Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

THE EFFECTS OF DIFFERENT NANOPARTICLES IN PALM OIL OLEIN AS SOLID ADDITIVES

Mohamad Ali AHMAD[1,*], Izatul Hamimi ABDUL RAZAK[1,2], Nadia Nurul Nabihah AHMAD FUAD[1], Khairul Syazwani SHAHRUDIN[1]

[1]Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam Selangor, Malaysia

[2]Mechanical & Manufacturing Section, Universiti Kuala Lumpur Malaysia France Institute, 43650 Bandar Baru Bangi, Selangor, Malaysia

*Corresponding author: mohama9383@uitm.edu.my, mohamad9383@salam.uitm.edu.my

Abstract: *Palm oil olein and palm oil ester is well-known potential candidate in plant-based oil to replace the conventional mineral oil. Harvested all year round, the advantages and benefits initiate the palm oil to be used in varieties of application. In this paper, palm oil olein was tested on its capability as a lubricant to replace the mineral oil. To enrich the performance of this oil, different types of nanoparticles additives were added. Previous studies proved that by adding small size of additives into lubricating oil can lessen the friction and improve anti-wear properties. The adjustment of the lubricating oil with nanoparticle additives will reduce the friction between two contact surfaces and produce less heat. In his study, three type material of solid additives namely nanoclay and carbon nanotubes were used. Four ball tester following ASTM D4072-94 was conducted to determine the optimum concentration of each additives and its tribological properties under boundary lubrication (metal to metal contact). Result obtained shows that the addition of 0.04 wt% of carbon nanotubes recorded the lowest coefficient of friction with a 10.8% improvement compared to the pure palm oil. The additive also contributed to better wear scar diameters and possessed good anti-wear properties for palm oil. This thus shows the significant potential of carbon nanotubes as the wear preventive additive for palm oil olein. It is also discovered that 0.04 wt% of nanoclays additive is the optimum concentration of the mixture with coefficient of friction reduced 22.16% compared to mineral oil.*

Keywords: *fourball tester, nanoclay, carbon nanotubes, graphene, extreme pressure, wear profile, scar diameter.*

1. INTRODUCTION

The depletion of conventional lubricant sources and the need to reduce environmental emissions have urged researchers to innovate and investigate alternatives green or renewable lubricant. In this regard, palm oil from agricultural feedstocks is a suitable substitute for petroleum lubricants because vegetable – based lubricants present biodegradability, and easy disposal. However, the resistance to extreme pressure, anti-wear characteristics, insufficiencies on low thermal and oxidation stability of this palm oil lubricant are questionable when evaluated against those of commercial petroleum oils [1, 2]. The prospect of solving the problems (extreme pressure and anti-wear characteristic) improved with the advent of nanotribology, while the insufficiencies on low thermal and oxidation stability have been improved via the inducement of chemical changes.

The palm oil is a well-known potential candidate in plant-based oil to replace the conventional mineral oil. Harvested all year round, the advantages and benefits initiate the palm oil to be used in varieties of application. Nowadays the utilization of palm oil as feedstock for bio-lubricants has been recognized in many studies [3, 4]. This is due to issues related to the depletion of world crude oil reserve, increasing crude oil prices and conservation of oil, which brought interest in the bio-based materials. Therefore, efforts have been placed with emphasis to develop a renewable, biodegradable, and environmentally friendly industrial fluids, or lubricant.

Lubricant plays a significant role in a tribology system to enhance the reliability and service life of friction units. Not only expected to perform as anti-friction media, it also should be able to facilitate smooth operations, reduce wear and heat loss from moving contact surfaces, prevent rust and reduces oxidation as well as act as seal against dirt, dust and water [5, 6].

Increasing demands for lubricant in present and future consumptions are in line with current technological growth. This promotes the development of alternatives for current industrial lubricants, particularly mineral and crude oils. In recent time, there are high growing interests in the alternative bio-lubricants derived from vegetable based. Numerous development and research have been carried out to explore the potential of vegetable oils to perform effectively as petroleum-based lubricants in ranges of applications including in automotive, metal working, machineries and others. The addition of several types of additives may also improve the friction reduction and anti-wear properties of the oils [3, 4].

The use of nanoparticles in vegetable lubricant as oil additives have extensively being studied in this past few years with main purpose to improve the oil properties. Metal-based, metal oxide, metal composite, boron-based and carbon-based nanoparticles are the five major groups of nanoparticles that usually added to lubricant [7]. The addition of few types of nanoparticles such as cuprum oxide (CuO), Molybdenum disulfide (MoS_2), Titanium Oxide (TiO_2), Zink Oxide (ZnO), graphite, graphene, and other metallic nanoparticles into the vegetable oils have proven the good contribution to wear and friction reductions [8–11]. This is due to the fine size of the nanoparticles which normally less than 100 nm allows it been easily deposited on the friction surfaces and forms a protective deposit film. Thottackkad *et. al.* [12] found that an optimum concentration of nanoparticles may improve the coefficient of friction and the specific wear rate. The study was carried out on the tribological properties of coconut oil with addition of CuO nanoparticles as additive. The authors also studied the optimum concentration of the additive. Kiu et al. [7] on his study was added graphene nanoparticles as additives to palm oil and found a significant improvement in the reduction of friction coefficient and wear scar diameter.

In the present study, the carbon nanotube (CNT) and nanoclays optimum weight percentage (wt%) were utilized as an additive in palm oil bio-based lubricant and the tribological properties were investigated. The different wt% concentration amount of the carbon nanotubes was tested and the ability in friction and wear characteristic was analysed.

2. METHODOLOGY

2.1 Sample preparation

The properties of palm oil olein and commercial mineral oil (20W-40) which were used in this study were listed in Table 1. Mineral oil (20W-40) was selected as reference during this testing. Single-walled carbon nanotube (>70% TGA) and nanoclays (size <20 nm) as oil additive was mixed with palm oil as base oil and shaken by using an ultrasonic vibrator to ensure homogeneous dispersion of mixture without agglomeration. Seven samples from each of additives were prepared for the testing specimens, which are palm olein oil mixed with carbon nanotube particle and palm olein oil mixed with nanoclays at 0.02 %, 0.03 %, 0.04 % 0.05 %, 0.06 %, 0.07 % and 0.08 % of weight percentages. Both carbon nanotubes and nanoclays were supplied by Sigma Aldrich Ltd.

Table 1. Palm oil olein and properties

Properties	Value
Palm Oil Olein	
Density (g/ml)	0.9081
Kinematic viscosity at 40˚C (mm^2/s)	43.85
Kinematic viscosity at 100˚C (mm^2/s)	8.72
Viscosity Index	182
Total acid number (mm KoH/g)	6.35
Mineral oil (20W-40)	
Density (g/ml)	0.883
Kinematic viscosity at 40˚C (mm^2/s)	134.1
Kinematic viscosity at 100˚C (mm^2/s)	14.7
Viscosity index	109

2.2 Four ball testing

A four-ball friction and wear tester produced by Koehler Instrument Company, Inc., were used to study the tribological properties of carbon nanotubes and nanoclays in palm olein oil as additive. The purpose of the four-ball wear test in this study is to test the wear preventive (WP) properties of a lubricant. In the WP test, the lubricant's coefficient of friction and the wear scar diameter when sliding actions between the balls with certain load can be measured.

The series of tests were conducted in accordance with ASTM D4172 (WP) [13] by four ball friction and wear tester equipment, with different concentration amount of carbon nanotubes additive. A new set of four steel balls (AISI 52100) was used for each set of tests with 14.7 mm ball mean diameter and hardness range between 61 to 63 HRC. These balls were thoroughly cleaned with n-Heptane and dried prior the test set up. The three stationary balls then been clamped into the ball pot and the forth ball was held in a rotating spindle. A sample volume of approximately 10 ml lubricant was poured into the ball pot assembly for each test. Figure 1 illustrates the four-ball assembly installed in the wear tester equipment. After the completion of the test, wear scar on the con-tact surfaces of balls was then observed under a digital optical microscope. The summary of test parameters for the WP test was listed in Table 2.

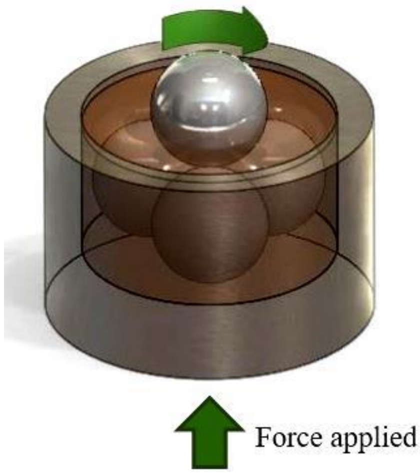

Figure 1. Four ball assembly

Table 2. Four ball tester parameters according to ASTM standard

Parameter	D4172
Load (kgf)	40±2
Duration (min)	60±1
Rotating speed (rpm)	1200±60
Temperature (°C)	75±2

3. RESULTS & DISCUSSION

3.1 Coefficient of friction

Carbon nanotubes (CNT) and nanoclays in the range of 0.02-0.08 wt% concentrations were added in commercial palm olein oil and the friction and wear properties were analysed. The average friction coefficient of the palm olein oil added with the different concentrations of CNT and nanoclays were depicted in Figure 3 and Figure 4. It shows the variation of coefficient of friction of the palm olein oil with seven concentrations of CNT additive. The coefficient of friction value reduced to from 0.073 to 0.067 and keeps reducing with the addition of 0.04 wt% of CNT.

In the case of nanoclay, the lowest coefficient of friction recorded was at wt% of 0.04 with the value of 0.081.

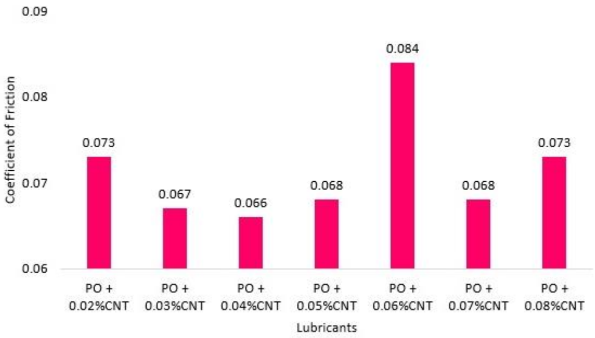

Figure 3. Average coefficient of friction with different wt% of carbon nanotubes

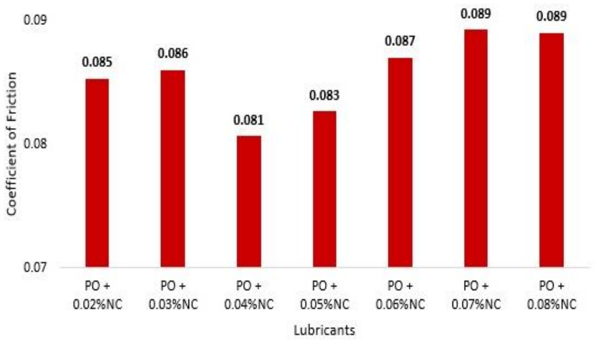

Figure 4. Average coefficient of friction with different wt% of nanoclay

The friction of friction obtained from minimum wt% of CNT and nanoclay was compared with the coefficient of friction obtained from commercial mineral oil and pure palm olein oil as show in Figure 5. The coefficient of friction value of 0.04 wt% of CNT, recorded the lowest coefficient of friction among the other samples with a 10.8% improvement compared to the pure palm olein oil. In this condition, the nanoparticles provided a thin lubrication film on the surfaces and minimize friction at the sliding interfaces.

The similar finding was also obtained by Kiu et al. [14] whose demonstrated the reduction in friction coefficient and wear when carbon nanotubes was added in the studied on vegetable oil. in addition, according to Cornelio *et al.* [15], the positive effect on lubricant properties by the addition of CNT is might be due to the high elastic modulus of the CNT which reducing the metallic contact between surfaces and leads to reduction of adhesive wear and friction coefficient. The authors added that, if higher contact pressure is applied, the carbon nanotubes can deform and forms a lamellar solid on the contact surfaces.

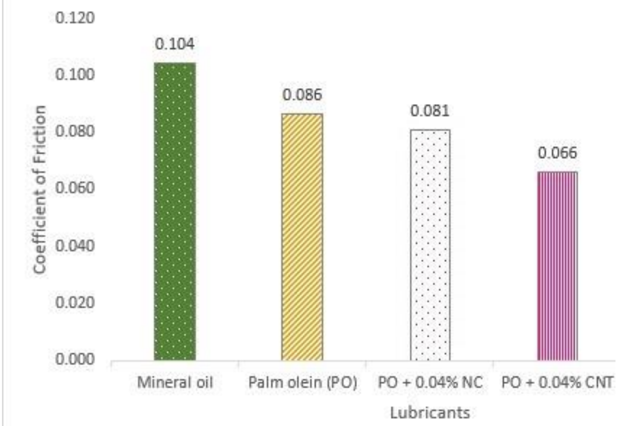

Figure 5. Comparison coefficient of friction between minimum concentration of mixed palm olein with additive with mineral oil and pure palm olein

Nanoclay able to reduced the 6% and 22% of coefficient of frictions compared to pure palm olein oil and mineral oil. Capability of nanoclay as crystalline materials to layer themselve would be possilitity of this reduction [16].

3.2 Wear scar diameter

Ball surface investigation by optical microscopy shows the different wear surface and scar diameter when the carbon nanotubes and nanoclays additive was included in palm oil. Figure 6 tabulated the average wear scar diameter for the palm oil with various concentration of CNT, nanoclays additive, pure palm olein oil and commercial mineral oil. Wear scar diameter is damaged on the balls contact surfaces due to the material removal during sliding contact.

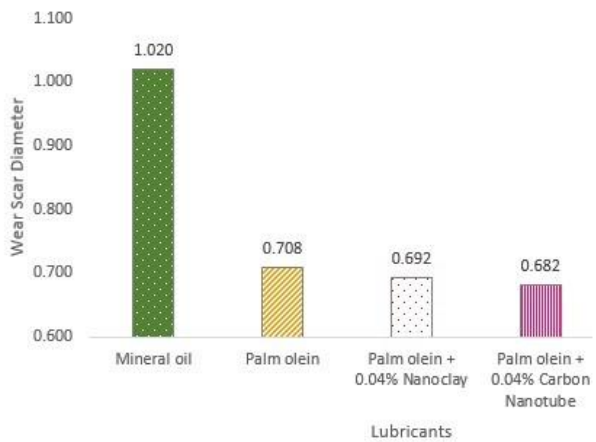

Figure 6. Wear scar diameter (WSD) between optimum concentration of mixed palm olein with additive, pure palm olein and mineral oil

The significance improvement in wear scar diameter was found for palm oil with 0.04 wt% of CNT, at 0.682 mm which is about 5.1% reduction compared to palm oil without additive. This shows that the CNT possess a good anti-wear behaviour with minimal concentration. Although the optimum concentration of the CNT additive (0.04 wt%) showing higher wear scar diameter, yet it still better as compared to the pure palm oil with about 2.4% improvement.

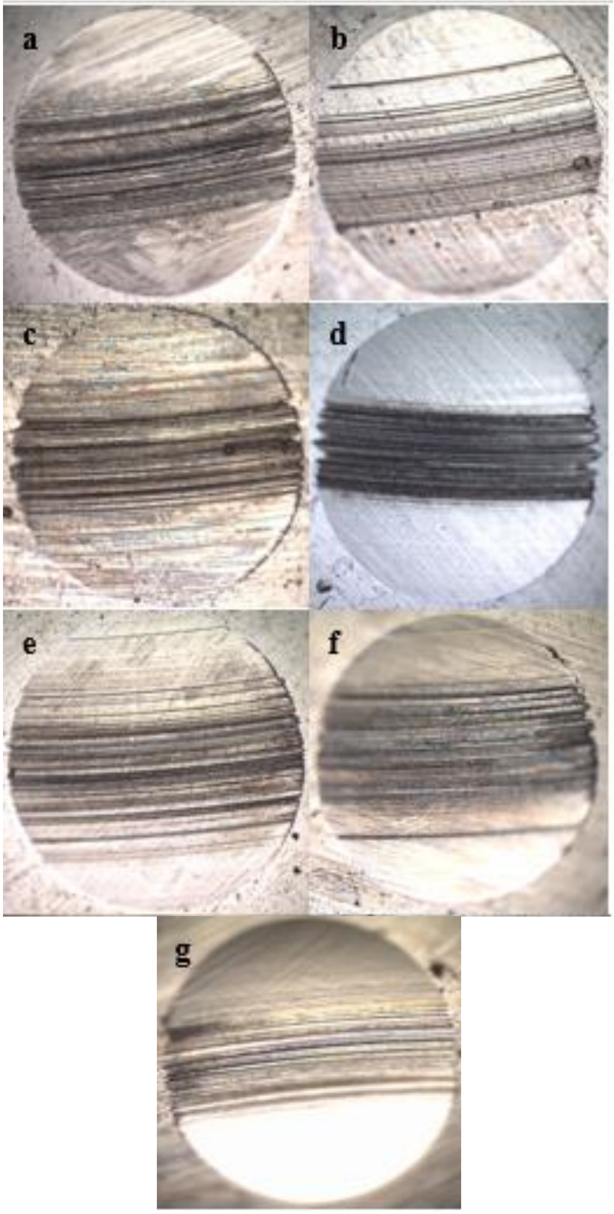

Figure 7. Optical micrograph of wear scars for palm oils with CNT concentration (magnification 200X): (a) 0.02 wt%, (b) 0.03 wt%, (c) 0.04 wt%, (d) 0.05 wt%, (e) 0.06 wt%, (f) 0.07 wt% and (g) 0.08 wt%

The optical micrograph images of the ball specimen wear scars are illustrated in Fig. 7. Observing the wear scar produced with palm oils with the solid additives, the presence of CNT particles can be seen on the scratch groove surfaces. The scattered CNT particles was observed in Fig. 5(c) for the palm oil with 0.04 wt% CNT, and a smoother scar edges was produced. The particles might contribute to less friction between the contact surfaces and producing lower coefficient of friction and wear scar size. This was supported by Gulzar et al. [3] who claimed that the precipitation of nanoparti-cles on the contact surface contributing to the smooth surface.

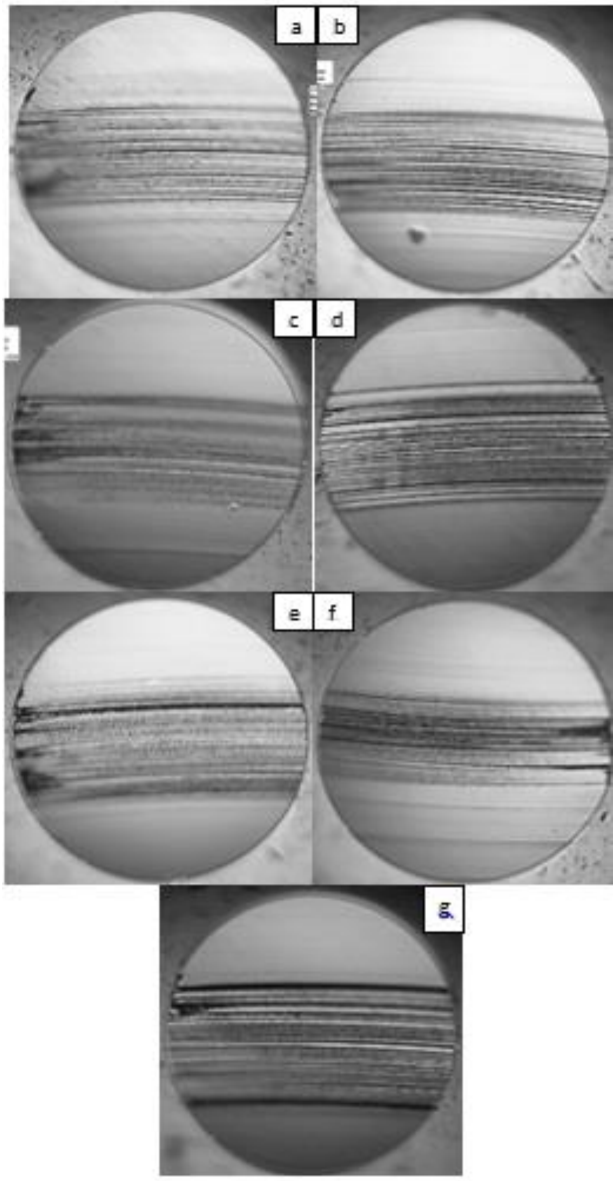

Figure 14. Optical micrograph of wear scars for palm oils with CNT concentration (magnification 200X): (a) 0.02 wt%, (b) 0.03 wt%, (c) 0.04 wt%, (d) 0.05 wt%, (e) 0.06 wt%, (f) 0.07 wt% and (g) 0.08 wt%

For the case of nanoclays, specimen wear scars are illustrated in Figure 8. As we can see, scratch on the surface is lesser compared to CNT. Nanoclays capability to stacked and layer themselve becomes benefits on surface protection compared to CNT.

4. CONCLUSION

This study focused to replace the conventional mineral oil to friendlier environment lubricant which was plant-based lubricant. The tribological testing were performed to prove that additional additives did improved and gave benefits to the palm olein lubricant. The improvement performance was compared with mineral oil which is the conventional lubricants that been used in the industry.

i. Nanoclays improve 22.12% for coefficient of friction while for wear scar diameter reduced by 32.16%.
ii. Carbon nanotube improved 36.54% for coefficient of friction while for wear scar diameter reduced by 33.14%.

In conclusion, addition of additives into the palm olein did gave improvement to the lubricant. It shows massive potential as an alternative to replace the current industrial mineral oil as lubricant.

ACKNOWLEDGEMENT

The authors would like to express gratitude to Institute of Research Management & Innovation (IRMI) of Universiti Teknologi MARA for the Research University Grant, LESTARI (087/2017), Faculty of Mechanical Engineering UiTM, and Ministry of Higher Education, Malaysia for their support.

REFERENCES

[1] T.M. Panchal, A. Patel, D.D. Chauhan, M. Thomas, J.V. Patel: A methodological review on bio-lubricants from vegetable oil based resources, Renewable and Sustainable Energy Reviews, Vol. 70, pp. 65–70, 2017.

[2] R.E. Gapinski, I.E. Joseph, B.D. Layzell: A vegetable oil-based tractor lubricant, SAE Tech Paper, 941785, pp. 1–9, 1994.

[3] M. Gulzar, H.H. Masjuki, M. Varman, M.A. Kalam, R.A. Mufti, N.W.M. Zulkifli, R. Yunus, R. Zahid: Improving the AW/EP abil-ity of chemically modified palm oil by adding CuO and MoS nano – particles, Tribology International, Vol. 88, pp. 271–279, 2015.

[4] E.K. Heikal, M.S. Elmelawy, S.A. Khalil, N.M. Elbasuny: Manufacturing of environment friendly biolubricants from vegetable oils, Egyptian Journal of Petroleum, Vol. 26, No. 1, pp. 53–59, 2017.

[5] H.M. Mobarak, E. Niza Mohamad, H.H. Masjuki, M.A. Kalam, K.A.H. Al Mahmud, M. Habibullah, A.M. Ashraful: The prospects of biolubricants as alternatives in automotive applications, Renewable and Sustainable Energy Reviews, Vol. 33, pp. 34–43, 2014.

[6] S.Z. Erhan, B.K. Sharma, J.M. Perez: Oxidation and low temperature stability of vegetable oil-based lubricants, Industrial Crops and Products, Vol. 24, pp.292-299, 2006.

[7] S.S.K. Kiu, S. Yusup, C.V. Soon, T. Arpin, S. Samion, R.N.M. Kamil: Tribological investigation of graphene as lubricant additive in vegetable oil, Journal of Physical Science, Vol. 28, pp. 257–267, 2017.

[8] N.W.M. Zulkifli, S.S.N. Azman, M.A. Kalam, H.H. Masjuki, R. Yunus, M. Gulzar: Lubricity of bio-based lubricant derived from different chemically modified fatty acid methyl ester, Tribology In-ternational, Vol. 93, pp. 555–562, 2016.

[9] A.G. Zen, G.W. Rashmi: Tribological Evaluation of Nano Graphene Platelets as an Additive to Biolubricant Base Fluid, EURECA, pp. 10–11, 2013.

[10] N.W.M. Zulkifli, M.A. Kalam, H.H. Masjuki, R. Yunus: Experimental analysis of tribological properties of biolubricant with nanoparticle additive, Procedia Eng, Vol. 68, pp. 152–157, 2013.

[11] Y. Su, L. Gong, D. Chen: An Investigation on Tribologi-cal Properties and Lubrication Mechanism of Graphite Nanoparti-cles as Vegetable Based Oil Additive, J. Nanomater, pp. 1–7, 2015.

[12] M.V. Thottackkad, R.K. Perikinalil, P.N. Kumarapillai: Experimental evaluation on the tribological properties of coconut oil by the addition of CuO nanoparticles, International Journal of Pre-cision Engineering and Manufacturing, Vol. 13, No. 1, pp. 111–116, 2012.

[13] ASTM4172-94 *Standard test method for wear preventive character-istics of lubricating fluid (four-ball method),* 2009.

[14] S.S.K. Kiu, S. Yusup, V.S. Chok, A. Taufiq, R.N.M. Kamil, S. Syahrullail, B.L.F. Chin: Comparison on tribological properties of vegetable oil upon addition of carbon-based nanoparticles, IOP Conference Series: Materials Science and Engineering, Vol. 206, No. 1, 2017.

[15] J.A.C. Cornelio, P.A. Cuervo, L.M. Hoyos-palacio, J. Lara-romero, A. Toro: Tribological properties of carbon nanotubes as lub-ricant additive in oil and water for a wheel – rail system, Journal of Materials Research and Technology, Vol. 5, No. 1, pp. 68–76, 2016.

[16] M. S.Nazir, M. H. M. Kassim, L. Mohapatra, M. A. Gilani, M. R. Raza, K. Majeed: Characteristic properties of nanoclays and characterization of nanoparticulates and nanocomposites, In R.M. Nasir, E.A. Rahim (Eds.) *Nanoclay reinforced polymer composites,* Springer, Singapore, pp. 35-55, 2017.