Jurnal Tribologi 32 (2022) 29-39

MYTRIBOS Malaysian Tribology Society
Jurnal Tribologi
Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

Effect of vegetable-based nanofluid enriched with nanoparticles as metalworking fluids during orthogonal cutting process

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KEYWORDS

Modified jatropha oil
Nanofluid
Nanoparticles
Metalworking Fluid
Orthogonal cutting
Copper Oxide
Activated Carbon

ABSTRACT

The performance of vegetables oil is poor compared to minerals oil in high resistance, viscosity and friction, so to overcome the weakness of vegetables oil, it has been mixed with various type of additives to improve its properties. The purpose of this study is to analysed the machining performance of modified jatropha oil with the addition of Copper Oxide (MJOc) and Activated Carbon (MJOa) at concentrations of 0.01, 0.025, and 0.05 wt. %, respectively. The machining performance of the nanofluids (MJOc1, MJOc2, MJOc3, MJOa1, MJOa2 and MJOa3) were compared with the commercial synthetic ester (SE) in terms of cutting temperature, chip thickness and tool chip contact length through orthogonal cutting process. with the minimum quantity lubrication (MQL) method. The result shows that MJOa has better machining performance compared to the MJOc. Among MJOa, MJOa2 (MJO + 0.025wt.% Activated Carbon) showed the best machining performances in terms of cutting temperature, chip thickness and tool chip contact length. In addition, the best machining performance among MJOc is MJOc2 (MJO + 0.025wt.% CuO). In conclusion, the overall best machining performance is MJOa2 (MJO + 0.025wt.% Activated Carbon). In terms of environmental concerns and energy savings, it has the capability to be on the lubricant market.

Received 2 June 2021; received in revised form 25 August 2021; accepted 14 October 2021.
To cite this article: Talib et al. (2022). Effect of vegetable-based nanofluid enriched with nanoparticles as metalworking fluids during orthogonal cutting process. Jurnal Tribologi 32, pp.29-39.

1.0 INTRODUCTION

A metalworking fluid (MWF) is a lubricant that is sprayed between two mobile surfaces to reduce friction, transfer heat, remove impurities, and enhance efficiency. MWFs are critical consumables in manufacturing. A MWF is made up of more than 90% base oil and fewer than 10% additive package (Talib & Rahim, 2018a). The MWFs sources consist of mineral oil, synthetic oil and vegetable oil. Vegetable's oil is good for environmental benefits because it's renewable and biodegradable. However, vegetable oil needs to be modified before use it, in order to enhance the limitation of vegetables oil to become better in terms of oxidation stability, high friction, high viscosity, thermal stability and corrosion resistance (Jamaluddin et al., 2020). Moreover, vegetable oil price is cheaper than other MWFs. Recently, demand for environmentally friendly MWFs is increasing because of the high concern for environmental protection. Vegetables oils are natural products and it also working as fast biodegradable fluids. Moreover, it's is environmentally friendly candidates for the base oils for lubrication (Woma et al., 2019).

In selecting a proper MWF, tribological characteristic such as friction, lubrication and wear mechanism plays an important role (Talib & Rahim, 2018a). Sayuti et al.(2014) used MWF in the cutting area to minimize frictions both externally and internally as well as heat generation. As a result, cutting efficiency improved. In this study, minimum quality lubricant (MQL) was used as metal working fluid to achieve the sustainability in manufacturing. For the sustainability in machining technology, the uses of bio-based oil obtained from vegetable's oil offers substantial environmental advantages of non-toxicity, sustainability, eco-friendly and highly compostable (Lee et al., 2012). Due to environmental concerns, (Hwang et al., 2007) vegetable oil finding its solution into lubricants for industrial and transportation application where scientists, engineers and inventors should know that green invention and technologies are good to our mother earth and can reduce energy bill, indeed offer safer and healthier products (Srivastava & Sahai, 2013).

However, the used of vegetable oil itself as MWF has disadvantages. This is because vegetable oil has weak thermal and oxidative stability, it is considered to be a lubricant that underperforms (Yunus et al., 2004). Vegetable oil has a number of physical and chemical qualities constraints in its raw form (Rahim et al., 2017). Many study were initiated to improve vegetable oil, including chemical modifications and the inclusion of additives. (Shashidhara & Jayaram, 2010; Talib et al., 2017). There are many additives that are suitable with vegetable-based oil such as molybdenum disulphide, hexagonal boron nitride, aluminum oxide and Copper Oxide. Anti-oxidants, anti-wear agents, rust and corrosion protectors, and viscosity index improvers are all functions of lubricant additives. Recently, nanofluids which from the combination of based oil and nanoparticles has a great potential as lubricant (Talib et al., 2017). Nanofluids have the ability to improve the thermal conductivity between the fluid and the absorber, increase the density-specific heat capacity product, allowing the fluid to carry more thermal energy, and increase thermal conductivity, resulting in a higher heat transfer coefficient (Hamdan et al., 2012). Nanofluids can also reduce the cost of production, time, and energy in a variety of machining procedures (Osama et al., 2017).

Talib & Rahim (2018b) studied on the physicochemical properties of hexagonal boron nitride in modified jatropha oils-based. hBN was added at different concentration of 0.05, 0.1 and 0.5 wt.%. The result show that Viscosity index increased with the increased of concentration of hBN. Overall, the physicochemical properties of MJOs were better than SE. Tribological evaluation of modified Jatropha oil containing hBN and graphene as a metalworking fluid was studied by Jamaluddin et al. (2020). The additives were blended with MJO at the lowest amounts (0.01, 0.025, and 0.05 wt.%). Physical testing and machining capabilities were assessed. They discovered that chemical modification of Jatropha oil and the addition of additives improve the fluids' physicochemical qualities. MJO has the lowest coefficient of friction with 0.025 weight percent graphene nanoparticles. They came to the conclusion that adding additives improved lubrication performance. Talib et al. (2021) studied on tribological test of different concentration of activated carbon (0.01, 0.025 and 0.05 wt.%) in non-edible jatropha oil. The result depicts that at concentration 0.025 wt.%, the coefficient of friction and mean wear scar diameter was the lowest. They concluded that jatropha oil with 0.025 wt.% of activated carbon was comparable with the metalworking fluid in the market.

Nanofluids that are prone to coagulation and hence lose their ability to transport heat. As a result, stability research is an inevitable problem that can affect the thermo-physical properties of nanofluids for application, and it's also crucial to understand the components that influence the stability of such suspensions(Mukherjee & Paria, 2013). Hwang et al. (2007) study on the stability and thermal conductivity characteristics of nanofluids. The stability of the nanofluids were estimated by using UV-vis spectrum analysis. The characteristic of the nano particles and base fluids such as particle morphology and chemical structure strongly affect the stability of the nanofluids. Thermal conductivity of the nanofluids were depends on the volume fraction of the nanoparticles. The particle concentration affects the dispersibility and stability of the nanofluids. Five different concentrations of ZnO nanoparticles (0, 0.2, 0.5, 0.8 and 1.0 wt.%) were added into the based oil respectively with oleic acid as surfactant. The sedimentation process over time of the nanofluids were visually examined. They found that, with concentration of 0.5 wt.%, the nanofluid remain stable (Ran et al., 2017).

For this study, modified jatropha Modified jatropha oil (MJO) was blended with two types of additives (Copper Oxide and Activated Carbon) to be used as MWFs. Machining performance in terms of cutting temperature, chip thickness, and tool chip contact length were used to estimate the potential of modified jatropha nanofluids.

2.0 EXPERIMENTAL PROCEDURE

2.1 Preparation of Bio-Based Nanofluids Lubricant

The preparation of MJO was started with the chemical modification of CJO. CJO undergo two step acid-based catalyst to produced JME. The first step is esterification process of CJO and phosphoric acid in which the content of fatty acid (%FFA) was reduced to less than 1%. The second step was transesterification of methanol with EJO in ratio (6:1) to produced JME. Next, MJO was developed through transesterification process of trimethylolpropane ester (TMP) + jatropha methyl ester (JME) in ratio (3.5 :1) with presence of presence of 1% (wt./wt.) sodium methoxide ($NaOCH_3$) (Jamaluddin et al., 2020; Talib & Rahim, 2018a). Then, MJO was blended with CuO and AC to formulate a nanofluid by using a magnetic stirrer at 700 rpm and at temperature 60^{o}C for 30 minutes. Table 1 shown the properties of CuO and AC. Table 2 shows all the lubricant samples prepared with nanoparticles additives.

Figure 1 depicts the Fourier transform infrared spectroscopy (FTIR) spectra of SE and MJO as base oils. From the figure 1, in the range 1735-1750 cm^{-1} and 1000-1300 cm^{-1} for both MJO and SE, the graph clearly exhibits an identical absorption band. This is due to stretching vibrations of C=O and C-O bonding in ester, thus verifies the existence of oxygen in SE and MJO in their molecular structures. The existence of C-H bending and stretching vibrations in the ester molecules of the SE and MJO lubricants is indicated by absorption peaks in 1350-1480 cm $^{-1}$ and 2850- 2950 cm^{-1}, respectively.

Table 1: Properties of nanoparticle additives (Katpatal et al., 2017).

Properties	**Copper Oxide (CuO)**	**Activated carbon (AC)**
Size	50 nm	0.5 – 2.36 mm
Appearance	Black to brown powder	Black
Density (g/cm^3)	6.31	True density: 0.46
Molecular weight (g/mol)	79.54	N/A
Melting Point (^oC)	1201	N/A
Thermal expansion coefficient (W/mK)	28	47

Table 2: Detail of MJO sample

Name of Sample	**Concentration of Additives (Wt.%)**	**Type of Nanoparticles Additives**
MJOc1	0.01	
MJOc2	0.025	Copper Oxide
MJOc3	0.05	
MJOa1	0.01	
MJOa2	0.025	Activated Carbon
MJOa3	0.05	

This finding supports the occurrence of an identical functional group of alkanes in ester lubricants. It was also discovered that the existence of the hydroxide group (OH) indicated by the absorption peak in range 3200-3600 $cm^{-1}$is small for MJO implying that the MJO produced by transesterification processes is complete and equivalent to the conventional SE (Abdul Sani et al., 2019).

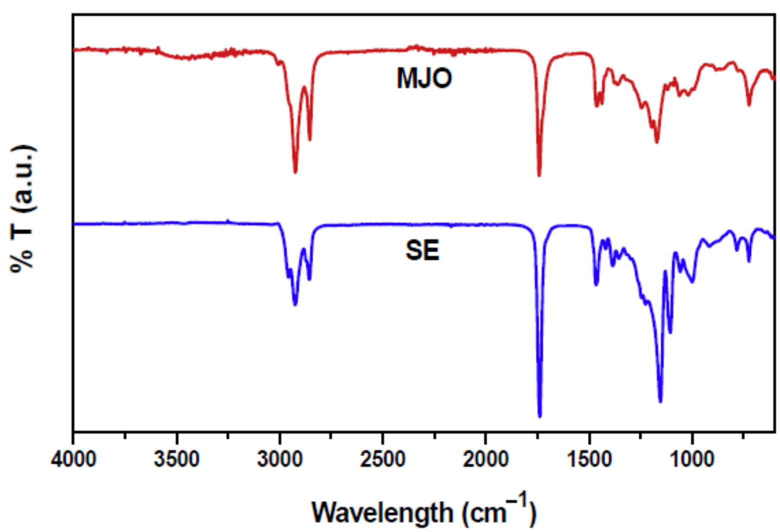

Figure 1: Characteristic IR Absorption Frequencies of SE and MJO lubricants (Abdul Sani et al., 2019).

2.2 Machining Performance

Orthogonal cutting was performed using an NC lathe machine (Alpha Harrison 400) with the orthogonal cutting parameters listed in Table 2. AISI 1045 is a plain medium carbon steel was chosen as workpiece in this study. AISI 1045 is extensively used in the engineering and industrial industries and is also often incorporated in modelling software (Hwang & Lee, 2010; Sharma et al., 2016; Vishnuja & Bhaskar, 2018). Due to its high specific strength, heat resistance, and superior machinability, coupled with ductility and viscosity, AISI 1045 carbon steel is an excellent steel. AISI 1045 carbon steel has traditionally been utilized in industrial bearings as well as other applications such as gears, machine tools, and various mechanical parts (Karimbaev et al., 2020) . A square form insert with the model number SPGN120308 was used as a cutting tool. Minimum quantity lubrication (MQL) method was used to supply the lubricant with input pressure of 0.4 MPa during the cutting process. The lubricant supplied was at constant flowrate of 0.16 ℓ/hr from the nozzle with inner diameter of 0.25 mm. The MQL nozzle was placed at angle of 45^{o} and approximately 8 mm from the cutting edge of the cutting tools. Thermal imager camera FLIR T640 was used measure the maximum cutting temperature by placing the camera in axial direction during machining process. Micrometer (model: Mitutoyo IP 65) was used to measure chip thickness. Ten pieces of chips had been taken to measure every machining parameter and the average reading of the chip thickness clarified. The tool-chip contact length was measured at the rake surface of the tool insert using Nikon MM-60 tool maker measuring microscope. The captured length of the tool-chip on the rake face of tool insert was displayed in Figure 2.

Table 2: Orthogonal cutting parameters.

Description	**Values**
Cutting speed, *Vc* (m/min)	350
Feed rate, *fr* (mm/rev)	0.08
Width of cut, *w* (mm)	2
Axial cutting length (cm)	10
MQL input pressure, MPa	0.4
Nozzle angle, ^{o}	45
Nozzle inner diameter, mm	2.5
Oil flow rate, ℓ/hr	0.16
Workpiece material	AISI 1045

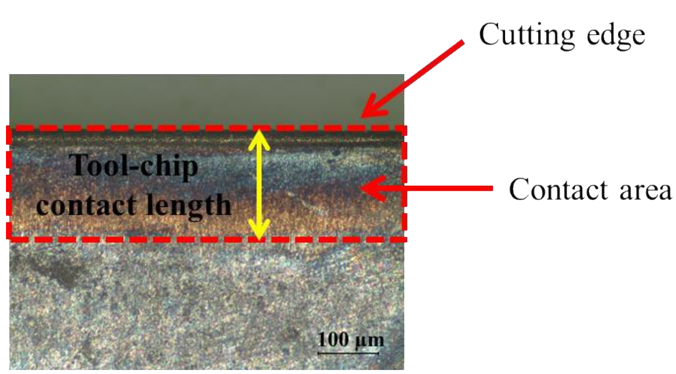

Figure 2: Tool-chip contact length at the rake surface.

3.0 RESULTS AND DISCUSSION

3.1 Cutting Temperature

The result for the maximum cutting temperature was shown in graph in Figure 3. From the graph, SE had higher cutting temperature when compared to MJO blended with additives. The highest cutting temperature is SE which is 244.1^{o}C because of the low Viscosity Index (VI) (139)(Talib et al., 2019). When the cutting tool interfaces with the workpiece, the heat was generated. Low VI caused weaker lubrication layer because of the high percentage of unsaturated fatty acid content in SE so the carbon chains of SE were easily broken and lubricant film evaporated at high temperature (Lawal, 2013). MJOs shows 2 to 10% lowest in cutting temperature compared to SE. It is as a result of the development of extensive, complex branches and polarity molecular chain of TMP trimester that provide strong lubrication film (Atabani et al., 2013).

The lower maximum cutting temperature is MJOa2 which is 130.6^{o}C. The mixture of Activated Carbon in MJO help of increasing the lubricating ability under high pressure, but if excessive of additives can increase high stress and high friction in oil, which is fluid films cannot protect surface area and caused the temperature to increase. For the MJOc, the lowest temperature is MJOc2 which is 211.3^{o}C and followed by MJOc3 and MJOc1. Maximum cutting temperature is important when evaluating the machining performance because can prolonging tool life (Uysal et al., 2015). The maximum cutting temperature for MJOa is lower than MJOc is because of the thermal expansion coefficient of Activated Carbon additives is higher that thermal expansion coefficient of Copper Oxide (Chan et al., 2018). Thermal expansion coefficient of additives plays an important role towards the cutting temperature. The cutting temperature decrease because of the high thermal expansion coefficient of the material (Atabani et al., 2013). The properties in terms of thermal conductivity of Activated Carbon and Copper Oxide help enhanced the lubricant oil in MJO that caused strong lubricant film compared to SE (Katpatal et al., 2017).

Heat generation can have an impact on dimensional accuracy, surface finish, and tool life on a workpiece during the machining process. (Talib et al., 2017). The creation of a lubricating layer from oil viscosity can reduce heat generation (Shashidhara & Jayaram, 2010). In this study, it is revealed that the lowest maximum cutting temperature was scored by the presence of 0.025 wt.% of nanoparticles in MJO. Figure 4(a) shows the rolling effect happen at the lubricant during machining process at the concentration of 0.01wt %. At lower concentration of nanoparticles less particle entrapped into the interface thus form poor lubrication film. Figure 4(b) demonstrates that a high concentration of CuO and Activated Carbon caused a high stress concentration, facilitating the abrasive character of particles at a concentration of 0.05wt.%. This discovery is in agreement with previous study by Talib et al.(2018). The higher concentration of additives particles would made higher friction between contact surface (Wan et al., 2015). The lubrication film for MJOc1, MJOc3, MJOa1 and MJOa3 were completely broken down and lubrication film cannot protect the contact surface between tool and chips that caused the increasing of cutting temperature. In conclusion, the lowest cutting temperature among all samples is MJOa2 because of the existence of fatty acids in TMP trimester and provide strong lubrication film formation between contact surface of toll and chips.

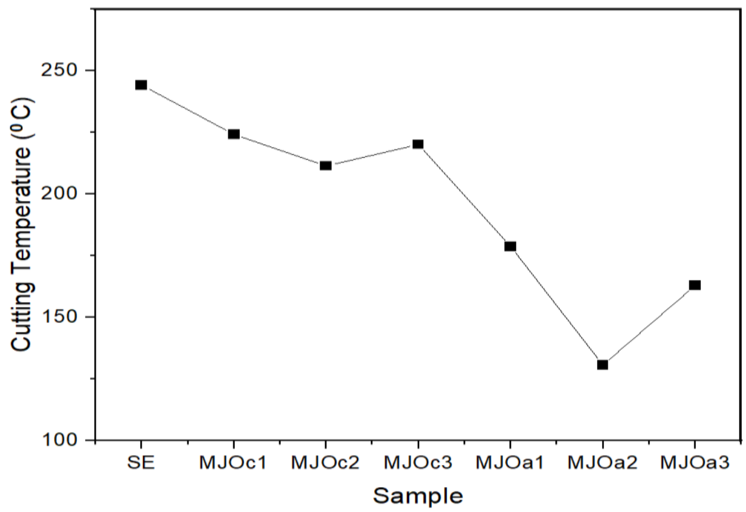

Figure 3: Cutting Temperature.

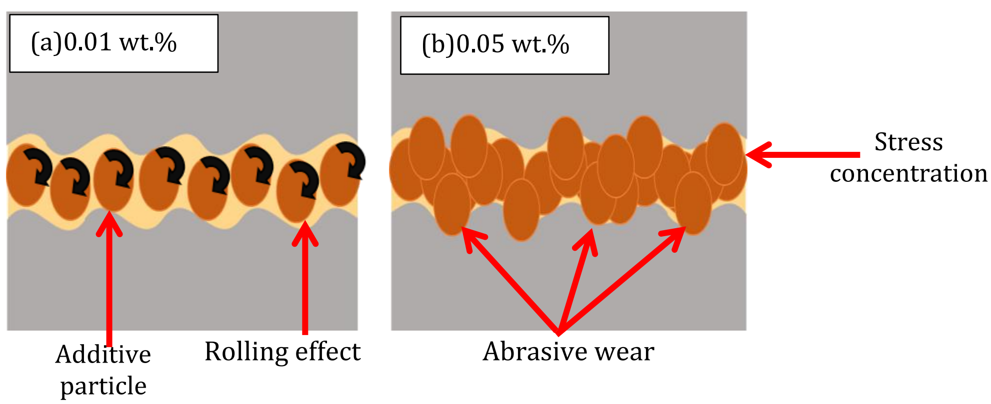

Figure 4: Schematic diagram of lubrication film in MJO samples with various concentrations. (a) 0.01wt.% (b) 0.05wt.%.

3.2 Chip Thickness

Figure 5 shows the graph of the chip thickness collected after machining process. The highest chip thickness among all samples is SE which is 0.223 mm. This is due to the MJOs' lubricating film, which reduces the contact area at the shear zone during machining. MJOs have a long and complex molecular chain that provides a resilient lubrication film, which decreases friction at the tool-workpiece contact (Huang et al., 2015; Talib et al., 2018). MJOc2 has the thinnest chip because the lubrication layer between tool-chip edges is sufficient (Dhar & Kamruzzaman, 2005). The reduction of chip thickness in MJOc2 are 15% lower than SE. In addition, the formation of a lubricating coating can help the chip move over the tool, resulting in a shorter contact length (Atabani et al., 2013). Moreover, for the MJOc3 have excessive of additives that resulting of smaller shear angles and thicker chips. Thus, the film layer cannot be formed resulting in an increase in contact area. Hence, the formation of chips become thicker. The lowest chip thickness among MJOa is MJOa2 which is 0.182mm and followed by MJOa1 and MJOa3. It is caused by an increase in friction between the contact surface and the tool (Wan et al., 2015). In conclusion, the best performance in terms of chip thickness is MJOc2 which is 0.178mm because have sufficient lubrication film layer when tool interface with surface area (Talib et al., 2017). The results showed that the higher concentration tends to the increasing chip thickness. Excessive among of additives increased friction during machining process and the lubrication film could not be formed and produced thicker chips. Furthermore, high stress concentration caused generated high amount of force. According to Figure 4(b), high concentration generated asperities due to large agglomeration particles, which produced excessive friction on the tool-chip contact surface (Osama et al., 2017).

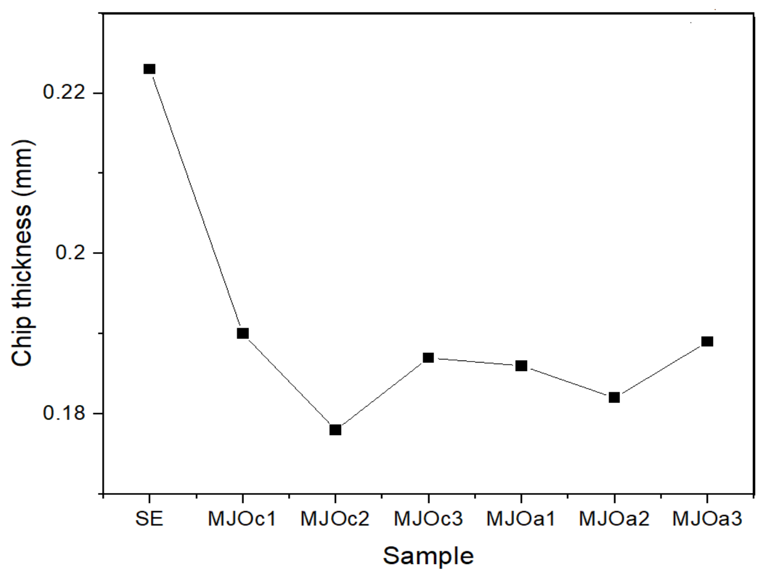

Figure 5: Chip thickness.

3.3 Tool Chip Contact Length

Figure 6 shows the optical image of the cutting tools at rake surfaces after orthogonal cutting process. From the images, it can be seen that the different composition of Copper Oxide and Activated Carbon have affected the tool chip contact length. It corresponded with the cutting temperature and chip thickness that have been reported in this study. Different MWFs that being applied in cutting edge strongly affected the cutting temperature and tool chip contact length (Abdul Sani et al., 2019). The MJOs have 5 to 10% shorter tool chip contact length than SE. It is because of the high construction of long and branched TMP triester and led to reducing friction between contact surface of tool and chips (Shashidhara & Jayaram, 2010). The shortest length among MJOa and MJOc are MJOa2 and MJOc2 which are 0.331 µm and 0.294 µm respectively. It was discovered that having enough lubrication has an impact on tool chip contact length reduction. Friction was minimized and tool chip contact length was decreased when lubricant penetrated into the shearing zone (Osama et al., 2017). The high formation in MJOa2 and MJOc2 provide sufficient protective film are capable to reduce the tool chip contact length and reduced friction between tool and metal surface (Ilhan et al., 2016). As for the MJOa3, the result 5% higher than MJOa2 because the presence of excessive additives that led to poor lubrication cause by increased in friction. The presence of additives in MJOc1, MJOc3, MJOa1 and MJOa3 showed bad performance in contact length as shown in Table 3. It is due to the higher concentration cased the protective film of MJOs started to break down. The excellent performance in terms of tool chip contact length is MJOc2 because of sufficient of lubricant formed protective layer that can reduced friction and tool chip contact length (Wan et al., 2015).

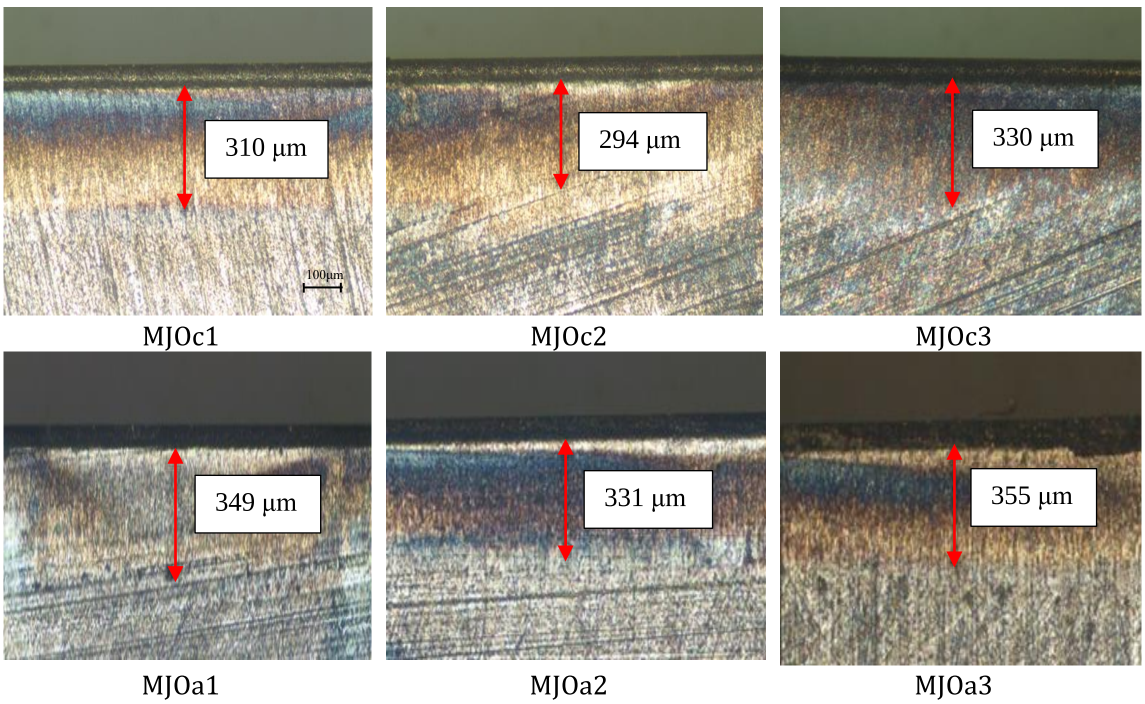

Figure 6: Tool chip contact length on the cutting insert.

CONCLUSION

As a conclusion, MJO with the presence of CuO and Activated Carbon nanoparticles at 0.025 wt.% respectively shows better result in orthogonal cutting process in terms of cutting temperature, chip thickness and tool chip contact length compared at composition 0.01 and 0.05 Wt.%. in addition, MJO with the presence of additives inhibit better machining performances compared to synthetic ester. The overall best machining performance is MJOa2 (MJO + 0.025wt.% Activated Carbon). In addition, in terms of environmental concern and energy efficiency, it has the potential to be on the lubricant market.

ACKNOWLEDGEMENT

The author would like to thank the Ministry of Higher Education Malaysia (MOHE) and Universiti Tun Hussein Onn Malaysia through Fundamental Research Grant Scheme (FRGS) (FRGS/1/2018/TK03/UTHM/03/10)(K077).

REFERENCES

Abdul Sani, A. S., Rahim, E. A., Sharif, S., & Sasahara, H. (2019). Machining performance of vegetable oil with phosphonium- and ammonium-based ionic liquids via MQL technique. Journal of Cleaner Production, 209, 947–964.

Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Fayaz, H. (2013). Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. Renewable and Sustainable Energy Reviews, 18, 211-245.

Chan, C. H., Tang, S. W., Mohd, N. K., Lim, W. H., Yeong, S. K., & Idris, Z. (2018). Tribological behavior of biolubricant base stocks and additives. Renewable and Sustainable Energy Reviews, 93(March 2017), 145–157.

Dhar, N. R., Khan M. M. A. & Kamruzzaman, M. (2005). A Study of Effects of MQL by Vegetable Oil on Cutting Temperature , Chips and Cutting Forces in Turning AISI-1060 Steel. Recent Advances in Manufacturing Technologies, October.

Hamdan, A., Fadzil, M., & Hamdi, M. (2012). Procitan Rad --- Performance Evaluation of Different Types of Cutting Fluid in the Machining of Aisi 01 Hardened Steel Using Pulsed Jet Minimal Quantity Lubrication System. Rg, July, 1–9.

Huang, S., Yao, W., Hu, J., & Xu, X. (2015). Tribological Performance and Lubrication Mechanism of Contact-Charged Electrostatic Spray Lubrication Technique. Tribology Letters, 59(2).

Hwang, Y. K., & Lee, C. M. (2010). Surface roughness and cutting force prediction in MQL and wet turning process of AISI 1045 using design of experiments. Journal of Mechanical Science and Technology, 24(8), 1669–1677.

Hwang, Y., Lee, J. K., Lee, C. H., Jung, Y. M., Cheong, S. I., Lee, C. G., Ku, B. C., & Jang, S. P. (2007). Stability and thermal conductivity characteristics of nanofluids. Thermochimica Acta, 455(1–2), 70–74.

Ilhan, B., Kurt, M., & Ertürk, H. (2016). Experimental investigation of heat transfer enhancement and viscosity change of hBN nanofluids. Experimental Thermal and Fluid Science, 77, 272–283.

Jamaluddin, N. A., Talib, N., & Abdul Sani, A.S. (2020). Tribological Assessment of Modified Jatropha Oil with hBN and Graphene Nanoparticles as a New Preference for the Metalworking fluid. International Journal of Engineering and Advanced Technology, 9(3), 3144–3149.

Karimbaev, R., Choi, S., Pyun, Y. S., & Amanov, A. (2020). Mechanical and tribological characteristics of cladded AISI 1045 carbon steel. Materials, 13(4).

Katpatal, D. C., Andhare, A. B., Padole, P. M., & Khedkar, R. S. (2017). Study of dispersion stability and thermo-physical properties of CuO-Jatropha oil-based nanolubricants. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 39(9), 3657–3668.

Lawal, S. A. (2013). A review of application of vegetable oil-based cutting fluids in machining non-ferrous metals. Indian Journal of Science and Technology, 6(1), 3951–3956.

Lee, P. H., Nam, J. S., Li, C., & Lee, S. W. (2012). An experimental study on micro-grinding process with nanofluid minimum quantity lubrication (MQL). International Journal of Precision Engineering and Manufacturing, 13(3), 331–338.

Mukherjee, S., & Paria, S. (2013). Preparation and Stability of Nanofluids-A Review. IOSR Journal of Mechanical and Civil Engineering, 9(2), 63–69.

Osama, M., Singh, A., Walvekar, R., Khalid, M., Gupta, T. C. S. M., & Yin, W. W. (2017). Recent developments and performance review of metal working fluids. Tribology International, 114, 389–401.

Rahim, E. A., Talib, N., Amiril Sahab, A. S., Syahrullail, S., & Mohid, Z. (2017). Tribological evaluation

on various formulation of modified rbd palm olein as sustainable metalworking fluids for machining process. Materials Science Forum, 882, 13–17.
Ran, X., Yu, X., & Zou, Q. (2017). Effect of Particle Concentration on Tribological Properties of ZnO Nanofluids. Tribology Transactions, 60(1), 154–158.
Sayuti, M., Erh, O. M., Sarhan, A. A. D., & Hamdi, M. (2014). Investigation on the morphology of the machined surface in end milling of aerospace AL6061-T6 for novel uses of SiO2 nanolubrication system. Journal of Cleaner Production, 66, 655–663.
Sharma, A. K., Tiwari, A. K., & Dixit, A. R. (2016). Effects of Minimum Quantity Lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: A comprehensive review. Journal of Cleaner Production, 127, 1–18.
Shashidhara, Y. M., & Jayaram, S. R. (2010). Vegetable oils as a potential cutting fluid-An evolution. Tribology International, 43(5–6), 1073–1081.
Srivastava, A., & Sahai, P. (2013). Vegetable oils as lube basestocks: A review. African Journal of Biotechnology, 12(9), 880–891.
Talib, N., & Rahim, E. A. (2018a). Performance of modified jatropha oil in combination with hexagonal boron nitride particles as a bio-based lubricant for green machining. Tribology International, 118(March 2017), 89–104.
Talib, N., Sasahara, H., & Rahim, E. A. (2017). Evaluation of modified jatropha-based oil with hexagonal boron nitride particle as a biolubricant in orthogonal cutting process. International Journal of Advanced Manufacturing Technology, 92(1–4), 371–391.
Talib, N., Jamaluddin, N. A., Sheng, T. K., Kiow, L. W., Abdullah, H., Ahmad, S., & Saleh, A. (2021). Tribological Study of Activated Carbon Nanoparticle in Nonedible Nanofluid for Machining Application Tribological Study of Activated Carbon Nanoparticle in Nonedible Nanofluid for Machining Application. EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 8(2), 454–460.
Talib, N. Nasir, R. M., & Rahim, E. A. (2018). Investigation on the tribological behaviour of modified jatropha oil with hexagonal boron nitride particles as a metalworking fluid for machining process. International Journal of Integrated Engineering, 10(3), 57–62.
Talib, N., & Rahim, E. A. (2018b). Experimental evaluation of physicochemical properties and tapping torque of hexagonal boron nitride in modified jatropha oils-based as sustainable metalworking fluids. Journal of Cleaner Production, 171, 743–755.
Talib, N., Abdul Sani, A. S., & Hamzah, N. A. (2019). Modified jatropha nano-lubricant as metalworking fluid for machining process. Jurnal Tribologi, 23(September), 90–96.
Uysal, A., Demiren, F., & Altan, E. (2015). Applying Minimum Quantity Lubrication (MQL) Method on Milling of Martensitic Stainless Steel by Using Nano Mos2 Reinforced Vegetable Cutting Fluid. Procedia - Social and Behavioral Sciences, 195, 2742–2747.
Vishnuja, U., & Bhaskar, G. B. (2018). Study on AISI1045 Material for Various Applications: An overview. International Journal of Engineering and Manufacturing Science, 8(2), 125–144.
Wan, Q., Jin, Y., Sun, P., & Ding, Y. (2015). Tribological behaviour of a lubricant oil containing boron nitride nanoparticles. Procedia Engineering, 102, 1038–1045.
Woma, T. Y., Lawal, S. A., Abdulrahman, A. S., Olutoye, M. A., & Ojapah, M. M. (2019). Vegetable oil based lubricants: Challenges and prospects. Tribology Online, 14(2), 60–70.
Yunus, R., Fakhru'l-Razi, A., Ooi, T. L., Iyuke, S. E., & Perez, J. M. (2004). Lubrication properties of trimethylolpropane esters based on palm oil and palm kernel oils. European Journal of Lipid Science and Technology, 106(1), 52–60.