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Tribological properties enhancement through organic carbon nanotubes as nanoparticle additives in boundary lubrication conditions

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KEYWORDS

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Boundary lubrication

ABSTRACT

This paper investigates the effect of inclusion of formulated organic nanoparticles of Eichhornia crassipes carbon nanotubes (EC-CNTs) in two different base lubricant (rapeseed and mineral oils) as lubricant additives. The use of inorganic ZDDP anti-wear additive was employed for comparison. The Raman analysis conducted on EC-CNT indicated good characteristics of carbon nanotube. Smoother operation from EC-CNT with tribo-film formation on the metal surface, seems responsible for the friction and wear reduction. High reduction in friction and wear was recorded with rapeseed oil than mineral oil at low conditions due to sufficient triacyl-glycerol molecule found in rapeseed oil with better chemical reaction towards film formation. However, when compared with ZDDP, shows good behavior towards tribological enhancement, though the result with ZDDP found better than EC-CNT both in friction and wear reduction. More patronage and modifications on bio-material products as additives, environmental catastrophe caused by non-biodegradable and toxic inorganic products will be mitigated.

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1.0 INTRODUCTION

Lubrication is the pronounced method of maintaining smooth activity in relative motion between two or more bodies. This is achieved through cooling, sealing of gaps, formulation of load carrying film, cleaning and fast power transmission, thereby preventing excessive friction and wear from occurring. During machine operation, the cause of damages and energy loss are mainly from friction, thus can be mitigated via lubrication (Zhang et al., 2017; Razak et al., 2015; Jabal et al., 2014). As such, it is important to enhance the lubricant properties as to meet the service and this is mainly done through suitable combination between base oil and inclusive additives. Many reported work that studied the inclusion of nanoparticles as additives in lubricants yield significant improvement in reducing friction and wear (Azman et al., 2016; Li et al., et al. 2017; Demas et al., 2012; Azman et al., 2019). However, the nanoparticles additive tribological performances depend on their physiochemical features like, size, concentration, thermal strength, dispersion ability, shape etc. In this regard, investigation conducted on the effect of particle size using nanoparticles of gold between 5 and 20 nm shows that gold particles of 20 nm offers better reduction effect on friction and wear than 5 nm particles gold additive by (Chinas-Castillo and Spikes, 2003). This low performance observation from 5 nm was due to extreme tiny nature of the nanoparticles thereby permits asperities interaction to occur compare to 20 nm particles. On the other hand, another analysis reported that smaller size nanoparticles possess higher tendency to interact with sliding surfaces to form protective tribo-film, for better anti-wear services (Azhari et al., 2014; Hassan et al., 2016). In case of nanoparticles shape together the size conducted on inorganic fullerene-like (IF) additives in lubricant, reported that smaller nanoparticles within 30 nm exhibit superior rolling, thermal strength, chemical resilience and higher elasticity (Zak et al., 2018). In application of nanoparticles additives, it is necessary to understand that base lubricants properties varies with different effects on the performance therefore, it is nessasery to ascertain the tribological behavior of suitable nano-additives in appropriate concentration when applied in lubrication regimes (Li et al., 2018; Gulzar, M et al., 2016).

However, owing to most of these inorganic additives inherent non-biodegradable nature and toxicity attribute, makes the class threat to the ecosystem and detrimental to human life (Kalin et al., 2013). With this global confrontation challenges, environmentally adopted nanoparticles additives have become more important in lubrication. This attracted attention of researchers on formulating new materials with potentials of enhancing the tribological properties of lubricating oil instead of fossil counterpart. The study on abundant biomass materials as inorganic additives substitute was employed because of their high percentage of carbonaceous (graphite and amorphous) strength, non-toxic and amphiphilic characteristic in performing the wear and friction reduction during lubrication (Although no serious work has been reported using pure organic biomaterial nanoparticles as additive on friction and wear reduction but applied it on composite formulation (Sohail et al., 2019; Sapawe et al., 2016) and reinforce technique (Rajkumar and Aravindan 2013; Valášek, 2015). Many investigations have been conducted on various CNTs as nano-additives for friction and wear reduction with results indicating enhancement on tribological properties especially on wear reduction (Sohail et al., 2019), except presentation by (Bakshi et al. 2011), shows decrease in the wear volume with macro-scale while increase in the wear volume with nano scale CNT coating. Therefore, this paper investigates the effect of inclusion of formulated organic nanoparticles of Eichhornia crassipes carbon nanotubes (EC-CNTs) in two different base lubricant (rapeseed oil and mineral oil from crude) as lubricant additives. The use of inorganic ZDDP anti-wear additive was employed for comparison. In addition, the anti-wear effects of EC-CNTs was studied using a HFRR machine, the worn surfaces analysis was done using optical magnified machine, further interpreted using specific wear rate formula (Fei et al., 2015).

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials

Eichhornia crassipes plant were obtained from Onuko River, Atani, Anambara state, Eastern part of Nigeria. The fresh of *EC* plant originally was in green color, having flower, depending on the size, with many tiny fibrous root systems. Other needed materials were electric dry blender, electric furnace, planetary ball mill machine (PM100) (Retsch Germany), drying oven, diluted HCL, ethanol, distilled water, additive ZDDP and Base rapeseed and mineral oil.

2.2 Preparation of Eichhornia Crassipes Nanoparticles of Carbon Nanotubes (EC-NPs)

The plant was exposed to direct sunlight for about 21days in preparation for oven dry. After this stage of little dry, it was divided into two different components (shoot and root) and subjected to an electric furnace at 250 0C for around four (4) hours for optimum dryness. This high dryness greatly helps to energize the plant's basic compositions. At this point, the materials take different color, as illustrated in preparation Figure 1. Before going for nanoscale, the various parts were reduced with electric dry blender. For nanoparticles generation, the grinding was done in two phase. The first was direct grind of each reduced parts of EC using planetary ball mill machine (PM100) (Retsch Germany) (250mL tungsten carbide (WC) as adopted by (Zaytseva and Neumann, 2016). The grinding jar was carefully loaded with about 70% by volume WC mill balls of 3 mm in diameter together with 33.3% by volume of dry grinded *EC* (approximately 78 mL). The grinding took about 4 hours at a programmed speed of 300 rpm.

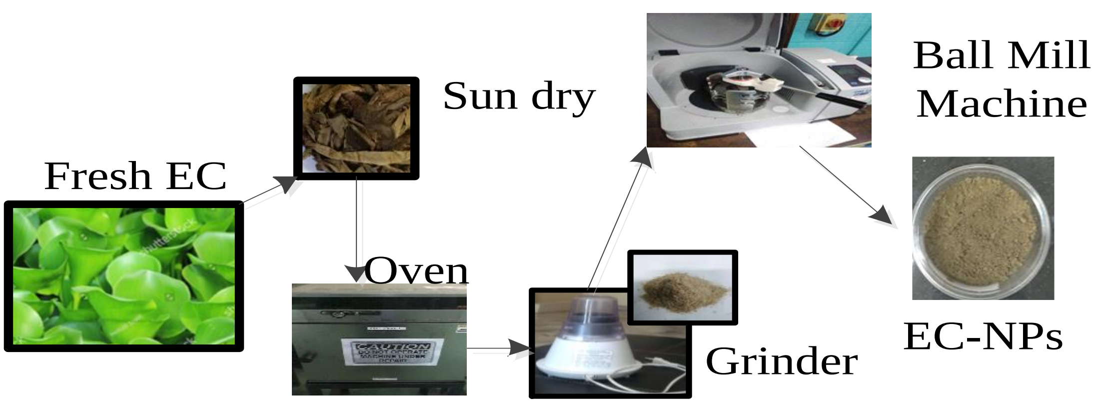

Figure 1: Preparation of EC-NPs for carbonaceous modification.

The selected quantity ratio 1:2 (shoot: root) were treated strictly by cyclic heating approach (Xie et al., 2009). Subjected into 240^0 C of heat for about four (4) hour for partial carbonize as in Figure 2. The collected sample were washed with dilute hydrochloric acid solution of 5%, thereafter washed again with deionized distilled water.

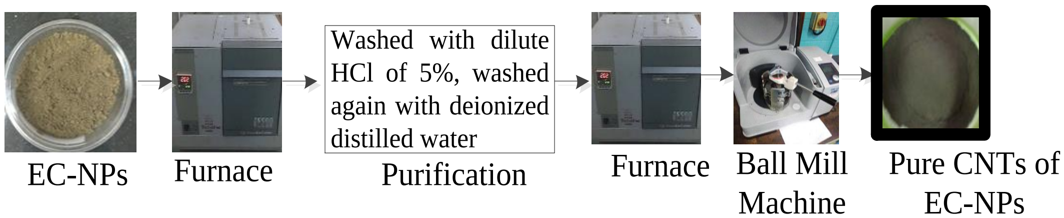

Figure 2: Formulation processes of EC-CNTs for additive application.

Next was about two (2) hours of drying of the samples with an electric furnace of about 240°C. Then re-grinded again with little quantity of ethanol to prevent agglomeration. The gel-like formulation (nanotubes of carbon) was placed in oven for about 5 hours for complete dry and for more activation of carbon nanotubes both the single and double wall carbon nanotubes.

2.3 Preparation and Characterization of EC-CNTs (FESEM, EDX and Particle size analyzer)

The characterization analysis on the sample was conducted both for nanoscale and the elemental compositions using FESEM and EDX. The EC-CNTs was characterized on its morphological profile was captured by Quanta FEG250 FESEM instrument, equipped with an energy dispersive x-ray analysis to ascertain the surface morphology and size dimension of the sample. The Energy Dispersive X-Ray analyzer (EDX) (SU 8000; Hitachi Japan) study is purely for elemental identification and composition information on the sample toward effective operation during usage. For more convention on the EC-CNTs sample shapes, the EC-NCTs size was determine using hydrodynamic light scattering of particle size analyzer Zetasizer Nano ZS; Malvern Instrument, United Kingdom.

2.4 Raman Spectroscopy Study

Application of Raman Lab RAM HR Evolution (Horiba Scientific, UK) was employed as to confirm the nature of carbon nanotube formulated within a spectral region of 400–2000 cm^{-1}. Raman spectra were collected at room temperature using a 633 nm solid state laser (12 mW) by focusing the laser on the formulated sample area using a microprobe equipped with a 100x eyepiece, adopted the approach used by (Salah et al., 2017) and (Costa et al., 2011). The dispersed scattered beam from the spectrophotometer was detected using a charge-coupled device chamber detector having a spectral resolution of 3 cm^{-1}.

2.5 Experiment Procedures

The investigation on the tribological properties of EC-CNT additives was carried out on sliding contact between a ball and a flat of high chromium steel (AISI 52100) using high frequency reciprocating test rig (HFHRR) under boundary lubrication conditions of highly stressed ball-on-flat contact as illustrated in Figure 3. The HFHRR is incoperated with system monitor for collection of datas. The hardness of the testing element flat steel (40x40 mm dimension) were made of AISI 52100 steel of approximatly 570-750 Hv while soft ball alluminium (10 mm diamater)were made from 190-210 Hv. The lubricants were purchased from Sigma-Aldrich with the properties according to ASTM standard test listed in Table. 1.

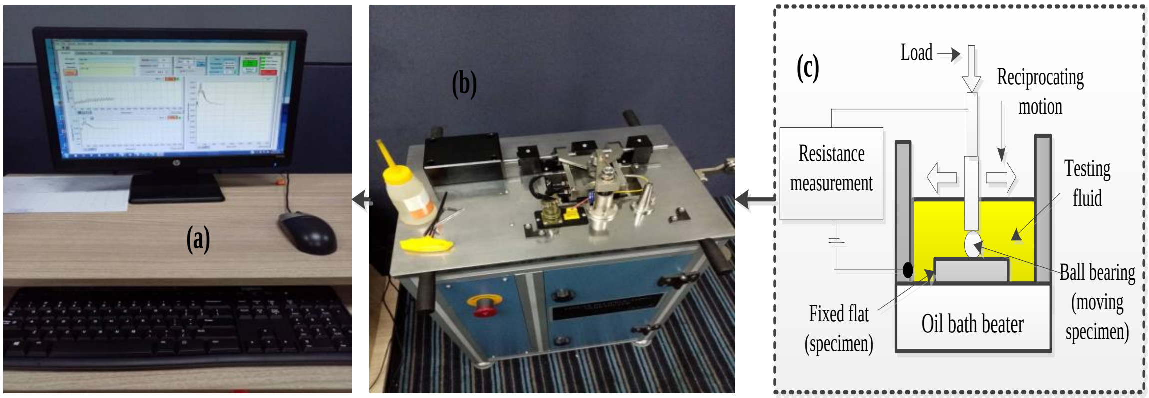

Figure 3: Machine operation set up. (a), system monitor, (b), HFHRR machine, (C), Skeletal coupling.

Table. 1: Properties of the base lubricants (mineral and rapeseed oils).

Properties	Rapeseed oil	Mineral oil
Kinematic viscosity @ 40 °C	40.3	85.3
Kinematic viscosity @ 100 °C	7.9	10.56
Vicosity index	220	107
Pour point	-18	-30
Gravity, API @ 15.6°C	0.913	28.3
Flash point	320	220

2.6 Friction and Wear Test

The experiment was conducted using the parameter listed in Table2 and 3. The lubricant (base oil and additive) of 25 mL was added to the flat steel surface, with every other condition programmed in the system. The operation is set to run for 30 min starting with base lubricants. It was continued with other samples together with their assigned working conditions (Table 2 and 3). Base oil applied in this experiment were rapeseed and mineral oil. The experiment was conducted in two different loads of 25 and 100 N respectively with constant temperature. After the first analysis with 25 N and 2 Hz, the second was tested applying 100 N and 5 Hz using the same percentage of EC-CNT additve and compered with anti-wear additive of ZDDP in accordance with preparation parameters in Table 2 and 3. During the analysis (Figure 4), the friction coefficient and temperation variations were recorded using a piezo-electric force transducer, thus confirmed as the convenient approach for tribological studies with inclusion of additives (Alves et al. 2013). Accordingly, the ball and flat wer thorughly clearned by ultrasonically agitated bath of acetone before and after HFRR test. For accuracy, each test was performed three different times as to ascertain mean values of coefficient of friction and friction forces. The specific rate K(mm^3/Nm) was determined as stated in equation (1) and (2), used by Fei Zheng et al. (2015).

$$AV = \frac{\pi\left(\frac{D}{2}\right)^2}{180}\arc\sin\frac{b}{D} - \frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{b}{2}\right)^2}}{2}\pi d \qquad (1)$$

$$K = \frac{\Delta V}{P \cdot L} \tag{2}$$

Where ΔV stands for the wear volume loss (mm), D is the diameter of the sliding ball (12 mm), L is the sliding distance (m), b is the width of the wear trace (mm), P is the applied load, K is the wear rate and d is the diameter of the flat plat (40 mm) (see Figure 3)

Table 2: Base oil lubricant and additive preparation.

Additive	Standard oil	Additives/oil solution
EC-CNTs (10%)	90%	1 wt. % EC-CNTs in 99% rapeseed oil solution
EC-CNTs (10%)	90%	1 wt. % EC-CNTs in 99% mineral oil solution
ZDDP (10%)	90%	1 wt. % ZDDP in 99% rapeseed oil solution
ZDDP (10 %)	90%	1 wt. % ZDDP in 99% mineral oil solution

Table 3: Experiment test conditions.

Tribotet ring	Ball-on-Flat
Lubricant	Rapeseed and mineral base oil
Load	25 N and 100 N
Additives	EC-CNTs and ZDDP
Motion type	Pure sliding (receprocating)
Frequency	2 Hz and 5 Hz
Temperature	75^{o} C
Operation duration	15 mins

3.0 RESULTS AND DISCUSSION

3.1 Characterization of EC-CNTs Additive

Figure 4 shows the morphology of EC-CNTs nanostructures examined using FESEM. The result indicated the tube-like nature of the EC-CNTs (Figure 4 a), whereas the EDX for the elemental composition in the EC-CNTs sample were shown in Figure 4b indicating various elements thus carbon and oxygen shows the highest percentages of 64.3 and 17.4 wt.% respectively. Figure 6 shows the particle size distribution of the particle size analyzer, calculated with hydrodynamic light dispersion. The findings showed optimum dispersion of EC-CNTs in N-Methyl-2-pyrrolidone polar/non-polar solution, however, average mean size of EC-CNTs was 77.8 nm (Figure 5).

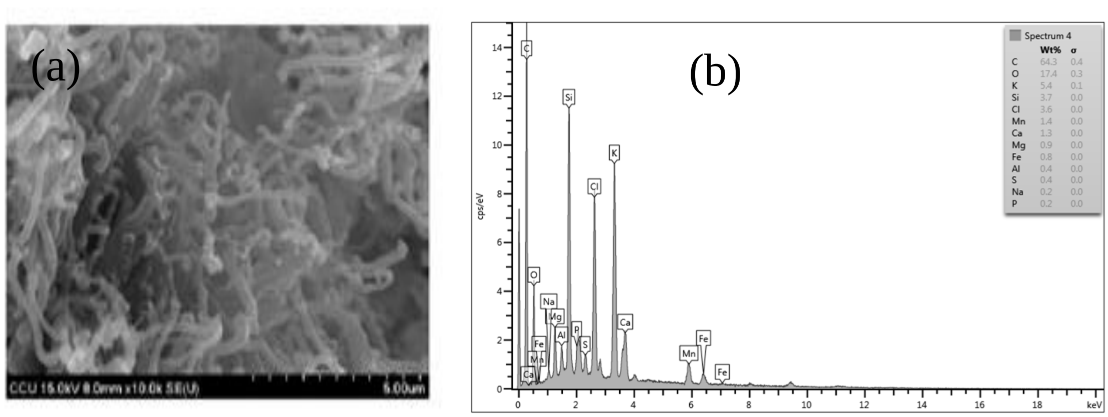

Figure 4: Images of EC-CNTs results, FESEM (a), EDX (b).

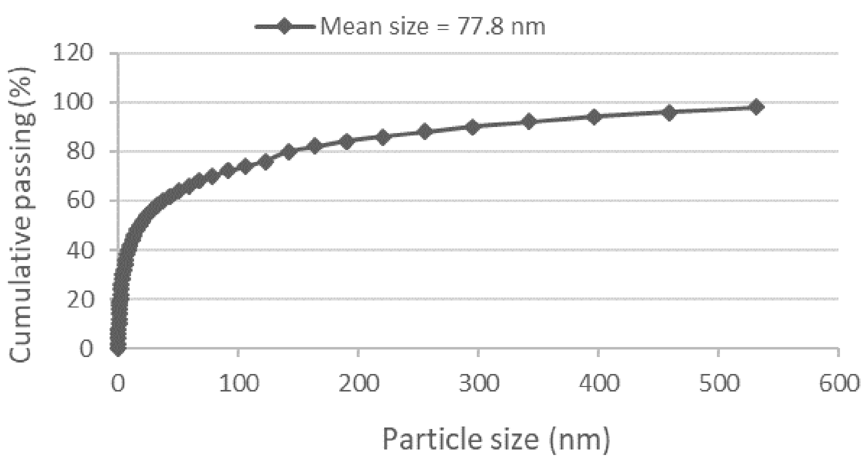

Figure 5: Particle Size distribution of EC-CNTs by hydrodynamic light scattering.

Figure 6 shows the image of EC-CNTs Raman spectroscopy study. The graph indicated two pronounced peaks at 1375.31 cm^{-1} for D-band and 1601.37 cm^{-1} for G-band respectively. This value is in line with analysis result of carbon nanotube reinforced aluminum composites at nano and macro scale conducted by Bakshi et al. (2011). It clearly shows higher intensity on G-band than D-band, indicates defect in graphene sheet (Costa et al., 2011), with significant G-band vibrations of SP^2 dominant carbon atom. However, the raman intensity nature of the two bands (D and G) was used to ascertain the crystalline order of the carbon constituents. The graph shows that $I_D < I_G$, simply indicate CNTs of the prepared sample of EC-CNTs (Figure 6).

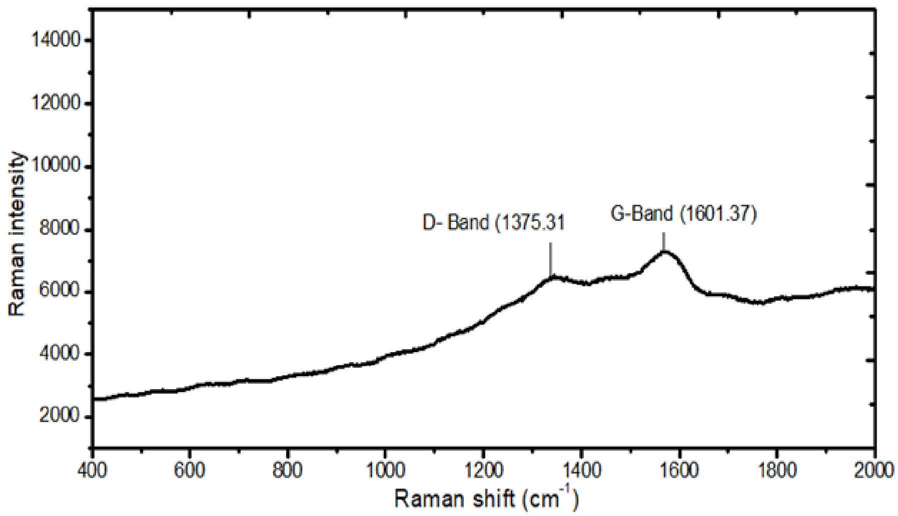

Fig. 6: Raman spectroscopy of EC-CNTs showing D and G bands.

3.2 Effect of EC-CNTs on Friction and Wear on Sliding

Figure 7 shows the coefficient of friction of formulated EC-CNTs when used on different base oil (mineral and rapeseed) samples during sliding at frequency of 2 Hz, under an applied load of 25 N. The experiment evidently depict that the operation regime exhibited was boundary lubrication approximately (μ = 0.15-0.2), in accordance with analysis findings by Shahabuddin et al. (2013). The investigation evidently show decrease in coefficient of friction with inclusion of EC-CNTs. This is similar to the study conducted by (Bastwros et al., 2013), this attributed to the reduction in coefficient of friction when compared to pure base oils. There is constant decrease in coefficient of friction in all the samples apart from sample of mineral base oil predicted to experience rapid increase in temperature beyond the operation set up of 75°C. However, the reduction in other samples coefficient of friction was as a result of formation of carbon film leading to smooth sliding. The mineral base oil still showcases similar constant decrease after approximately 240 s, meanwhile, base rapeseed oil COF started decreasing before base mineral, suggested to be the time of formation their various film on the sliding surface. On this applied conditions, EC-CNTs shows similar behavior in mineral and rapeseed base oil as seen in Figure 7. For example, considering effect of EC-CNTs, the best result was observed with a combination of rapeseed oil, although, both shows better synergism. Similar results were reported from experimental work conducted on nanoparticles with different base oils by Alves et al., (2013). However, better result found when used in rapeseed lubricant, because of tribo-chemistry nature associated with polarity, enhanced the adsorption on metal surface leading to friction and wear reduction through formation of sacrificial thin layer for optimal contact separation. With inclusion of nanoparticles, the tribological behavior of third body improved for better friction coefficient. According to Zhang et al., (2011) nanoparticles possesses the ability to penetrate between the sliding contact area, deposit the particles film, thus possible owing to their smaller size nature.

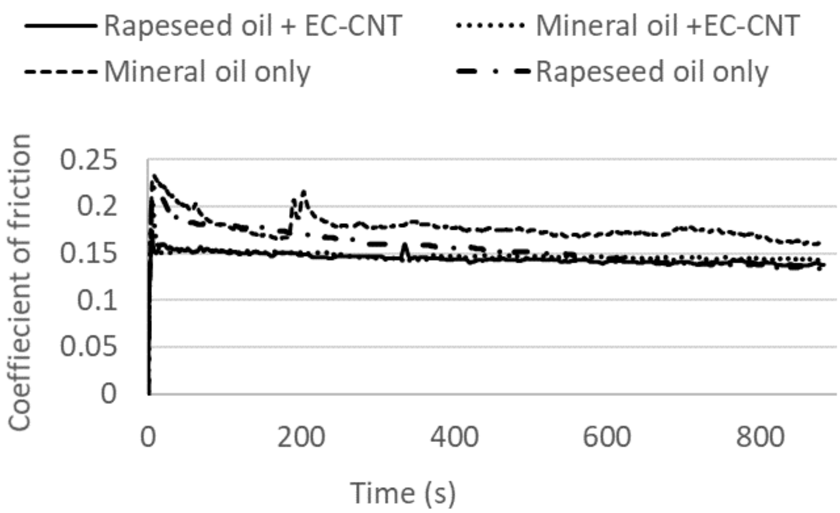

Figure 7: Effect of coefficient of friction against sliding time for EC-CNT (1%) under 2Hz and 25N.

Figure 8, shows the lubricant samples temperature profile during sliding operation under 75°C. Increase in frictional temperature of tribo-couple is a complex process and associated with some factors such as sliding speed, contact area, thermal conduction, normal load, also properties of intermediate sacrificial tribo-layer can affect it. In the aspect of sliding contact area (real contact area) due increases with increase in normal load which in turn increases the temperature of the sliding body (Rajkumar and Aravindan, 2013). However, in Figure 8**,** the temperature behavior of all the samples observed to be the same except base mineral oil. The base mineral oil shows rapid increase in temperature with average temperature of 77.95°C, while other samples showcases similar average temperatures of 74.86°C, 74.89°C, and 74.94°C for mineral oil + EC-CNTs, base Rapeseed oil and rapeseed oil + EC-CNTs respectively. This is to say that film formation is strongly influenced by oil base and additive inclusion. From the test performed with mineral (Figure 8), it shows that the film formation takes long time to formulate thereby generate rise in temperature which also affect friction coefficient of mineral base lubricants as seen Figure 8. This is similar to the analysis conducted by Alves et al. (2013) on nanoparticles behavior in different base oils. Figure 8 shows that inclusion of EC-CTs has the potential to retain the temperature from increasing compared to base mineral oil presentation. According to Figure 8, sample of rapeseed oil + EC-CNTs shows increase in temperature towards the end of the testing. The results concluded that base mineral oil high coefficient of friction recorded in Figure 8 was the effect from temperature profile. In Figure 9, it can be seen that scratches of the metal wear scar obtained from the mineral base oil (Figure 9a) are deeper furrows followed by rapeseed base oil (Figure 9c) before the mineral oil + EC-CNT (Figure 9b) and rapeseed oil + EC-CNT (Figure 9d) respectively as seen in Figure 10. However, further check indicted that EC-CNT under both base oil lubricants play an important role in reducing coefficient of friction and improves the anti-wear properties of the base oil but more significant with mineral base oil thereby reduces the friction coefficient drastically (see Figure 9). Thus perform mechanism of penetrating in the friction area and from separating layer at the contact area as suggested by Rabaso et al., (2014) .

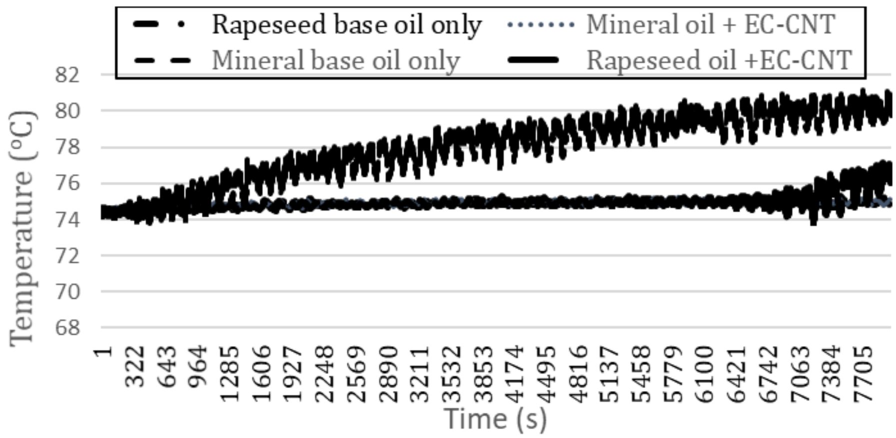

Figure 8: Effect of lubricant samples on temperature profile at frequency of 2Hz and load of 25N.

Optical micrographs in Figure 9 shows that the base oil wear track is clearly recognizable and displays evidence of significant abrasive wear, especially with base mineral oil. The path of wear on the material surface with EC-CNT is much less visible and seems to be smoother than the wear route, which means that much of the wear that occurred was in the removal of top asperities through polishing mechanism.

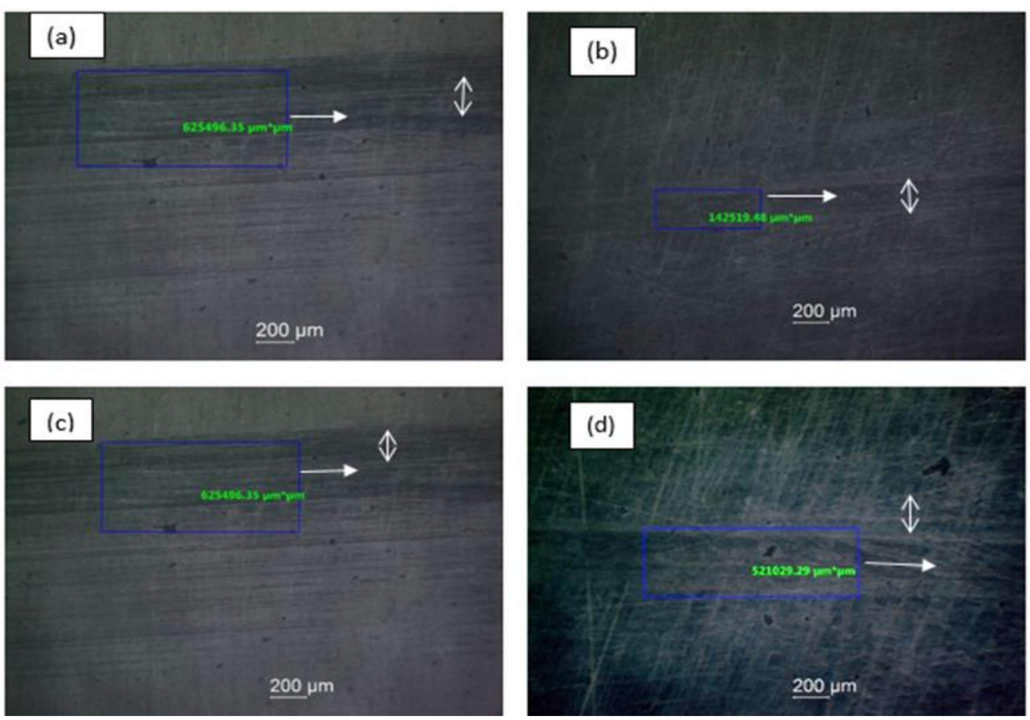

Figure 9: Optical magnified images of various lubricant at load of 25 N and frequency of 2 Hz: (a) base mineral oil only; (b) mineral oil + EC-CNT; (c) base rapeseed oil only; (d) rapeseed oil + EC-CNT.

Figure 10 simply contrasts the efficacy of various lubricant samples towards wear reduction without EC-CNT and with EC-CNT. It is observed that with addition of EC-CNT in both base oil (mineral and rapeseed), shows significant decrease in the wear rate compared when tested only base oils. Inclusion of EC-CNT additive reduced the wear rate to approximately 58.4% for both mineral and rapeseed oil. The decrease effect from EC-CNT nanoparticles was due to their physiochemical properties especially thermal strength (Lara-Serrano et al., 2016); (Salah et al., 2017), supported by the improved coefficient of friction results as seen in Figure 8. The low wear rate from base rapeseed oil compared to base mineral oil implied a strong absorption mechanism by rapeseed oil, thus form shielding and reducing friction against wear on the metal surface. This observation is similar to the result by Shahabuddin et al., (2013). According to Bastwros et al., (2013), reported good reduction in wear rate with the addition of CNT, however, stated formation of agglomeration at high concentration which could poor tribological performance as a result of poor densification.

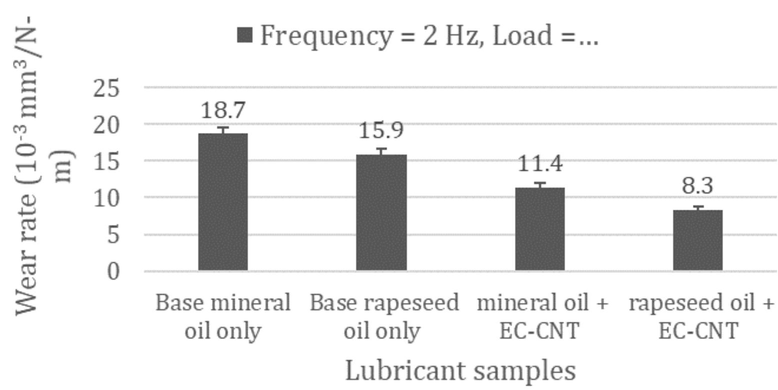

Figure 10: Wear rate against lubricant samples (without EC-CNT and with EC-CNT).

Figure 11, presents the coefficient of friction against sliding time for the same concentration of EC-CNTs (1 %) under frequency of 5 Hz and applied load of 100 N. The application of ZDDP additive was applied to compare the efficacy of EC-CNTs in oil lubricant lubrication. With increase in working parameters, the operation observed decrease in coefficient of friction in all the samples, but shows more disorderliness on rapeseed oil + EC-CNTs and mineral oil + ZDDP samples. Figure 11 and 12 shows that inclusion of EC-CNTs in base Rapeseed and mineral oil significantly influence the tribological properties of the lubricating oil. Although the performance observed from samples with ZDDP shows better results. With increase in frequency and load, there is not too much variation among the individual samples and also shows slight changes on the sample's behavior from the beginning of the testing to the end. This observation manifested because of nature of boundary lubrication which involves regime chemical interactions between the surfaces and lubricant. The products of the reaction yield significant role in the effectiveness of the lubrication process, thus, the viscosity of lubricant has little or no effect on tribological properties on friction and wear (Alves et al., 2013). Tab. 4 gives the overall summary on the closeness nature of the lubricants behavior as listed in the standard deviation. The standard deviation indicated that under load of 25 N and frequency of 2 Hz, observed changes within 0.09475 to 0.10138, compared to the operating condition of load 100 N and frequency of 5 Hz, with standard deviation close to each other and shows almost the same values for the samples of rapeseed oil + EC-CNTs and mineral oil + EC-CNTs, thus considered closer, while mineral oil + ZDDP and rapeseed oil + ZDDP showed more close result (Table 4). Although friction coefficient of various lubricants (additives) under 100 N and frequency of 5 Hz were alike, but the outcome on their wear resistance performed differently as in Figure 11 and 13 respectively. Rapeseed oil with EC-CNT had lower wear rate than operation with mineral oil with EC-CNT thus showing good synergism towards anti-wear properties at the temperatures studied.

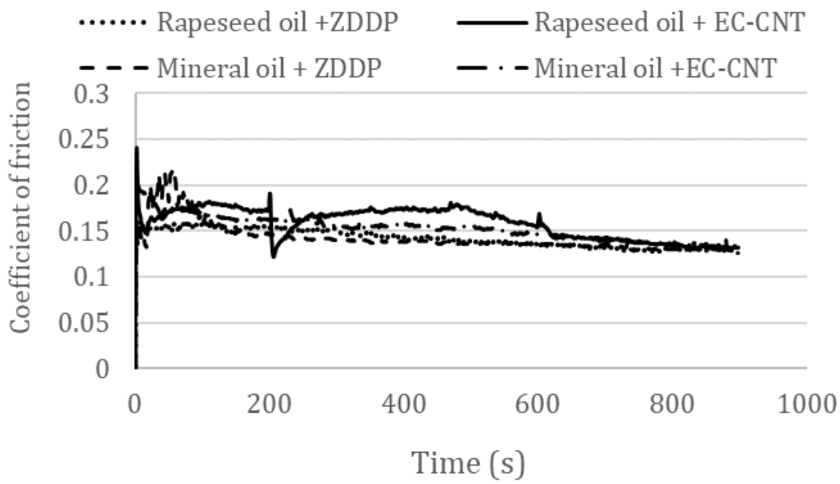

Figure 11: Effect of coefficient of friction versus the sliding time for EC-CNTs (1 wt.%) and ZDDP (1 wt. %) on two different oil samples under 5 Hz and 100 N.

Table 4: Mean friction coefficient of HFHRR and standard deviation.

Test condition	**Lubricants**	**Mean friction coefficient**	**Standard deviation**
Load = 25 N Frequency = 2 Hz	Base Rapeseed oil	0.1565	0.09475
	Base mineral oil	0.1772	0.10138
	Rapeseed oil +EC-CNTs	0.1446	0.09758
	Mineral oil + EC-CNTs	0.1473	0.09970
Load = 100 N Frequency = 5 Hz	Rapeseed oil + EC-CNTs	0.1586	0.09334
	Mineral oil + EC-CNTs	0.1530	0.09333
	Rapeseed oil + ZDDP	0.1419	0.08838
	Mineral oil + ZDDP	0.1423	0.08909

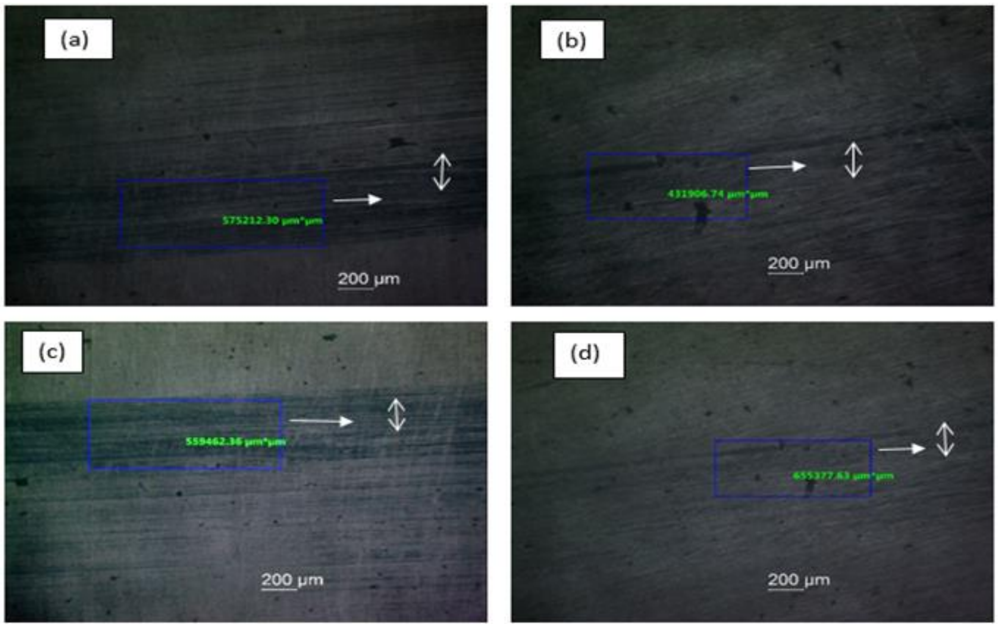

Figure 12: Optical magnified images of various lubricants under load of100 N and frequency of 5 Hz: a, rapeseed oil + EC-CNT; b, rapeseed oil + ZDDP; c, mineral oil + EC-CNT; d, mineral oil + ZDDP.

From the above study, it is reasonably to say that the friction reducing and ant-wear mechanisms from the EC-CNT in the lubricants precisely under high operating condition (frequency of 5Hz and applied load of 100 N) are attributed to two factors, including; physiochemical absorption from oleic acid constituent of the lubricants during sliding to form adsorption film (load carrying film) and tribo-chemistry reactions for the formation of some useful oxides products leading to friction and wear reduction within the sliding pair. This is similar with the experimental result by Ettefaghi et al., (2013). Also, from the flexible structure and thermal strength of nanoparticles (EC-CNT) (Asep Handaya 2015) in resisting direct contact between the sliding bodies

Figure 13 shows the wear rate behaviors on sliding metals using different lubricant samples with EC-CNT and ZDDP anti-wear additives. It has been established in tribology that wear reduction during sliding is from the formation of sacrificial film layer that works as a separator between two contact (Zhang et al., 2017). Also that polar functional groups in base oil especially in triacyl-glycerol molecule maintain excellent lubricating characteristics through chemical adsorption and optimal physical properties in contact with the metal surface (Alves et al., 2013). These features are mostly pronounced at high working conditions like load, speed and temperature. Figure 13 shows good tribological enhancement from ZDDP and EC-CNT. It is obvious that with load of 100 N and frequency of 5 Hz, formation of tribo-film was achieved both on mineral and rapeseed oils with the two additives. The result indicated that mineral oil with ZDDP shows the best synergism with least wear rate. In the side of EC-CNT additive with the oil lubricant, shows that rapeseed oil with EC-CNT additive yield lower wear rate compared to rapeseed oil with ZDDP. This could be because of sufficient triacyl-glycerol molecule found in rapeseed oil thus lead to fast formation of tribo-film for protection of metal surface. This observations is similar to the finding from tribological behavior of lubricants by Alves et al., (2013). Thus, the performance and anti-wear mechanism of these lubricating oil towards friction and wear reduction is completely centered on their ability to penetrate between the contact and to form tribo-film.

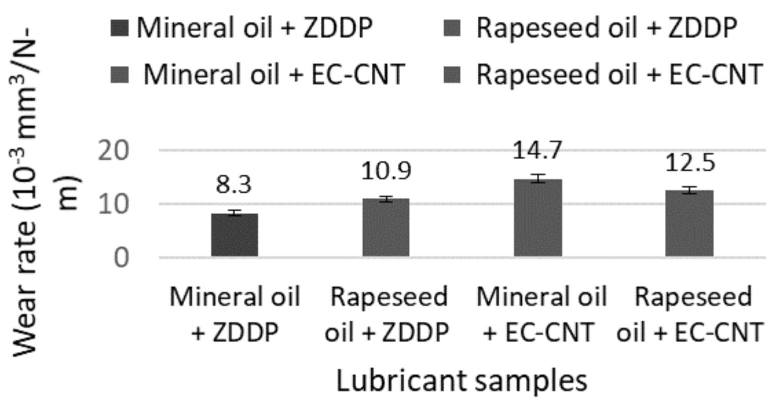

Figure 13: Wear rate against lubricant samples (without EC-CNT and with EC-CNT).

4.0 CONCLUSION

The effect of formulated EC-CNT on tribological properties of different base oils was investigated and compared with ZDDP. Considering the results presented above in the characterization indicated good properties from EC-CNT for lubricants additive application. However, the study concluded that the formulated EC-CNT shows good tribological properties enhancement and its performance depends significantly on its compatibility with lubricant base oil. The results show that increase in working conditions (load and frequency), combination of mineral oil with EC-CNT shows better result than rapeseed oil with EC-CNT. On the side of wear rate performance, it was shown that at low condition, combination of rapeseed oil with EC-CNTs provide better protection on the sliding contact than mineral oil with EC-CNTs, though the effect were small if compared to lubricating oil with ZDDP. The analysis can be deduced that the tribo-chemical reaction from sufficient triacyl-glycerol molecule found in rapeseed oil and the excellent tribological properties of nanoparticles (EC-CNT) material could be reason for the fast formation of tribo-film for metal surface protection. The results of this tribological experiments concluded that EC-CNT nanoparticles show good friction and wear reduction both at low and high working conditions but exhibited better response when used at working condition.

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