EXPERIMENTAL STUDIES ON TRIBOLOGICAL PROPERTIES OF RBD PALM OLEIN USING COPPER PIN

NURASMIDA BINTI MUHAMMAD AZMIN

A thesis submitted in partial fulfilment of the
requirement for the award of the degree of
Master of Science (*Mechanical Engineering*)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2017

TO MY BELOVED…

Husband (Muhammad Yazid Bin Che Mi)

Father (Muhammad Azmin Bin Ibrahim)

Mother (Normah Binti Zakaria)

Thanks for Your Support!!

ACKNOWLEDGEMENTS

First and foremost, I would like to thank to Allah SWT for His bless for giving me strength and opportunity to complete my Master Project which is one of part for course requirement that I am undergoing in Universiti Teknologi Malaysia (UTM). So I would like to take this golden opportunity to thank to those who are involved in this project. Specially, my utmost gratitude goes to these individuals who have contributed an immeasurable amount of guidance, advice and assistance along the Master Project time frame.

I would like to say a million of thanks to my project supervisor, Associate Professor Dr. Syahrullail Bin Samion for all his advices, encouragement, patience and comment that are given to me during the entire process of completing this master project. Other than that, my supreme thanks also to all staffs who involved, especially Mr Sahlan and Madam Jannah in their shared knowledge and help while conducting the experiments.

I also would like to express my gratitude to all of my fellow friends for their idea, supporting me to survive all kinds of challenges and always been on my side for all the time while completing this Master Project.

Last but not least, thanks to my beloved parents and husband for all their understanding, encouragement and support in term of moral and financial. Then, thanks to all that involved directly or indirectly in this project.

Thank you.

ABSTRACT

Lubricants have an important role in world industrial and economic development, mainly by reducing friction and wear in mechanical contacts. In the last 25 years, there has been an increasing interest in the use of biodegradable products due to environmental problems that have increased the need to limit pollution from lubricants and hydraulic fluids based on mineral oils. Therefore, vegetable oils are potential substitutes for petroleum-based oils according to their lubricating properties such as a high viscosity index, high lubricity, and low volatility. Other than that, vegetable oils also are environmentally friendly, renewable and less toxic. Thus, in this research, the tribological properties of refined, bleached and deodorized (RBD) palm olein were evaluated by determining the coefficient of friction, wear rate and wear scar diameter with different sliding speeds and applied loads. Besides that, the surface roughness and the surface wear of the cooper pin specimens were analysed lubricated with RBD palm olein for different sliding speeds and applied loads. The experiment is carried out by using pin-on-disk tester. The material used for pin specimen is copper and disk type SKD11. The lubricant used was supplied continuously on sliding surface of rotated disk at different sliding speeds from 1 m/s to 5 m/s and applied loads of 1 kg and 10 kg for one hour as recommended by the American Society for Testing and Materials (ASTM). From the analysis, the coefficient of friction and wear obtained lubricated with RBD palm olein was the lowest compared to SAE40 engine oil for both conditions of different sliding speeds and applied loads of 0.011 at 1 m/s for 10 kg load and 0.62 $x10^{-5}$ mm^3m^{-1} at 1 m/s for 1 kg load respectively. RBD palm olein shows better anti-friction and anti-wear performances compared to SAE40 engine oil in term of coefficient of friction and wear at different sliding speeds and applied loads. Therefore, palm oil has the possibility to be used as a lubricant by mating component.

ABSTRAK

Pelincir mempunyai peranan yang penting dalam pembangunan industri dan ekonomi dunia, terutamanya untuk mengurangkan geseran dan haus dalam kenalan mekanikal. Dalam tempoh 25 tahun yang lalu, terdapat minat yang semakin meningkat dalam penggunaan produk mesra alam kerana masalah alam sekitar yang telah meningkatkan keperluan untuk menghadkan pencemaran dari pelincir dan cecair hidraulik berasaskan minyak mineral. Oleh itu, minyak sayuran adalah pengganti berpotensi untuk minyak berasaskan petroleum mengikut sifat-sifat pelincir mereka seperti indeks tinggi kelikatan, pelinciran yang tinggi, dan turun naik yang rendah. Selain itu, minyak sayuran juga mesra alam yang boleh diperbaharui dan kurang toksik. Oleh itu, dalam kajian ini, sifat-sifat nilai pemalar geseran dan ciri haus bertapis, diluntur dan dinyahbau (RBD) olein sawit telah dinilai dengan menentukan pekali geseran, kadar haus dan diameter parut dengan kelajuan gelongsor yang berbeza dan beban yang dikenakan. Eksperimen ini dijalankan dengan menggunakan penguji pin-on-cakera. Bahan yang digunakan untuk spesimen pin adalah tembaga dan cakera jenis SKD11. Minyak pelincir yang digunakan dibekalkan secara berterusan pada permukaan cakera berputar gelongsor pada kelajuan gelongsor yang berbeza dari 1 m/s hingga 5 m/s dan beban adalah 1 kg dan 10 kg bagi satu jam digunakan seperti yang disyorkan oleh Persatuan Amerika untuk Ujian dan Bahan (ASTM). Dari analisis, pekali geseran dan kadar haus diperolehi dilincirkan dengan minyak kelapa sawit olein RBD adalah paling rendah berbanding dengan minyak enjin SAE40 untuk kedua-dua keadaan kelajuan gelongsor yang berbeza dan kadar haus ialah 0.011 dikenakan pada 1 m/s untuk beban 10 kg dan 0.62 $x10^{-5}$ mm^3m^{-1} pada 1 m/s untuk 1 kg beban. Minyak kelapa sawit olein RBD menunjukkan lebih baik anti-geseran dan anti-haus berbanding minyak enjin SAE40 dari segi pekali geseran dan kadar haus pada kelajuan gelongsor yang berbeza dan beban yang dikenakan. Oleh itu, minyak sawit mempunyai kemungkinan untuk digunakan sebagai minyak hitam dengan gabungan dua komponen.

TABLE OF CONTENTS

2 LITERATURE REVIEW

3 METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RBD	-	Refined, Bleached and Deodorized
SAE	-	Society of Automotive Engineers
ASTM	-	American Society for Testing and Materials
COF	-	Coefficient of Friction
WSD	-	Wear Scar Diameter
CCD	-	Charge-Coupled Device
EVA	-	Ethylene-Vinyl Acetate
MPOB	-	Malaysia Palm Oil Board
VI	-	Viscosity Index
LVDT	-	Linear Variable Differential Transducer
RPM	-	Revolution Per Minute
mm	-	Milimeter
m/s	-	Meter Per Second
kg	-	Kilogram
N	-	Newton

LIST OF NOMENCLATURE

μ	-	Coefficient of Friction
F	-	Friction Force
N	-	Normal Load
F_p	-	Rate of Angular Friction Force
F_N	-	Applied Normal Load
d_p	-	The Distance Between Center to the Pin
d_N	-	The Distance Between Center to Normal Force
Q	-	Wear Rate
Δv	-	Volume Loss
s	-	Sliding Distance
M	-	Mass Loss
ρ	-	Density
μ	-	Micro
R_a	-	Surface Roughness
ºC	-	Degree Celcius
v	-	Kinematic Viscosity

CHAPTER 1

INTRODUCTION

1.1 Research Background

Wear and friction produced or created due to the two contact surfaces in relative motion. Based on engineering field, the components of engines or machines that continuously run in a long period of time will more severe. The mating components will damage caused by friction and wear. In order to overcome this problem, lubricant as a suitable candidate to be selected to reduce friction and wear of two contact surfaces. Consequently, the systems of engines or machines will operate with an extended time. In addition, adequate lubrication allows smooth continuous operation of equipment with only mild wear and without excessive stresses. Apart from that, the conventional lubricant from petroleum based had been used widely for so long times ago as lubrication oil. Nevertheless, by using petroleum based as lubricant it will cause environmental pollution from being disposed into the environment without undergo any treatment. As earth becomes more polluted, human tend to increase their awareness regarding environmental and health issue, society puts an extra effort to replace or reduce the usage of conventional petroleum based lubricant.

Nowadays, in a modern world technology development the industries are looking for efficient ways to reduce friction and wear while designing the new products. Other that that, the research and development in lubricant technology have been carried out by numerous researchers to find better ways to protect the environment or at least to reduce environmental pollutants is driven by public

demand, industry concerns, and governmental agency policies. Moreover, it is only natural that lubricant technology has advanced as a result of concerns for protecting and preserving the environment in all aspects of our lives. The negative impact of the spillage or leakage of lubricants has led to the development of oils and greases that are less detrimental to the environment if inadvertently spilled or leaked.

In Malaysia, the richness of the palm oil has potential to develop and used it as alternative lubricant. The palm oil is widely used in industrial applications for engines and machines. The widely production of palm oil in Malaysia has influenced numerous researchers to study on the palm oil as an alternative oil compared to the mineral oil. As a user and observant, we know that the source of mineral oil will become lesser in the future. That's the reason people are looking forward to palm oil, instead of current use in the food industry, it is very pleasant if the usage of palm oil could be extend to other field like machinery and heavy industry. Meanwhile, the palm oil is economical due to low cost. In addition, vegetable oil as the potential source of environmentally friendly lubricant regarding to their advantages which are non-toxicity, high biodegradability, renewable resources and good low temperature properties.

1.2 Problem Statement

Vegetable oils as potential source of environmentally favourable lubricants, due to combination of biodegradability, renewability and excellent lubrication performance. Based on the potential source, vegetable oil is desirable to be chosen as a replacement for conventional lubricant. In addition, vegetable oil is one of alternatives to be considered substituting petroleum based lubricant for any application related such as industrial and transportation activities. However, there are some limitation of vegetable oil that need to be considered that such as low oxidation and thermal stability, poor low–temperature properties and narrow range of available viscosities. Furthermore, some vegetable oil tends to solidify when goes below, then room temperature and some of vegetable oil are readily in solid state even at room temperature. It became crucial issue and problems when down to the application.

Lubricant need to be in a liquid state when in application because need to heat first before used.

Apart from that, the palm oil is used as an alternative oil in tribological test is conducted in order to verify the ability of palm oil to replace mineral oil, since our country was rapidly growth and developed in the palm oil industry. Meanwhile, palm oil has been widely used in industrial applications for engines and machines. Thus, the physical properties and characteristics of the palm oil also are studied in order to understand the limitations and benefits of palm oil compared to the mineral oil. Therefore, the tribological test is conducted in this research to study the lubricity performance of lubricant in terms of friction and wear created. Hence, the types of lubricant used in this study is varying such as SAE40 engine oil and RBD palm olein. Besides that, pin-on-disk tribotester machine are used as a tool of measurement in order to determine wear and frictional force. However, the contact surface between pin and rotating disk will create and produce friction and wear, but it is limited to the small contact area surface.

1.3 Research Objectives

The objectives of this research are as follows:

i. To determine the coefficient of friction value of RBD palm olein tested with different sliding speeds and applied loads.
ii. To determine the wear rate value and the wear scar diameter of RBD palm olein tested with different sliding speeds and applied loads.
iii. To analyse the surface roughness and surface wear of the tested lubricants under different sliding speeds and applied loads.

1.4 Scope of Research

The study is done to highlight the behaviour and performance of RBD palm olein under the different sliding speed and applied load. The scopes of the study are:

i. Different sliding speeds from 1 m/s to 5 m/s are applied in this study.
ii. Two different loads of 1 kg and 10 kg are applied in this study.
iii. Refined, bleached and deodorized (RBD) palm olein and SAE40 engine oil as lubricant tested.
iv. The material of pin is Copper and the material of disk is SKD11.
v. The lubricants are continuously supplied during the experiment.

1.5 Theoretical Framework

The research study is planned systematically in order to get the desired and successful results. Hence, the theoretical framework of the research is made by referring the Figure 1.1. The theoretical framework can be clearly seen on how the research study is carried out.

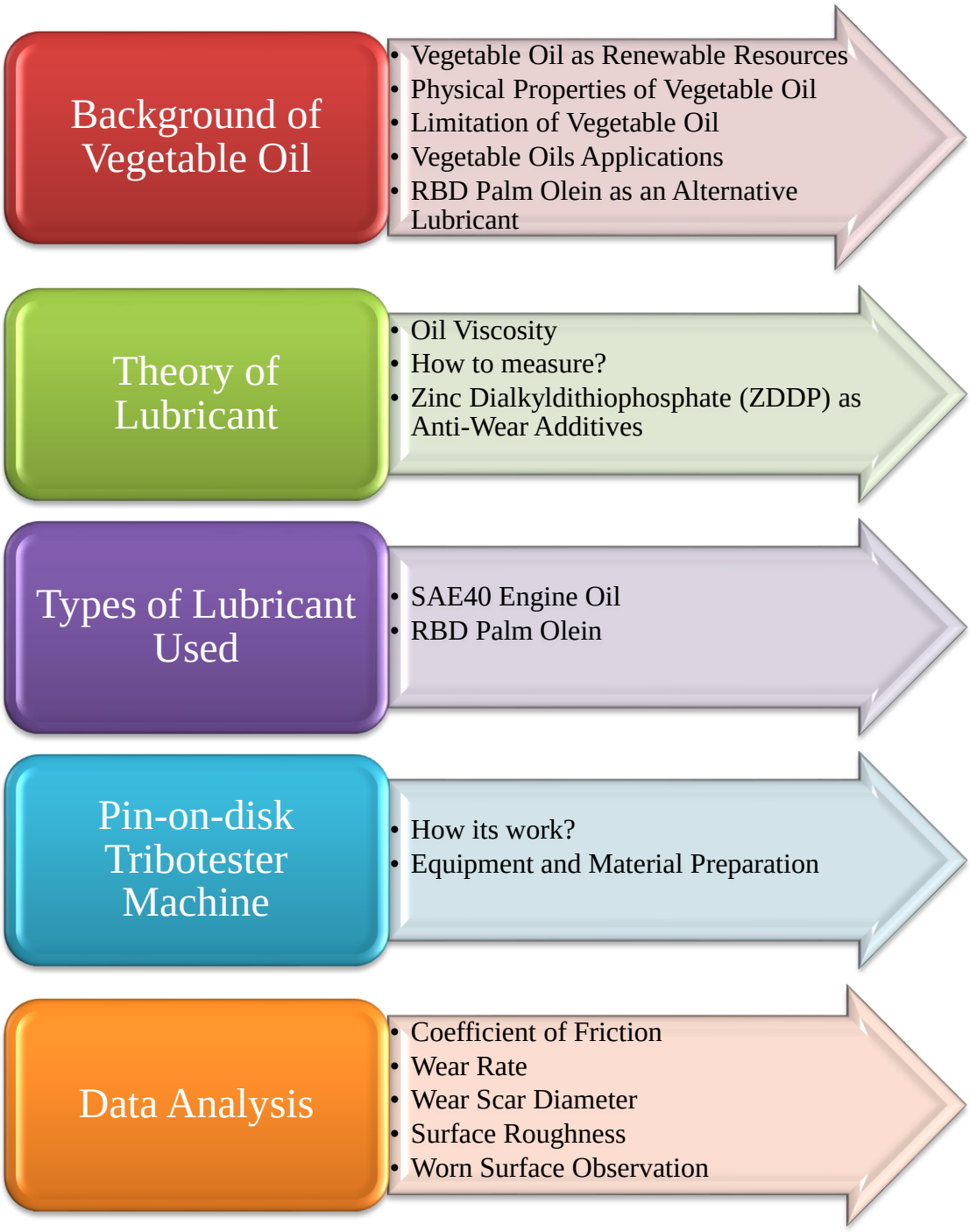

Figure 1.1: Theoretical Framework of the research

1.6 Research Outline

This research consists of five main chapters where each chapter will focus on the topics as follows:

Chapter 1 is an introduction to the research study where it describes briefly the background of the research, the problem statement, the research objectives, the research scope and the theoretical framework.

Chapter 2 of the research contains a literature review for the purpose of understanding the topic of the research in detail. Moreover, in this chapter also presents the physical properties of the vegetable oil as a renewable resource. Furthermore, limitation and application of vegetable oil also has been included. In addition, the experiment on pin-on-disk conducted by numerous researchers is being studied in detail in terms of the parameter and method carried out.

Chapter 3 describes the methodology adopted for the research. Also describes about on how the equipment and material preparations of the experiment are made. Meanwhile, the procedure of experimental on pin-on-disk tribotester and data collection of the research methodology also are focussed.

In chapter four, the final result discusses the results obtained from the study. The discussion to be made based on the result obtained. Hence, the results are being analyzed in this chapter as well. The arguments and evidences on the results also have been discussed.

The last chapter as chapter five will formulate the overall conclusion and findings obtained from this research study. This chapter starts by restating the objective of the study and the outcome of the research. The conclusions will be made based on the methodology selected for this research and the results obtained. To reinforce the outcome of this project, some recommendations were made at the end of this chapter where the propose future studies to be carried out.

REFERENCES

[1] Abdullah, M. A., Saleman, S. A., Tamaldin, N., & Suhaimi, M. S. (2013). Reducing wear and friction by means of lubricants mixtures. Procedia Engineering, 68, 338–344.

[2] Michael, L.W., Gregory, S. and Pushkarraj, D. (2006). On the friction and wear performance of boric acid lubricant combinations in extended duration operations. Wear, 260, 1295–1304.

[3] Izhan, M. I., Wira, J. Y., Abdul Kadir, M. R., & Syahrullail, S. (2013). Experimental Study on the Effect of Different Speeds Applied with Palm Olein Using Pin-on-Disk Tester. Applied Mechanics and Materials, 315, 946-950.

[4] Stachowiak, G. W., & Batchelor, A. W. (2006). Physical Properties of Lubricants. In G. W. S. W. Batchelor (Ed.), Engineering Tribology (Third Edition),11-50. Burlington: Butterworth-Heinemann.

[5] Fox, N. J., & Stachowiak, G. W. (2007). Vegetable oil-based lubricants-A review of oxidation. *Tribology International*, *40*(7), 1035–1046.

[6] Ing, T. C., Mohammed Rafiq, A. K., Azli, Y., & Syahrullail, S. (2012). The Effect of Temperature on the Tribological Behavior of RBD Palm Stearin. Tribology Transactions, 55(5), 539–548.

[7] Shahabuddin, M., Masjuki, H. H., & Kalam, M. A. (2013). Experimental investigation into tribological characteristics of biolubricant formulated from Jatropha oil. *Procedia Engineering*, *56*, 597–606.

[8] Stemmelen, M., Lapinte, V., Habas, J. P., & Robin, J. J. (2015). Plant oil-based epoxy resins from fatty diamines and epoxidized vegetable oil. *European Polymer Journal*, *68*, 536–545.

[9] Kalam, M. A., Masjuki, H. H., Shahabuddin, M., & Mofijur, M. (2012). Tribological characteristics of amine phosphate and octylated / butylated diphenylamine additives infused bio-lubricant, *30*(1), 123–136.

[10] Siniawski, M. T., Saniei, N., Adhikari, B., & Doezema, L. (2008). Influence of Fatty Acid Composition on the Tribiological Performance of Two Vegetable-Based Lubricants. Journal of Synthetic Lubrication, 25(March), 45–55.

[11] Castro, W., Perez, J. M., Erhan, S. Z., & Caputo, F. (2006). A study of the oxidation and wear properties of vegetable oils: Soybean oil without additives. JAOCS, Journal of the American Oil Chemists' Society, 83(1), 47–52.

[12] Battersby, N.S., Pack, S.E., Watkinson, R.J., (1998). A correlation between the biodegradability of oil products in the CEC L-33-T-82 and modified strum tests. Chemosphere 24, 1998–2000.

[13] Randles, S.J., Wright, M. (1992). Environmentally considerate ester lubrication for the automotive and engineering industries. Journal of Synthetic Lubrication, 9, 145–161.

[14] Jayadas, N. H., Prabhakaran Nair, K., & G, A. (2007). Tribological evaluation of coconut oil as an environment-friendly lubricant. Tribology International, 40(2 SPEC. ISS.), 350–354.

[15] Alla, M. P. and Richard, J. A. (2004). Oxidation Stability and Tribological Behavior of Vegetable Oil Hydraulic Fluids. Tribology Transactions, 47(2), pp 182–187.

[16] Erhan, S. Z., Sharma, B. K., & Perez, J. M. (2006). Oxidation and low temperature stability of vegetable oil-based lubricants. Industrial Crops and Products, 24(3), 292–299.

[17] Syahrullail, S., Nakanishi, K., Kamitani, S. (2005). Investigation of the Effects of Frictional Constraint with Application of Palm Olein Oil Lubricant and Paraffin Mineral Oil Lubricant on Plastic Deformation by Plane Strain Extrusion, Journal of Japanese Society of Tribologist,50, 12, pp.877-885.

[18] Rudnick, L., (2002). Biobased Industrial Fluids and Lubricants, AOCS Press, Champaign, IL.

[19] Jayadas, N. H., & Nair, K. P. (2006). Coconut oil as base oil for industrial lubricants- evaluation and modification of thermal , oxidative and low temperature properties, 39, 873–878.

[20] Fox, N., Tyrer, B., & Stachowiak, G. (2004). Boundary lubrication performance of free fatty acids in sunflower oil. Tribology Letters, 16(4), 275–281.

[21] Castro, W., Weller, D. E., Cheenkachorn, K., & Perez, J. M. (2005). The effect of chemical structure of basefluids on antiwear effectiveness of additives, 38, 321–326.

[22] Erhan, S. Z., & Asadauskas, S. (2000). Lubricant basestocks from vegetable oils. Industrial Crops and Products, 11(2-3), 277–282.

[23] Vizintin, J., Arnsek, A. and Ploj, T. (2000). Lubricating properties of rapeseed oils compared to mineral oils under a high load oscillating movement. J. Synthetic Lubrication, 17: 201–217.

[24] Quinchia, L. A., Delgado, M. A., Reddyhoff, T., Gallegos, C., & Spikes, H. A. (2014). Tribological studies of potential vegetable oil-based lubricants containing environmentally friendly viscosity modifiers. Tribology International, 69, 110–117.

[25] Delgado, M. A., Quinchia, L. A., and Galegos, C. (2010). Viscosity Modification of Different Vegetable Oil with EVA Copolymer for Lubricant Applicants. Industrial Crops and Products, 32, pp 607–612.

[26] Delgado, M. A., Garcia-Rico, M., Franco, J. M. (2014). The use of rosemary extracts in vegetable oil-based lubricants. Industrial Crops and Products 62; 474–480.

[27] Jayadas, N. H., Prabhakaran Nair, K., & G, A. (2007). Tribological evaluation of coconut oil as an environment-friendly lubricant. Tribology International, 40(2 SPEC. ISS.), 350–354.

[28] Shahabuddin, M., Masjuki, H. H., & Kalam, M. A. (2013). Experimental investigation into tribological characteristics of biolubricant formulated from Jatropha oil. Procedia Engineering, 56, 597–606.

[29] Rudnick, L. R. (2006). Synthetics, mineraloils, and bio-based lubricants: chemistry and technology. In: Rudnick LR, Erhan S Z,editors. Natural oils as lubricants. New York: CRC/Taylor &Francis Group.

[30] Mohammed Rafiq, A. K., Syahrullail, S., & Izhan, M. I. (2014). Tribological investigation of RBD Palm Olein in different sliding speeds using pin-on-disk tribotester. 21(1),162-170.

[31] Farooq, M., Ramli, A., Gul, S. and Muhammad, N. (2011). The study of wear behaviour of 12-hydroxystearic acid in vegetable oils", Journal of Applied Sciences, 11(7), pp. 1381-1385.

[32] Pantzaris, T.P. (2000). Pocketbook of Palm Oil Uses, 5th Edn., Malaysian Palm Oil Board.

[33] Mondal, D. P., Das, S., Rao, R. N., & Singh, M. (2005). Effect of SiC addition and running-in-wear on the sliding wear behaviour of Al-Zn-Mg aluminium alloy. Materials Science and Engineering A, 402(1-2), 307–319.

[34] Lozano, D. E., Mercado-Solis, R. D., Perez, A. J., Talamantes, J., Morales, F., & Hernandez-Rodriguez, M. A. L. (2009). Tribological behaviour of cast hypereutectic Al-Si-Cu alloy subjected to sliding wear. Wear, 267(1-4), 545–549.

[35] Rao, R. N., Das, S., Mondal, D. P., & Dixit, G. (2009). Dry sliding wear behaviour of cast high strength aluminium alloy (Al-Zn-Mg) and hard particle composites. Wear, 267(9-10), 1688–1695.

[36] Rao, R. N., Das, S., Mondal, D. P., & Dixit, G. (2010). Effect of heat treatment on the sliding wear behaviour of aluminium alloy (Al-Zn-Mg) hard particle composite. Tribology International, 43(1-2), 330–339.

[37] Daoud, A., & Abou El-khair, M. T. (2010). Wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material. Tribology International, 43(3), 544–553.

[38] Kelly, G. L., & Finlayson, T. R. (1998). Modification of a pin-on-disk wear machine for rolling contact wear. Wear, 214, 287–288.

[39] Syahrullail, S., Nuraliza, N., Izhan, M. I., Abdul Hamid, M. K., & Razaka, D. M. (2013). Wear characteristic of palm olein as lubricant in different rotating speed. Procedia Engineering, 68, 158–165.

[40] Izhan, M. I., Wira, J. Y., Abdul Kadir, M. R., & Syahrullail, S. (2013). Experimental Study on the Effect of Different Speeds Applied with Palm Olein Using Pin-on-Disk Tester. Applied Mechanics and Materials, 315, 946–950.

[41] N. Sapawe, S. Syahrullail, M. I. I. (2014). Evaluation on the tribological properties of palm olein in different loads applied using pin-on-disk tribotester. Jurnal Tribologi, 3(August), 11–29.

[42] Windarta, M.B.S. and Khairul, F. (2011). Inuence of applied load on wear characterizations of rail material", Journal of Applied Science, 11(9), pp. 1636-1641.

[43] Tu, C.F. and Fort, T. (2004). A study of fiber–capstan friction–Stribeck curves. Tribology International, 37, 701–710.

[44] Temel, S. and Zeki, A. (2008). An investigation of lubricated friction and wear properties of Zn-40Al-2Cu-2Si alloy in comparison with SAE 65 bearing bronze", Wear, 264, pp.920-928.

[45] Williams, J. (2005). Engineering Tribology, Cambridge University Press, Cambridge, UK.

[46] Ching-Fang, T. and Tomlinson, F. (2004). A study of Stribeck curves. Tribology International, 37, pp. 701-710.

[47] Chowdhury, M.A., Khalil, M.K., Nuruzzaman, D.M. and Rahaman, M.L. (2011). The effect of sliding speed and normal load on friction and wear property of aluminum. International Journal of Mechanical and Mechatronics Engineering, 11, 53–57.

[48] Kano, M. (2006). Super low friction of DLC applied to engine cam follower lubricated with ester-containing oil. Tribology International, 39(12), 1682–1685.

[49] Bayer, Raymond G. (2004). Mechanical Wear Fundamentals and Testing, revised and expanded. CRC Press.

[50] Bressan, J.D., Daros, D.P., Sokolowski, A., Mesquita, R.A. and Barbosa, C.A. (2008). Influence of hardness on the wear resistance of 17-4 PH stainless steel evaluated by the pin-on-disc testing", Journal of Materials Processing Technology, 205, pp. 353-359.

[51] Rahim, E.A. and Sasahara, H. (2011). A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys. Tribology International, 44(3), pp. 309-317.

[52] Masjuki, H.H. and Maleque, M.A. (1996). The effect of palm oil diesel fuel contaminated lubricant on sliding wear of cast irons against mild steel", Wear, 198, pp. 293-299.

[53] Maleque, M.A., Masjuki, H.H. and Haseeb, A.S.M.A. (2000). Effect of mechanical factors on tribological properties of palm oil methyl ester blended lubricant",Wear, 239, pp.117-125.

[54] Chiong Ing, T., Rafiq, A. K. M., Azli, Y., & Syahrullail, S. (2012). Tribological behaviour of refined bleached and deodorized palm olein in different loads using a four-ball tribotester. Scientia Iranica, 19(6), 1487–1492.

[55] Groche, P., Nitzsche, G. and Elsen, A. Adhesive wear in deep drawing of aluminum sheets. CIRP Annals- Manufacturing Technology, 57, pp. 295-298 (2008).

[56] Masjuki, H. H and Maleque, M. A. Palm oil and mineral oil based lubricants — their tribological and emission performance,vol. 32, no. 1999, pp. 305–314, (1999).

[57] American Society for Testing and Materials (2010). ASTM D4172-94. Pennsylvania: ASTM International

[58] Muraki, E. T. M. Frictional properties of some additives for sliding guide way lubricants in a sliding speed range between 0.002 and 1.5m/s with a thrust collar friction tester, *Tribology International*, vol. 34, pp. 437–442, 2001.

[59] Sharma, E. S., Doll K.M,. Ester hydroxyl derivatives of methyl oleate: tribological, oxidation and low temperature properties, *Bioresourse Technology*, vol. 99, pp. 7333–7340, (2008).

[60] Pradeep, L.M., Kishore and Satish, V.K. "Effect of surface roughness parameters and surface texture on friction and transfer layer formation in tin-steel tribolo-system", *Journal of materials processing technology*, 208, pp. 372-382 (2008).

[61] Menezes, P.L., and Kailas, S.V. "Effect of surface roughness parameters and surface texture on friction and transfer layer formation in tin–steel tribo-system", *Journal of Materials Processing Technology*, vol. 208, no. 1–3, pp. 372–382, Nov. (2008).

[62] Hisakado, T., Miyazaki, K., Kameta, A., and S. Negishi. "Effects of surface roughness of roll metal pins on their friction and wear characteristics",*Wear*, vol. 239, no. 1, pp. 69–76, Apr. (2000).

[63] Szeri A.Z. *Tribology: Friction, Lubrication and Wear*. McGraw-Hill: New York, USA, (1980).

[64] R. Yunus, A. Fakhru'l-Razi, T. L. Ooi, S. E. Iyuke, and J. M. Perez. "Lubrication properties of trimethylolpropane esters based on palm oil and

palm kernel oils", *European Journal of Lipid Science and Technology*, vol. 106, no. 1, pp. 52–60, Jan. (2004).

[65] Pradeep, L.M., Kishore and Satish, V.K. "Influence of surface texture and roughness parameters on friction and transfer layer formation during sliding of aluminium pin on steel plate", *Wear*, 267, pp. 1534-1549 (2009).

[66] Z. M. Hu and T.A. Dean. "A study of surface topography, friction and lubricants in metal forming" *Int. J. Mach. Tools Manuf*, vol. 40, pp. 1637–1649, (2000).

[67] H. S. I. B. Gulati. "Tribological Behaviour of Based Oils and Their Sperated Fractions" *Wear*, vol. 147, pp. 207–218, (1991).

[68] Bowden, F.P. and Tabor, D. "The nature of metallic wear", In The Friction and Lubrication of Solids, In Oxford Classic Texts, pp. 285-298, Oxford University Press, New York (2001).