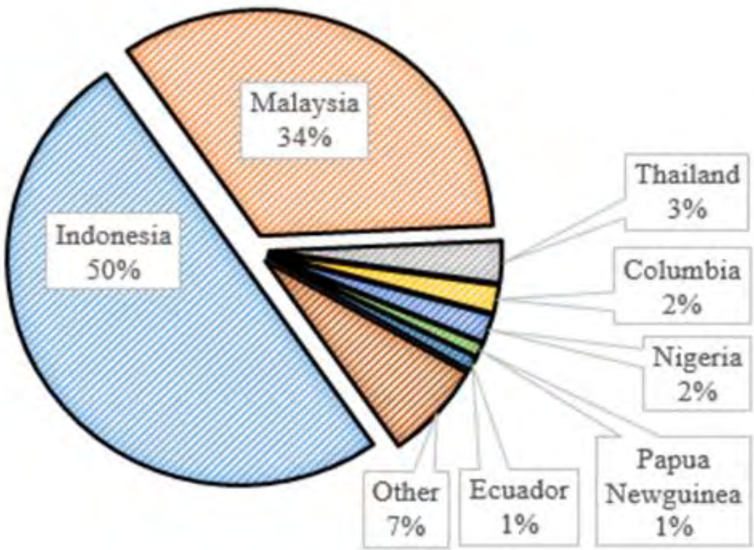

Figure 1.2 Distribution of palm oil worldwide in 2013
[Source: GreenPalm at slideshare.net]

1.2 Problem Statement

It has become a whole wide problem that friction and wear causing a huge amount of loss. The need to reduce friction and wear in the automotive industry to obtain maximum efficiency—while at the same time being environment-friendly by reducing waste—consistently creates an increasing demand for research in Tribology, especially in lubrication. Accordingly, presenting more efficient lubrication or self-lubricating materials may be the solution in overcoming these problems.

Nowadays, studies on carbon reinforced with various types of matrix as reinforcement has become popular as an alternative to current lubricating materials has become an attraction in Tribology field. Studies on the use of natural products such as fibre into composites have already been done by a number of researchers such as Nirmal et. al (2015) and Bakry et. al (2013). However, there is a research gap on the use of waste as self-lubricating materials.

It is noted that carbon may come in many forms such as fibres, flakes, tubes, and more [Brostow et. al (2010), Luo (2013), and Zamri and Shamsul (2011)]. In addition, amorphous carbon were found as waste product of palm oil seed, which is called activated carbon [Zamri et. al (2011)]. According to Zamri et. al (2011), activated carbon has the potential to act as a self-lubricating agent when reinforced with aluminium. It would be highly beneficial if these unique properties of carbon can be used as self-lubricating agents for reducing friction and wear besides reducing the waste product from the oil extraction process.

Meanwhile, oil extraction process from palm oil produces lots of waste that may become a problem on later days. This waste has potentials to become self-lubricating materials due to its residual oils, but with transformation as activated carbon.

To summarize, the need to maintain optimal function of automotive machines is a pressing issue that calls for efficient solutions. The direction is to recycle waste product, particularly of palm oil into self-lubricating materials. It is also a sustainable and environment-friendly alternative.

1.3 Objectives

The study objectives were largely influenced by findings from other previous studies as well as anchored on the potential of carbon in reducing friction and wear. The scope and limitations of the study further de-limits the study to the following objectives:

a) To investigate the tribological behaviour of palm kernel activated carbon reinforced epoxy composite at different temperatures and sliding distance;

b) To identify the predominant wear mechanisms of palm kernel activated carbon reinforced epoxy composite under dry sliding conditions;

c) To propose mathematical equations for friction and wear of palm kernel activated carbon reinforced epoxy composite using ANOVA.

1.4 Scope

This research is limited to the study of palm kernel activated carbon (PKAC) reinforced epoxy (E). Specifically, the parameters studied were sliding temperature ranging from 27 °C (room temperature) up to 150 °C. Meanwhile the sliding distance ranging from 500 m to 2500 m, sliding speed ranging from 500 m to 1750 m, composition of PKAC ranging from 60 % to 75 %, surface roughness (Ra) ranging from 0.2 µm to 0.8 µm, and applied load ranging from 19.62 N to 49.05 N. The details on selected ranges were discussed in chapter 3.3.

Accordingly, the work done in this study was divided into several stages. First, the samples were prepared using the compaction method, after which the specimens were subjected to hardness and density tests. After arriving at a suitable composition, the composites were first tested on the pin-on-disc tribometer testing or tribological test at different temperatures and sliding distances. It should be noted that these tests were done in order to analyse the behaviour of the composites under high temperature, and additionally, evaluate the effect on the composites at different sliding distances, including its effect on the sliding disc.

Likewise, the surface morphology of the worn surface was taken under Scanning Electron Microscopy (SEM) and energy dispersive X-ray (EDX) to determine chemical composition contents. Finally, data results from the tests were utilised to propose both wear and friction equation using Analysis of Variance or ANOVA. In addition, the Minitab statistical software was used to design the orthogonal arrays.

1.5 Thesis Structure

This thesis specially describes the effect on coefficient of friction and wear rate of PKAC-E on dry sliding conditions following ASTM G99 standards. There are five chapters briefly outlined as shown in Figure 1.3. The chapters of this paper are as follows:

Chapter 1 is an introduction to the potential of palm kernel activated carbon—a by-product of the growing palm oil industry— as a self-lubricating. In addition, this chapter describes the problems, purpose and objectives as well as the scope of the study.

Chapter 2 aims to clarify the importance as well as the need to understand tribological issues with a brief history of Tribology and basic theories on lubrications. In addition, this section discusses the effects of coefficient of friction and wear on metal matrix composite and polymer composite, including additional information on PTFE and DLC.

Chapter 3 gives a detailed description of the procedure and flow of the study. Related figures, tables, and illustrations in this chapter are in the Appendix.

Chapter 4 presents the findings of the study. Data results from the tests were interpreted from the context of some lubrication theories as well as by building on the findings of other related studies. The qualitative approach was used in the interpretation of data based on the observations from the surface morphology image while quantitative analysis, specifically, analysis of variance or ANOVA was used to interpret friction and wear data that was used to build the wear and friction model.

Lastly, Chapter 5 presents a summary of the major findings of this work and its implications for current research. In addition, through knowledge generated by the study, the authors suggest further research that can expand the field of study on using waste products as alternative sources for active carbon-based lubricating materials.