



THE PERFORMANCE OF HEXAGONAL BORON NITRIDE AS AN ADDITIVE IN THE BIO-BASED MACHINING LUBRICANT

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ABSTRACT

Recently, bio-based oil was used as industrial lubricant due to the increasing consideration on environment effect and health issues and in order to replace the usage of petroleum-based oil. The modified vegetable oil exhibit excellent lubrication and tribological performances when compared to the petroleum-based oil. In this study, the crude jatropha oil was modified via chemical modification process and enhanced by hexagonal boron nitride (hBN) particles. hBN were varied at 0.05wt.% (MJO5a), 0.1wt.% (MJO5b) and 0.5wt.% (MJO5c). The modified jatropha oil (MJO5) and blended MJO5 with hBN particles were evaluated on the machining performances in terms of cutting force, cutting temperature and chip thickness. All samples were compared with commercially synthetic ester, SE. The results show that the addition of 0.05wt.% of hBN in MJO5 exhibit better anti-wear and anti-friction ability that significantly influenced the machining performances. This study presented that MJO5a is a sustainable candidate to replace SE as bio-based metalworking fluid.

Keywords: modified jatropha oil, lubricant additive, hexagonal boron nitride, tribology, sustainable metalworking fluid.

INTRODUCTION

Metalworking fluid (MWF) was extensively used in the machining operations in order to reduce the heat generate and friction at the tool-workpiece interfaces. Metalworking fluids consist of two major component which are basic fluids and additive package (Winter *et al.*, 2012). Marksberry and Jawahir (2008) indicated that 100 million of MWF was used annually for several purposed. However, most commercial MWF consist of petroleum-based oil and chemically derives additive that are toxic and low biodegradable. It is reported that all occupational diseases of operators due to the skin contact with MWF (Nicol and Hurrell, 2008; Syahrullail *et al.*, 2014). Therefore, bio-based MWF from vegetable oils offer positive effect to environment and human health.

The usage of vegetable oil as a MWF in the machining process reduced wear, friction, heat generate and produced better surface finish (Lawal *et al.*, 2012; Rahim and Sasahara, 2011; Shashidhara and Jayaram, 2013). Crude vegetable oil was enhanced by the chemical modification process and mixed with additive in order to improve the lubrication and tribological behavior. Trimethylolpropane (TMP) ester has excellent lubrication behavior than the crude vegetable oil. It promising excellent thermal and oxidative stability, higher flash point and viscosity index, good anti-wear and anti-friction ability, non-toxic and biodegradable (Arbain and Salimon, 2011; Talib and Rahim, 2015; Talib and Rahim, 2014; Yunus *et al.*, 2003; Zulkifli *et al.*, 2013). Furthermore, these properties can be enhanced by solid additive particles such as boron and nitrogen in TMP ester. Solid lubricant have been extensively studied by recent researcher as superior anti-wear additive to be added in the lubricant (Ji *et al.*, 2012; Nguyen *et al.*, 2012; Reeves *et al.*, 2014). The concentration and size of additive significantly influenced the additive performances in terms

of wear and friction. The addition of boron and nitrogen additive lowered the wear rate and changed the sliding effect to the rolling effect that leads to reduce the friction at the two metal surfaces (Ilman *et al.*, 2014). In this study, the modified jatropha oils (MJOs) were varied at different composition of boron nitrogen particles in order to determine the effect of tribological behavior on the machining performances.

METHODOLOGY

Lubricant preparation

In this study, the modified jatropha oil namely MJO5 with enhanced by hexagonal boron nitride (hBN) additive were used as metalworking fluid for the orthogonal cutting process lubricant. It was prepared by the transesterification process of jatropha methyl ester (JME) and trimethylolpropane (TMP) at the molar ratio of 3.5:1 (JME: TMP). The jatropha oil was chosen, because of it was non-edible vegetable oil that demonstrated excellent lubrication and tribological performances (Golshokouh *et al.*, 2013; Zulkifli *et al.*, 2014). Jatropha oil have been extensively studied for the usage as biofuel and industrial lubricant such as hydraulic fluid, engine oil and metalworking fluid (Bilal *et al.*, 2013; Nakpong and Wootthikanokkhan, 2010; Shashidhara and Jayaram, 2013). The particles size of hBN was in between of 2 to 5 μ m. The hBN was blended with the MJO5 at various composition percentages; 0.05wt.%, 0.1wt.% and 0.5wt.% (based on oil weight) as shown in Table-1. In this experiment, the synthetic ester was chosen as the reference oil and was compared with the MJO5 samples.

**Table-1.** Lubricant sample.

Symbol	Descriptions
SE	Synthetic ester
MJO5	Modified jatropha oil
MJO5a	Modified jatropha oil+0.05wt.% hBN
MJO5b	Modified jatropha oil+0.1wt.% hBN
MJO5c	Modified jatropha oil+0.5wt.% hBN

Orthogonal cutting process

The workpiece material used in this study was a disk of AISI 1045 with a diameter and thickness of 150 mm and 2 mm, respectively. The orthogonal cutting process was carried out on a NC lathe machine as shown in Figure-1. In this experiment, the uncoated carbide inserts was mounted at the tool holder. Both insert and tool holder was fixed on the dynamometer, Kistler 9257BA to measure the cutting force. The dynamometer was connected to multichannel amplifier and the cutting force value was recorded by Dynoware software. The

cutting temperature was captured via FLIR T640 thermal imager camera. The thicknesses of the deformed chips were measured by using tapered nose micrometer. The average value of ten samples of deformed chip thicknesses was recorded. The experiment were varied at three levels of cutting speeds and feed rates as shown in Table-2.

Table-2. Machining conditions.

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 (°)	5
MQL input pressure (MPa)	0.4
Lubricant flowrate (l/hour)	0.16
Nozzle diameter (mm)	2.5
Nozzle distance (mm)	8
Nozzle angle (°)	45

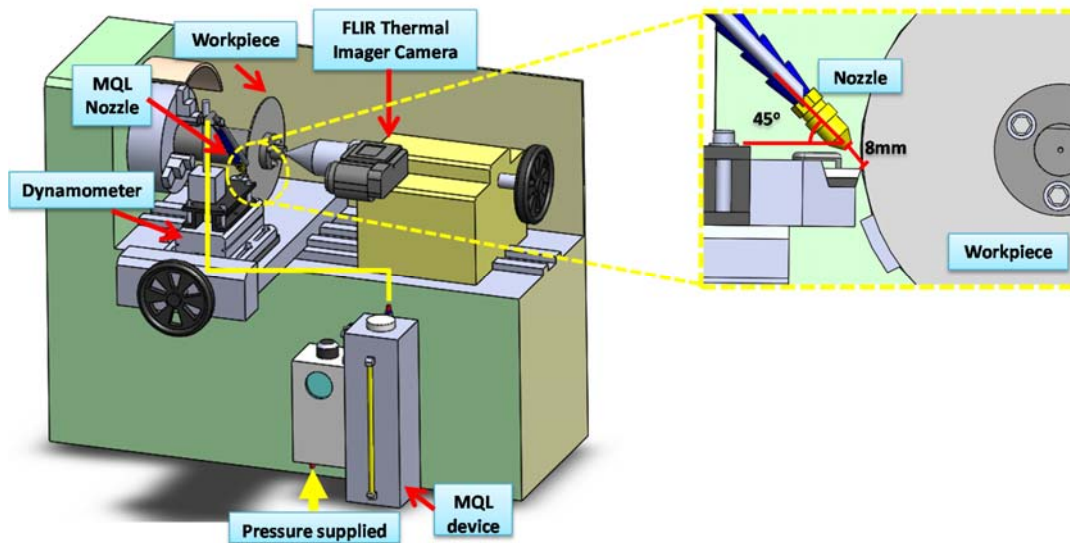
**Figure-1.** Orthogonal cutting setup.**RESULTS****Cutting force**

Figure-2 (a), (b) and (c) show the results of cutting force after the orthogonal cutting process. It can be observed that the cutting force increased as the feed rate increased. This is due to the increasing amount of chip load. Besides, the cutting force decreases when increasing the cutting speed. This is due to the reduction of removal material per revolution. From the results, the MJO5 shows better performance compared to SE. It significantly proved that the lubrication behavior was improved by the chemical modification process.

Furthermore, due to the excellent performances in wear and friction behavior, MJO5a displays lower cutting force compared to SE and MJO5. The coefficient of friction (COF) and wear scar diameter (WSD) of the lubricant were significantly affected the machining performances. MJO5a recorded the lowest COF and WSD compared to other lubricant (Talib *et al.*, 2015). The lubrication film produced by the 0.05wt.% hBN particles in MJO5 tends to separate the interacted surfaces between tool and workpiece. The hBN particles changed the sliding effect to the rolling effect that reduces the friction at the tool-workpiece interfaces. The lubricant film of MJO5a is able to withstand wear and friction between the tool and workpiece.

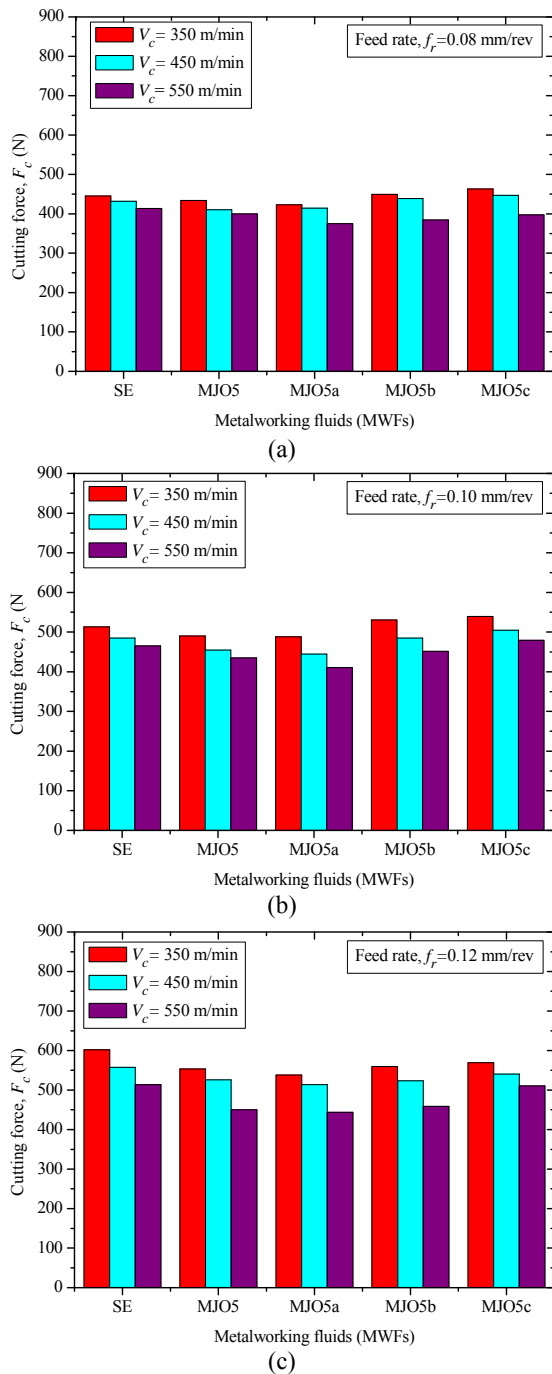


Figure-2. Cutting force at (a), $f_r=0.08$ mm/rev, (b) $f_r=0.1$ mm/rev and (c) $f_r=0.12$ mm/rev.

However, the addition of 0.1wt.% and 0.5wt.% hBN in MJO5 tends to increase the cutting force. This is due to the high value of WSD and COF of MJO5b and MJO5c (Talib *et al.*, 2015). The WSD become worse due to the excessive amount of hBN particles leads to detrimental the interaction surfaces and causes high friction and wear between tool and workpiece (Reeves *et al.*, 2014). Moreover, the bigger size of additive particles

act as abrasives that increased the friction between two metal surfaces (Peng and Chen, 2010).

Cutting temperature

Figure-3 (a), (b) and (c) displayed the maximum cutting temperature recorded after the orthogonal cutting process. The cutting temperature increased when increases the cutting speed. This is due to the increasing friction

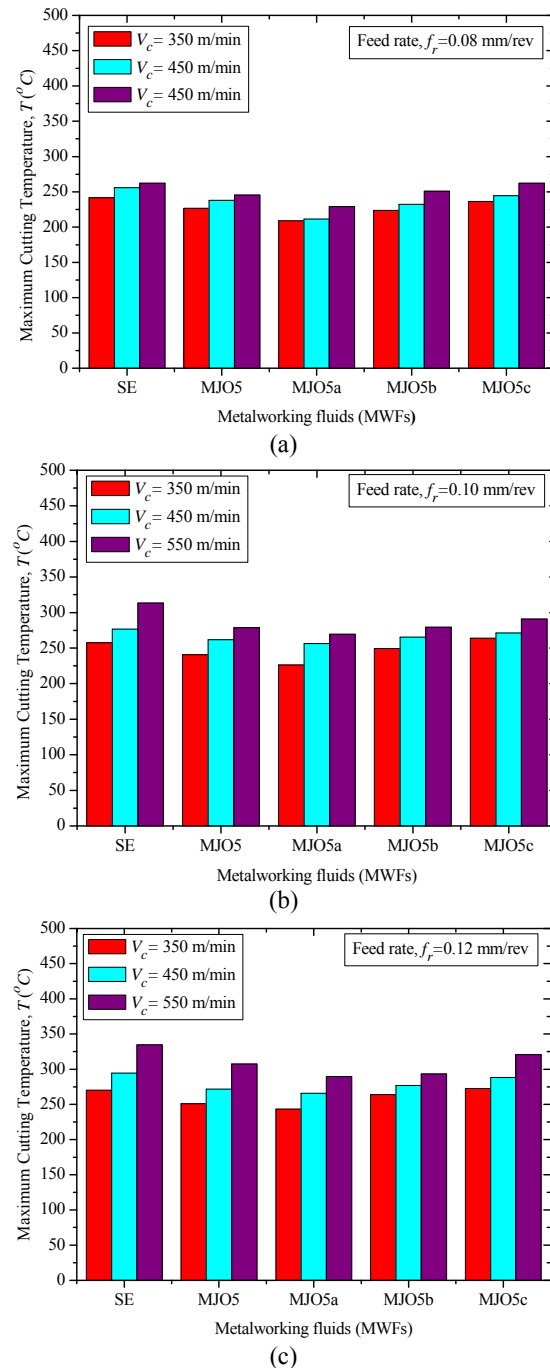


Figure-3. Cutting temperature at (a) $f_r=0.08$ mm/rev, (b) $f_r=0.1$ mm/rev and (c) $f_r=0.12$ mm/rev.

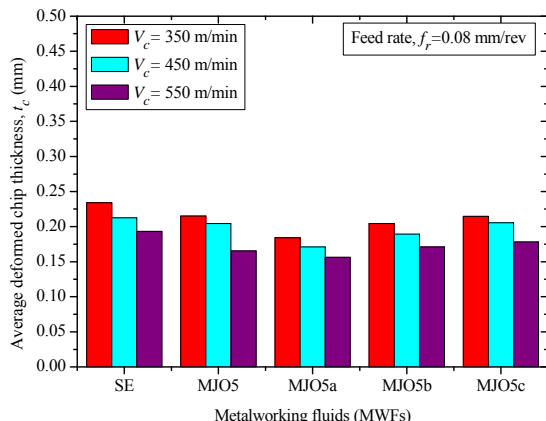


between tool and workpiece. Additionally, high feed rate increased the cutting temperature. This is due to the increasing required machining energy. As the feed rate increases from 0.08mm/rev to 0.12mm/rev, MJO5 tends to reduce the cutting temperature between 6 to 7% when compared to SE. The lubrication film formed by the MJO5 was able to withstand the friction between tool and workpiece and reduced the heat generated.

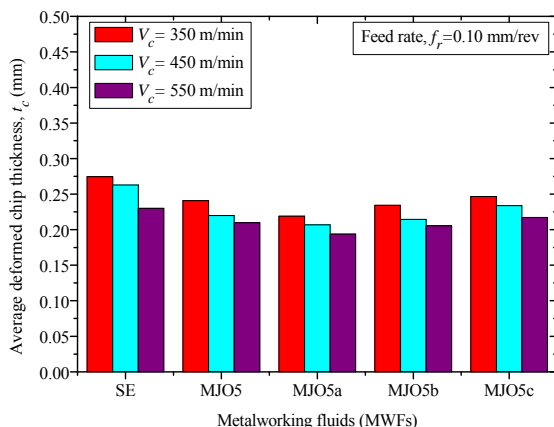
Furthermore, MJO5a which enhanced by 0.05wt.% of hBN tends to reduce the cutting temperature. This is due to the hBN particles prevent the adhesion wear between tool and workpiece and reduced the interaction surfaces (Ji *et al.*, 2012). However, the cutting temperature increased when the hBN composition is increased. The excessive amount of hBN increased the COF and WSD. They were severed the interact surfaces due to the abrasive wear (Syahrullail *et al.*, 2014). Even though MJO5b and MJO5c generate high cutting temperature, however they were much better compared to SE.

Deformed chip thickness

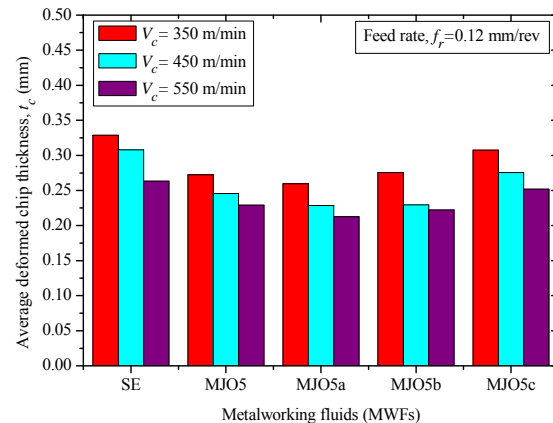
Figure-4 (a), (b) and (c) presented the average deformed chip thickness after the orthogonal cutting process. The thickness of the chip is significantly influenced by the feed rate. The increasing of feed rate



(a)



(b)



(c)

Figure-4. Average deformed chip thickness at
(a) $f_r=0.08$ mm/rev, (b) $f_r=0.1$ mm/rev and
(c) $f_r=0.12$ mm/rev.

from 0.08mm/rev to 0.12mm/rev had increased the chip thickness. This is due to the increased of tool chip contact length (Rahim *et al.*, 2015). The chips thickness reduced when the cutting speed increases. The reduction of cutting speed causes decrement in material removal per revolution.

The deformed chip thickness also affected by the lubrication film. It can be seen that, MJO5 showed 3 to 20% reduction of chip thickness when compared with SE. The lubricant film formed by MJO5a provided better anti-wear and anti-friction ability. The mixture of 0.05wt.% hBN in MJO5a was able to increase the lubricant film performances. Therefore, the thickness of chip was much thinner than MJO5. However, if the mixture is more than 0.05wt.% of hBN composition, it caused damage at the lubrication film. It increased the interaction between the tool and workpiece. Hence, the chip thickness of MJO5b and MJO5c increases due to the increasing contact surfaces.

CONCLUSIONS

The tribology behavior significantly influenced the effect of hBN particles on machining performances. The following conclusion can be drawn from this study;

- MJO5a formed a lubrication film that can resist the friction and heat generate at the tool-workpiece interfaces. It shows that MJO5a has excellent anti-wear and anti-friction ability when compared to SE and MJO5. The excellent wear and friction behavior tends to reduce the cutting force, cutting temperature and the thickness of the chips.
- MJO5b and MJO5c contain 0.1wt.% and 0.5wt.% of hBN particles, respectively. The high percentage of concentrations of additive particle significantly contributed to negative effect. The contact surface suffered from high friction especially at the tool-workpiece interfaces.
- MJO5a which enhanced with 0.05wt.% of hBN particles is able to form superior lubricant film. The



evidence shows that MJO5a is the best substitute to SE as a bio-based MWF.

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