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Tribology Effect On Turning Machine Process Using Jatropha Oil with AC Nanoparticle

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Abstract: Synthetic-based lubricant is widely used in industry for metalworking fluid in machining. However, it can be dangerous to operator's health and environment due to chemical components. Thereupon, a development of biodegradable oil with low toxicity has been taken as initiatives to be a substitute of existing lubricant. The purpose of this study was to formulate new environmentally friendly lubricant with modified jatropha oil (MJO) as based oil and activated carbon (AC) as nanoparticle at various concentrations (0.01wt%, 0.025wt% and 0.05wt%) and to analyze tribological performance in terms of cutting temperature tool wear and tool life using turning process. The tribological performance of MJO + AC was compared with benchmark oil, synthetic ester (SE) using minimum quantity lubricant technique (MQL). Tribological performances such as cutting temperature was recorded in the first 100 mm axial cutting length. From the result, MJO + 0.025wt% AC shows outstanding performance in cutting temperature compared to all samples. The addition of 0.025wt% of AC which had porous structure increases the adsorption thus provides protection layer and sufficient concentration of AC promotes rolling action. Hence, the experiment was continued using MJO + 0.025wt% AC and SE to compare tool wear in terms of average flank wear (VB_B), maximum flank wear (VB_{Bmax}), notch wear (VB_N) and tool life. MJO + 0.025wt% AC has longer tool life (7000mm cutting length at 49 minutes machining time) compared to SE (6000mm cutting length at 42 minutes machining time). In conclusion, MJO + 0.025wt% AC exhibit outstanding tribological performance and suitable to replace synthetic oil as MWF.

Keywords: Metalworking Fluid, Activated Carbon, Jatropha Oil, Tribology, Turning Process

1. Introduction

In today's industries, most of the lubricant that industrialists are using in production manufacturing is synthetic based lubricant oil (SLO). SLO is chemically manufactured using petroleum that has been modified its components rather than the whole crude oil itself. SLO is a chemical component with a complex mixture which contain paraffins, olefins, naphthenes and aromatic hydrocarbon [1]. The chemical containing harmful compounds are dangerous when the compounds are released to the environment as these mixtures shows low biodegradability in its

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**Corresponding author: fazillah@uthm.edu.my* content. In order to preserve the environment condition, a development of biodegradable oils with zero toxicity is being studied from the extraction of vegetables oil available in natural procurement to replace synthetic oil that requiring a higher waste management budget.

Vegetable's oil can be derived to produce a bio-based oils are considered to be useful to replace petroleum-based oils. Vegetable oils can be categorized as two types, edible and non-edible. The non-edible oil such as jatropha oil shows deficiency in terms of poor thermal-oxidative stability showed by crude jatropha oil that leads to poor lubrication behavior [2]. This deficiency could be improved by improvising crude jatropha oil through transesterification process and with addition of nanoparticle such as hexagonal boron nitride (hBN) [2].

Bio-based lubricant which is line of vegetable oil uses minimum quantity lubricant (MQL) technique in machining process to minimize the excessive use of lubricant during machining process as MQL method forms mist droplets with a higher contact area and amplify the possibility of oil to reach the whole part of workpiece interfaces and thus increase cooling capacity and heat transfer [2]. However, bio-based oil alone has deficiency in several aspect due to high content of unsaturated fatty acids and polyunsaturated in vegetable oils hence additive is needed to enhance or even impart new properties [2]. A study suggest the use of activated carbon (AC) as additive in lubricant due to its porous structure that exhibits remarkable improvement toward the base oil and hence jatropha oil is used to study the tribological performance of the nanofluid by using AC as nanoparticle to compare with existing lubricant oil [3]. Porous structure of AC has large surface area for the adsorption of molecules to the adsorbent thus creating layer of protective film and it strengthen the interaction between polar and non-polar adhesion [3].

The main focus of this study is to highlight the suitable lubricant oil to replace the current available synthetic oil use in turning machine when cutting in shape an AISI 1045 steel in terms of the tribological performance. Tribological performance can be observed in term of the lubrication of nanofluids in terms of cutting temperature, tool wear and tool life.

2. Materials and Methods

2.1 Preparation of metalworking fluid

Crude jatropha oil (CJO) is developed into MJO via transesterification. Initially, CJO is converted into jatropha methyl ester (JME) by two-step acid-based catalyst transesterification. High content of free fatty acids is reduced to less than 1% through esterification process to achieve high yield of JME. In esterification, the reaction between oil and methanol in the presence of 0.5% of sulphuric acid (H_2SO_4) as catalyst reduced the value of free fatty acid. Later, the sample undergo transesterification of triglyceride with methanol to produce JME with presence of 1wt% sodium hydroxide (NaOH). The JME produced then react with trimethylolpropane (TMP) via transesterification with addition of 1% of sodium methoxide ($NaOCH_3$) to develop MJO. The MJO produced was filtered to remove impurities. Table 1 shows the physicochemical properties of MJO. The molar ratio effect was observed by varying the ratios of JME to TMP in between 3:1:1 and 3:5:1. MJO was mixed with AC at various concentration of 0.01wt%, 0.025wt% and 0.05wt% via magnetic stirrer at 700 rpm and 60°C in the oil bath condition for 30 minutes [2]. Table 1 shows the properties of MJO + AC at various concentration and SE.

Table 1: Properties of MJO + AC at various concentration with SE [4]

Properties		SE	MJO	MJO + 0.01wt% AC	MJO + 0.025wt% AC	MJO + 0.05wt% AC
Kinematic Viscosity, v (mm^2/s)	**40°C**	19.05	16.87	16.72	18.32	16.43
	100 °C	4.33	4.49	5.78	5.80	5.42
Viscosity index, VI		137	196	344	302	315
Density at 15°C (kg/m^3)		0.94	0.9126	0.9367	0.9346	0.9332

2.2 Turning process

The tribological performance in terms of cutting temperature, tool life and tool wear were evaluated via turning process using the sample of lubricants. The experiment was conduct on AISI 1045 steel using NC Harrison Alpha 400 based on the parameter on Table 2. The MWF was supply using MQL technique and Figure 1 shows the turning setup.

FLIR T640 thermal imager camera was setup manually on the turning machine used to analyze the maximum cutting temperature of each sample at first 100mm length axial cutting at the contact area. Nikon MM-60 tool maker microscope was used to analyze the wear progression at flank face for average flank wear (VB_B), maximum flank wear (VB_{Bmax}) and notch wear (VB_N) at interval of 500mm cutting length according to guideline ISO 3685:1993. Formation of crater at rake face and nose face was also observed. Tool life was measured based on the total machining time (min) and total cutting length (mm).

Table 2: Turning parameter for turning machining [2]

Description	Values
Cutting speed, *Vc* (m/min)	300
Feed rate, f_r (mm/rev)	0.2
Depth of cut (mm)	1
Oil flow rate (l/hour)	0.16
Workpiece material	AISI 1045
Workpiece diameter (mm)	150
Cutting tool	Uncoated cermet
Type of lubricant	MJO + 0.01wt% AC MJO + 0.025wt% AC MJO + 0.05wt% AC
Benchmarking oil	Synthetic ester (Unicut Jinen MQL)

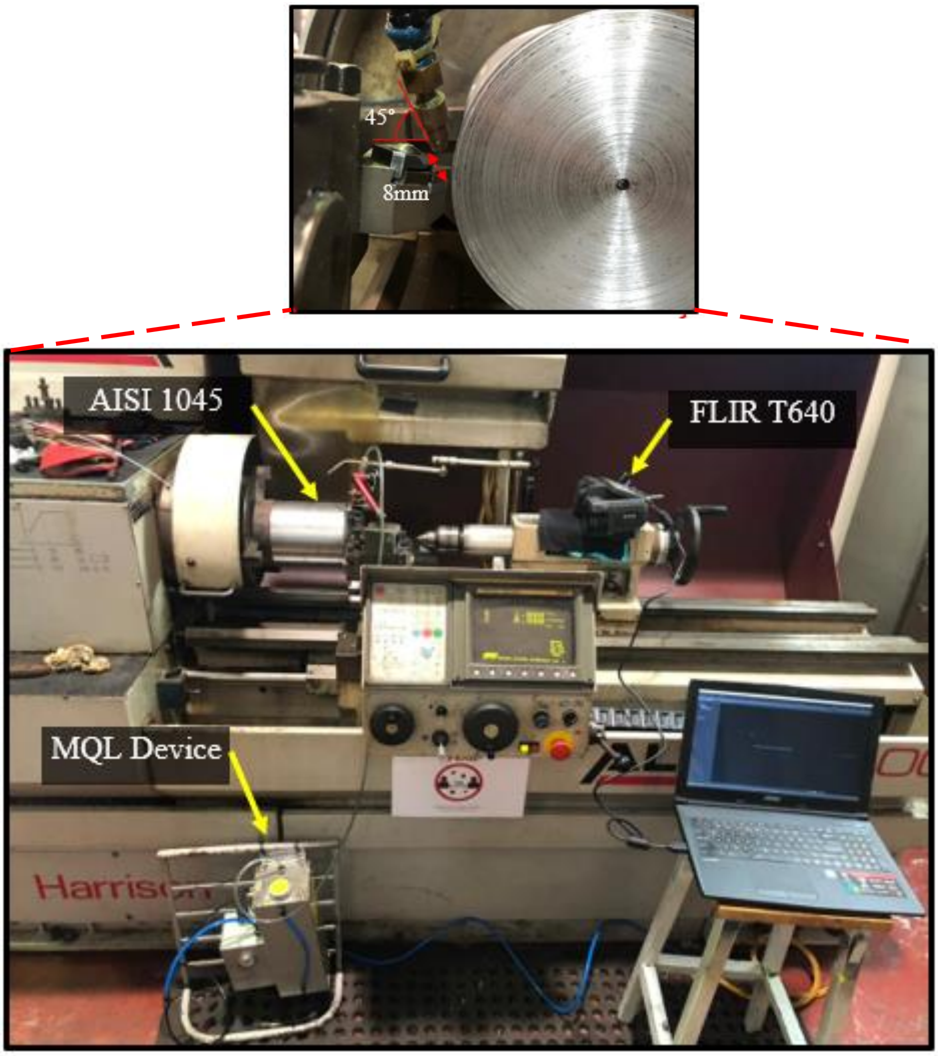


Figure 1: Turning setup

3. Results and Discussion

3.1 Cutting temperature

Table 3: Result of cutting temperature for all sample

Samples of MWF	Maximum Cutting Temperature (°C)
MJO + 0.01wt% AC	136.7
MJO + 0.025wt% AC	101.9
MJO + 0.05wt% AC	122.6
SE	198.8

Heat was created throughout the machining process at the tool-chip interfaces' primary, secondary, and tertiary deformation zones. From Table 3, SE recorded highest value of cutting temperature because of long chain of fatty acid which is between C_8 and C_{10} compared to MJOs which has long chain of fatty acid between C_{16} and C_{18} that enhancing lubrication film [2]. Long chain of fatty acids in MJOs tends to reduce friction and increase the adsorbed film thickness which subsequently increase the protection of surface area [5]. This explain the poor tribological performance shows by SE compared to MJOs. The addition of AC nanoparticle to the MJOs at various concentration enhance the tribological performance as AC has large surface area, strong mechanical strength and stability in chemical properties provide excellent adsorption and friction reducer [3].

Among three samples of MJOs with AC, MJO + 0.01wt% AC and MJO + 0.05wt% AC shows poorer tribological performance compared to MJO + 0.025wt% AC. This is because MJO + 0.01wt% AC has insufficient concentration of nanoparticle thus reduce the strength of lubrication film and shifted rolling mechanism to sliding mechanism resulting to inadequate cooling capabilities and rougher surface [6]. MJO + 0.05wt% AC cause the agglomeration of nanoparticle in nanofluid thus increase kinematic energy to the surface of the workpiece [7]. Agglomeration from high abrasive nanoparticle increased friction at tool-chip interfaces cause breakdown of lubrication film thus [8]. In addition, agglomeration cause unenduring stress as shown in Figure 2 resulting in poor lubrication stability.

Superior and excellent performance was recorded by MJO + 0.025wt% AC because sufficient amount of nanoparticle provides rolling mechanism as shown in Figure 3. Besides, adsorptive properties of AC to form protective layer is mainly due to dispersion component of the Van der Waals forces [9]. Excellent adsorptive properties of AC act as spacer to prevent asperities of two metal surface from contact with each other [3].

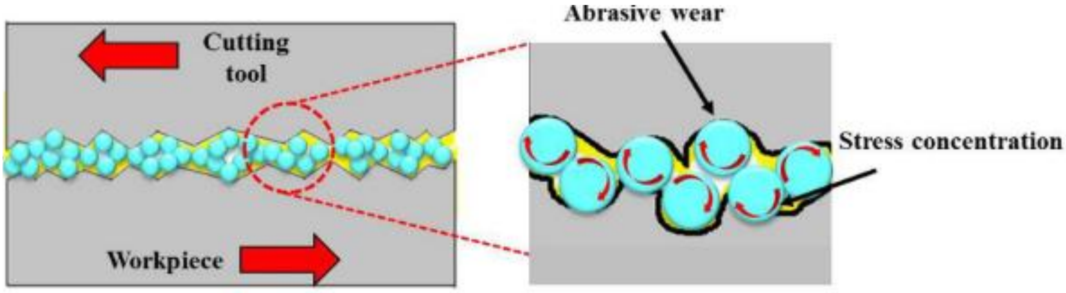


Figure 2: Mechanism of nanoparticle at high concentration [8]

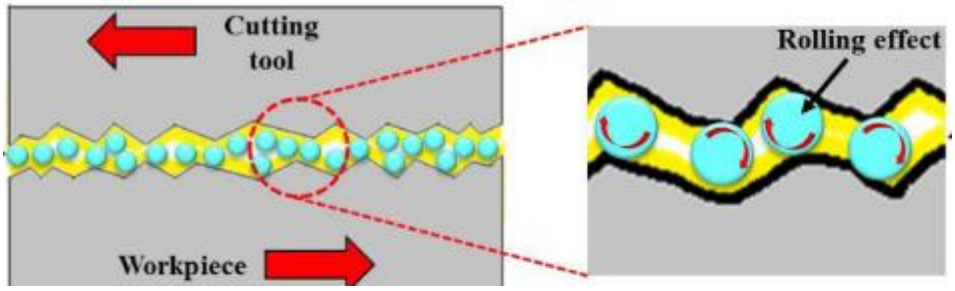
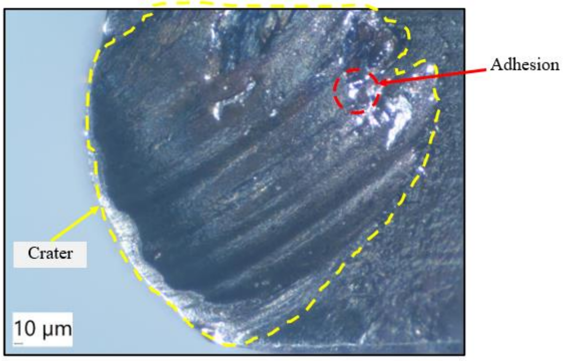
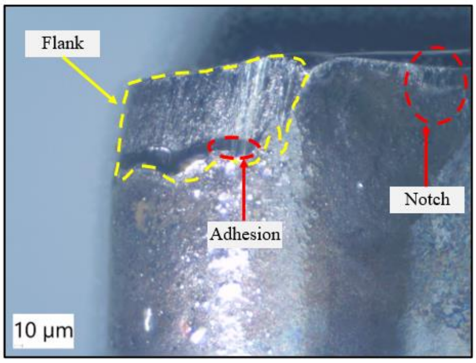


Figure 3: Rolling mechanism of nanoparticle [8]

3.2 Tool wear and tool life

The cutting tool can wear from the rubbing action and friction to remove a material from the workpiece causing functional surface to degrade which eventually leading to tool failure. Crater wear shown in Table 4 occurred from adhesion, diffusion and abrasion meanwhile flank wear occurred by microchipping and abrasion [8]. Crater wears occur from the plucking action between the cutting edge and chip that take away the tool particle at the rake face. Adhesion wear from sliding effect of the chips at the tool surface during the deformation process generate high temperature [8]. Abrasion wear occur at the flank wear as the material of the tool is peeled off by hard particles that can be loose [10]. The formation of abrasion grooves was due to the broken hard particles at the tool and sliding chips. In addition, severe abrasion at the depth of cut line on the flank face cause the formation of notch wear at flank face [11].

Table 4: Wear progression of cutting tool

Crater wear	Flank wear
	

ISO 3685:1993 was used as guideline in monitoring tool life value which is the tool failure when exceed tool wear criteria. SE tool life failed when its notch wear (VB_N) exceeds 0.6mm at 6000mm cutting length and machining time of 42 minutes. Meanwhile, MJO + 0.025wt% AC failed when its average flank wear (VB_B) exceeds tool wear criteria of 0.3mm at 7000mm cutting length and machining time of 49 minutes. Figure 4 shows the progression of average flank wear (VB_B) for MJO + 0.025wt% AC and SE.

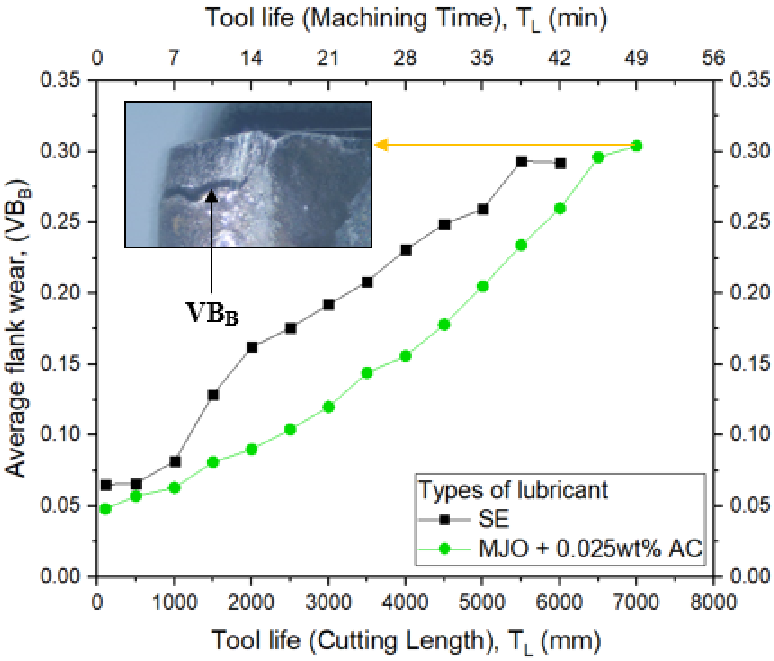


Figure 4: Graph of average flank wear, VB_B of SE and MJO + 0.025wt% AC

4. Conclusion

In conclusion SE show a poor tribological performance due to shorter fatty acid chains (C_8 and C_{10}) compared to MJO which has long fatty acid chains (C_{16} and C_{18}). These properties of SE minimize the adsorbed film thickness and friction which consequently show bad tribological behavior resulting in high cutting temperature and shorter tool life. The addition of AC nanoparticle to the MJO corresponds to good lubricating properties. Overall, the performance of MJO with various nanoparticle still above the performance of SE. The experimental results revealed that MJO + 0.025wt% AC shows outstanding performance in cutting temperature and tool life compared to all samples thus can best be proposed to substitute SE as an environmentally benign MWF with regard to sustainability for machining operation.

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