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The effect of tribology behavior on machining performances when using bio-based lubricant as a sustainable metalworking fluid

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Abstract

Metalworking fluid (MWF) is commonly used to reduce wear and friction, thus improve the machining productivity and quality. However, the usage of conventional MWF made from mineral oil causes negative effects to the ecology and human health. Therefore, it is desirable to formulate a sustainable MWFs as an alternative to petroleum-based oils. The crude jatropha oil was chemically altered via transesterification process of jatropha methyl ester and trimethylolpropane to develop various compositions of modified jatropha oils (MJOs). The orthogonal cutting process was carried out and the lubricants were supplied by using minimum quantity lubrication (MQL) technique. It was observed that the MJO5 exhibits an outstanding performance in terms of wear and friction as well as cutting force and maximum cutting temperature when compared to commercial synthetic ester (SE). This works shows that MJO5 is a viable candidate to replace SE as a machining lubricant.

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Keywords: bio-based lubricant; modified jatropha oil; orthogonal cutting; tribology behaviour

1. Introduction

A variety of metalworking fluids (MWFs) were used for various machining operations. The main sources of these fluids are from mineral oil-based, vegetable oil-based and synthetic oils. The bio-based oil from vegetables oil has high biodegradation percentage and provides better lubrication performances in terms of physical and tribological behavior. It was estimated that 52% of the worldwide consumption of MWFs is used for the machining purposed [1]. The main function of MWF is to reduce heat generated at the tool-chip interface during the machining operation [2]. Additionally, the MWF provides a thin film between two contact surfaces that reduce wear and friction [3]. The sufficient lubrication effect of the MWFs reduces the amount of required coolant to absorb the heat generated during the machining operation. Therefore, less friction occurred at the machining zone that contributes reduction in energy consumption.

The used of MWF from bio-based oil is due to the increasing concern on the sustainable element in the machining process. Sustainable machining required an environmentally friendly machining that consists of dry machining, minimum quantity lubrication (MQL) and vegetable-based lubricant [4]. In addition, prolonged used of the conventional MWF from petroleum-based oils can cause environmental pollution and hazardous to human due to the toxic contains. Besides, it needs high processing cost to dispose the oil due to the low degradable percentage of 15 to 35%.

The used of bio-based oil for lubrication purposed has been practiced in many applications such as in engine oil, hydraulic fluids, two stroke oils, grease and metalworking fluids. It was anticipated that only 0.1% of the lubricant used is from vegetable-oil based [5]. There are two types of vegetable oil which are edible and non-edible. Previously, the edible vegetable oil such as sunflower, rapeseed, soya bean and palm oil have been used as MWF in various machining process [6–8]. However due to the increasing demand on food industry, non-edible oils such as jatropha, castor and neem oil have been used as the sources of bio-based lubricant [9, 10]. The used of bio-based lubricant from the vegetable oil improved the machining performances in terms of cutting force, cutting

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temperature surface roughness and tool wear. The problem of using vegetable oils is they are lack of thermal and oxidative stability due to the existing double bonds in their molecular structure [11]. There are several solutions to overcome this problem which is chemical modification process, additive reformulation and genetic modification from the oil seed [12].

Therefore, this study mainly deals with the experimental works at various machining parameters in order to investigate the effect tribological behavior of modified jatropha oils as a MWF for MQL method of lubricant. The machining performances consist of cutting force and cutting temperature were analyzed in order to discover the potential of modified jatropha oil as a sustainable MWF.

2. Methodology

2.1. Sample preparations

The crude jatropha oil (CJO) was chemically modified via transesterification process. The modification of crude oil is crucially needed to improve the lack of thermal and oxidative stability of the oil [13]. The modified jatropha oils (MJO) were produced at various molar ratios of jatropha methyl ester (JME) and trimethylolpropane (TMP) as shown in Table 1. The reaction was regulated at 120^{o}C for eight hours and 1% w/w sodium methoxide, CH_3ONa as the catalyst (based on weight of oil).

The lubricant properties of the crude and modified oils such as viscosity, viscosity index (VI), wear scar diameter (WSD) and coefficient of friction (COF) are tested according to the ASTM standard. The samples were compared with commercially synthetic ester (SE), Unicut Jinen. The kinematic viscosities of lubricant were measured by using viscometer. The viscometer was immersed in the heated lubricant at 40^{o}C and 100^{o}C of based on ASTM D445. After that, the viscosity index value was calculated according to ASTM D2270 by using the data from kinematic viscosity at 40^{o}C and 100^{o}C. Furthermore, the coefficient of friction (COF) and wear scar diameter (WSD) was measured by using four ball tester machine according to ASTM D4172. The testing were conducted with four steel balls at constant parameters as follows, controlled temperature, 75 ± 2^{o}C, applied load 392N, top ball rotation, 1200 ± 60 rpm and 1hour operation time.

Table 1. Modified jatropha oils.

Description	Molar ratio
MJO1	JME:TMP; 3.1:1
MJO3	JME:TMP; 3.3:1
MJO5	JME:TMP; 3.5:1

2.2. Orthogonal cutting set up

The machining operation was conducted through orthogonal cutting process by using NC lathe machine as shown in Fig. 1(a). An AISI 1045 mild steel disk with the thickness and diameter of 2 mm and 150 mm respectively was used for this operation. The uncoated carbide insert was used throughout the experiment. Both tool holder and insert were fixed on the dynamometer, Kistler 9257BA to measure the cutting force value. The dynamometer was connected to the multichannel amplifier and the cutting force data was recorded by using Dynoware software. MQL method was implemented in order to supply metalworking fluids. The nozzle was placed approximately 8 mm to the cutting edge with 45^o of angle as shown in Fig. 1(b).

In addition, the cutting temperature at the machining zone was measured by using FLIR T640 thermal imager camera. The emissivity was set at a constant value. The maximum cutting temperature was measured by using FLIR thermal imager in between the ranges of 0^o to 1000^{o}C during the machining operation. The performances of all samples were operated at various cutting speed and feed rate as shown in Table 2.

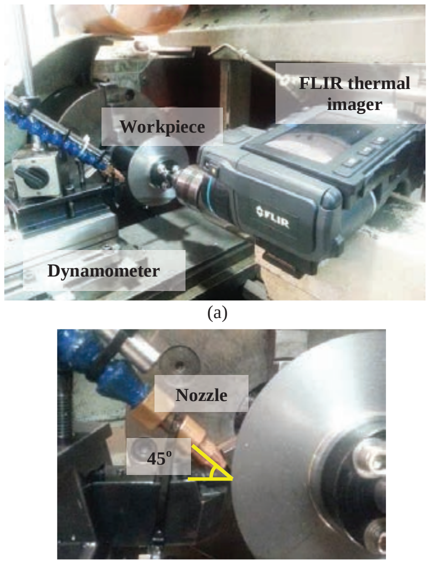

Fig. 1. (a) Orthogonal cutting set up; (b) Nozzle location.

Table 2. Machining parameters

Description	Values
Cutting speed, V_c (m/min)	350, 450, 550
Feed rate, f_r (mm/rev)	0.08, 0.10, 0.12
Width of cut, d (mm)	2
Tool rake angle, α (^{o})	5
MQL input pressure (MPa)	0.4
Lubricant flow rate (l/hour)	0.16
Nozzle diameter (mm)	2.5
Nozzle distance (mm)	8