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Influence of Molybdenum Disulphide (MoS_2) Nanoparticles Loading in Treated Used Palm Oil Bio-lubricant on Surface Roughness during Turning of AISI420

Muhamad Azwar Azhari[1], Nor Hasrul Akhmal Ngadiman[1,*], Noordin Mohd Yusof[1], Ani Idris[2], Norazlianie Sazali[3]

[1] Department of Material, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[3] Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

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ABSTRACT

The environmental impact and non-biodegradability of petroleum-based lubricants has caused some researchers to shift the formulation of lubricant formulation using plant-based oil, However, food security has caused concerns in development of new bio-lubricants. In this study, treated used cooking palm oil added with Zinc Dialkyldithiophosphate and Molybdenum Disulphide nanoparticles were used as lubricant to assist the cutting of hardened martensitic stainless steel AISI420 using coated carbide tool. Surface roughness of the cut workpiece was investigated using a surface roughness tester. From the study, treated used cooking oil added with ZDDP and 0.8wt% MoS_2 nanoparticles displayed the lowest average surface roughness of workpiece with Ra = 0.532µm and total roughness Rz = 4.006µm. This concluded that the new formulated bio-lubricant can successfully replace the readily available commercial cutting fluid as it produces a low surface roughness during cutting process.

1. Introduction

Commercially available petroleum-based lubricants are known to be harmful to the environment [1]. The improper disposal of its waste may cause severe damage to the environment. Apart from that, some health concerns arise while dealing with petroleum-based lubricants especially on handling and inhaling of its fumes during high temperature processes [2]. With these in view, many researchers have shifted the precursor for lubricant formulation to bio-based products. Vegetable oil-based lubricants were seen to be a very suitable candidate to replace petroleum-based counterpart for its high stability in high temperature and excellent lubricity characteristics. According to Rao *et al.,* vegetable oil was selected for the bio-degradability and renewability characteristics as

[*] *Corresponding author.*
E-mail address: norhasrul@utm.my

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well as the small impact it has upon the environment during disposal [3]. Farhanah *et al.,* studied the use of palm oil as lubricant [4], Shafi and Charoo studied the feasibility of utilizing hazelnut oil as bio-lubricant [5] while Nuri *et al.,* studied the use of corn oil to replace petroleum-based oil as bio-lubricants [6]. The addition of various additives into the different type of oil has successfully displayed the superiority of vegetable-based lubricant as a substitute to petroleum-based lubricant. However, due to food security concerns, it is not advisable for lubricant to be formulated using food-based oil [7]. Some concerns arise pertaining to food availability if the food-based vegetable oil is being used as precursor for machinery lubricant.

Malaysia is one of the biggest palm oil producer and consumer in the world. Currently the usage of palm oil in Malaysia has produced up to 50,000 tons of waste cooking palm oil [8]. This is such a huge amount of waste that could be use and utilize to be the precursor for a bio-lubricant formulation. However, prior to be use as a bio-lubricant, these used cooking palm oil shall be treated as to remove unwanted impurities such as solid particles, free fatty acids and free water diluted in the oil from frying processes [9,10].

The machining industry is an important and strategic industry for manufacturing sectors. Investigations have been carried out on machining processes by varying the cutting conditions and measuring the various machinability responses [11]. One of the main problems in conventional cutting processes is the high temperature caused by the friction between the workpiece and the cutting tool, which leads to a decrease in productivity and a breakdown in the cutting tool [12]. Since long, mineral oils have been commonly used as a base fluid in conventional cutting. However, there has been no solid evidence that treated used cooking oil can be successfully replace the use of petroleum-based lubricant. As such, this study has investigated the use of treated used cooking oil added with Zinc Dialkyldithiophosphate (ZDDP) and Molybdenum Disulphide (MoS_2) nanoparticles as bio-lubricant to assist turning of martensitic hardened stainless steel AIS420 using a coated carbide tool.

2. Methodology

2.1 Sample Preparation

Used cooking palm oil were collected from local food chain restaurants. Solid particles were removed from the used cooking palm oil and further neutralized using 2ml of 18wt% Sodium Hydroxide (NaOH) solution. Upon addition of NaOH into the waste cooking oil, the mixture was heated at 60℃ for 30 minutes. The prepared samples were centrifuged at a speed of 1200 rpm for 10 minutes and then filtered for soap and solid particles removal. Zeolite 4A were used to remove free water contained in the treated used cooking oil. Zinc Dialkyldithiophosphate (ZDDP) and Molybdenum Disulphide (MoS_2) nanoparticles were purchased and used without any treatment process. ZDDP were added at a constant concentration of 2wt% while concentration of MoS_2 were varied at 0.4wt%, 0.8wt% and 1.2 wt%.

2.2 Preparation of Workpiece and Cutting Tools

Martensitic Stainless Steel AISI420 with a HRC of 50 (dimension: 50mm diameter, 90mm length) were used as workpiece. Turning of the workpiece uses the Pinacho S-90/180 lathe machine for 0.20 mm depth of cut at a moderate machining (135 m/min) medium speed and 0.20 mm/rev feed rate. The cutting tool used was coated carbide with TiA1N. The cutting of the workpiece employed a dry lubrication as well as flood lubrication at 6L/hour.

2.3 Determination of Additive Dilution

The prepared samples were tested for the additive dilution by using Spectroil Q100 Rotating Disc Electrode Atomic Emission Spectroscopy (RDE-AES) in accordance with ASTM D6595. The concentrations of zinc, molybdenum and phosphorus particles in the samples were determined by using RDE-AES to observe the dilution of ZDDP and MoS_2 nanoparticles into the treated used cooking palm oil.

2.4 Surface Roughness

The surface roughness of the cut workpiece was examined using a Mitutoyo SJ-310 surface roughness tester. A gaussian filter was used at λ = 0.5mm/s and λc = 0.25.

3. Results

3.1 Determination of Elements

The prepared samples were tested for dilution of additives. The dilution for Zinc, Phosphorous and Molybdenum were investigated as this will ensure the effectiveness of the newly formulated bio-lubricant developed through addition of ZDDP and MoS_2 nanoparticles. The concentration of each elements observed were recorded as in Table 1.

Table 1
Concentration of Zinc, Phosphorous and Molybdenum in different bio-lubricant samples

Sample	Concentration (ppm)		
	Zinc	Phosphorous	Molybdenum
Treated used cooking oil	Not detected	17	Not detected
TCO + 0.4wt% MoS_2	Not detected	18	1872
TCO + 0.8wt% MoS_2	Not detected	16	3551
TCO + 1.2wt% MoS_2	Not detected	17	5497
TCO + ZDDP + 0.4wt% MoS_2	1404	1675	1861
TCO + ZDDP + 0.8wt% MoS_2	1399	1660	3529
TCO + ZDDP + 1.2wt% MoS_2	1434	1719	5476

From Table 1, it can be observed that treated used cooking oil do not contain any Zinc and Molybdenum. Zinc was also not detected for treated used cooking oil added with MoS_2 nanoparticles without ZDDP. However, it can be clearly seen that when the treated used cooking oil were added with MoS_2 nanoparticles, the concentration of Molybdenum started to increase. This clearly indicated that the Molybdenum was properly dissolved into the precursor of treated used cooking oil. On the other hand, while the treated used cooking oil were added with ZDDP and MoS_2 nanoparticles, the concentration of Zinc and Phosphorous started to increase as well as the concentration of Molybdenum. The gradual consistent increase in Molybdenum correlates with the increase in MoS_2 nanoparticles loading whereby the loading were gradually increase from 0.4wt% to 0.8wt% and 1.2wt%. The almost constant value of Zinc concentration confirms that the Zinc added to all samples were at the same concentration which is at 2.0wt%. This is a clear statement of dilution of ZDDP and MoS_2 as ZDDP were made of Zinc and Phosphorous elements while MoS_2 resulted from the combination of Molybdenum and Sulfur [13]. The similar trend was also observed by Nuri *et al.,* using RDE-AES to confirm dilution of Zinc in corn oil [6].

3.2 Surface Roughness

To investigate the effect of different concentration of Molybdenum Disulfide in the newly formulated bio-lubricant, the treated used cooking oil added with different additives were tested during cutting process of martensitic stainless steel AISI420 using a coated carbide tool. The surface roughness of the cut workpiece was investigated and the value recorded. The trend of average surface roughness, Ra and height of roughness Rz were depicted as in Figure 1.

From the data, it is evident that the workpiece cut without any lubricant applied displayed a very high Ra at 2.922µm and Rz of 13.523µm. However, with the assistance of a simple lubricant, a treated used cooking oil, the average surface roughness reduced to Ra = 1.959µm and Rz = 9.909µm. This clearly indicated that without any lubrication during the cutting process, the workpiece experienced a highly abrasive cutting process. This is because the cutting process without any lubricant has caused the workpiece to experience a higher friction between the workpiece and cutting tool. This increased friction between the contacting surfaces caused the workpiece to result in a higher abrasive wear which in showed through the high value of Ra and Rz. With the application of lubricant, the workpiece was being protected by a thin layer to prevent from excessive heat being generated during cutting process [14]. The lubrication applied also assisted in lowering the friction during cutting process that caused the wear to also reduce. This is clear through a reduction of Ra and Rz compared to the cutting process without any lubricant.

The addition of MoS_2 nanoparticles further reduced the value of average surface roughness and total surface roughness of the workpiece. As the treated used cooking palm oil were added with 0.4wt% MoS_2, the average surface roughness reduced to 1.366µm and total surface roughness of 8.929µm. Further reduction was recorded when the treated used cooking oil were added with 0.8wt% MoS_2 nanoparticles with Ra = 1.105µm and Rz = 4.992µm. The addition of MoS_2 nanoparticles into the lubricant were seemed to be lowering the surface roughness of workpiece. The addition of sufficient amount of MoS_2 nanoparticles is seen to be assisting in reducing the friction as MoS_2 nanoparticles at the desired amount can be an efficient friction modifier. The presence of MoS_2 nanoparticles supported in the sliding effect between the contacting surfaces causing the friction to be lowered hence reducing the wear within [15,16]. This is the reason for the reduction in surface roughness values when the treated used cooking oil were added with 0.4wt% and 0.8wt% of MoS_2 nanoparticles. However, when 1.2wt% of MoS_2 nanoparticles were being added into the treated used cooking palm oil, the surface roughness of the workpiece displayed a slight increase of Ra to 1.153µm and Rz to 4.429µm. The excessive addition of MoS_2 nanoparticles into the treated used cooking palm oil bio-lubricant has caused the nanoparticles to excessively collide between one another and cause the friction to increase. This may be the reason of increase in surface roughness as the friction between cutting tools and workpiece increased due to the excess concentration of MoS_2 nanoparticles.

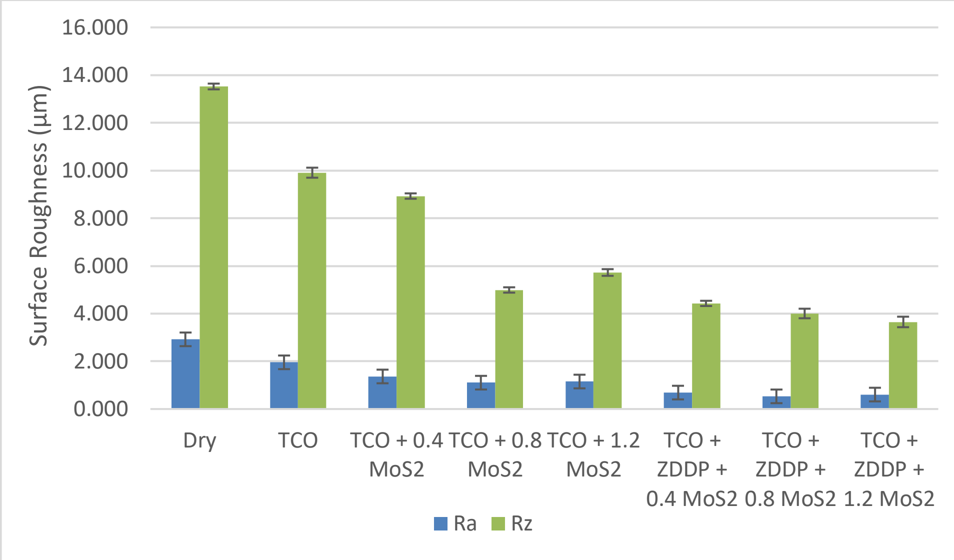

Fig. 1. Average surface roughness and total roughness of workpiece cut with different concentration of additives

As the treated used cooking oil were added with ZDDP and MoS_2 nanoparticles, the average surface roughness and total height roughness of workpiece were observed to be reducing further. The interaction between ZDDP and MoS_2 has completely given a well lubricated workpiece. The average surface roughness Ra, of the workpiece lubricated with treated used cooking palm oil with ZDDP and 0.4wt% MoS_2 nanoparticles was reduced to 0.690µm with Rz reduced to 4.429µm while addition of ZDDP and 0.8 wt% MoS_2 reduced the average surface roughness of the workpiece lower to Ra = 0.532µm and total roughness Rz = 4.006µm. ZDDP added into the lubricant as additive acted as a protective surface layer that could reduce unwanted wear from occurring [17]. The synergistic effect between ZDDP and MoS_2 nanoparticles clearly effected in lowering the wear with the optimum concentration of MoS_2 nanoparticles added was at 0.8%wt [18–20]. Trend increasing trend of average surface roughness was also observed when the treated used cooking oil was added with ZDDP and 1.2wt% MoS_2 nanoparticles. While the ZDDP added acted as an anti-wear agent to reduce wear, excess MoS_2 nanoparticles were observed to increase the collision within the lubricant causing the friction to increase hence increasing the value of average surface roughness of workpiece. The microstructure of different cutting lubricants is depicted as in Figure 2.

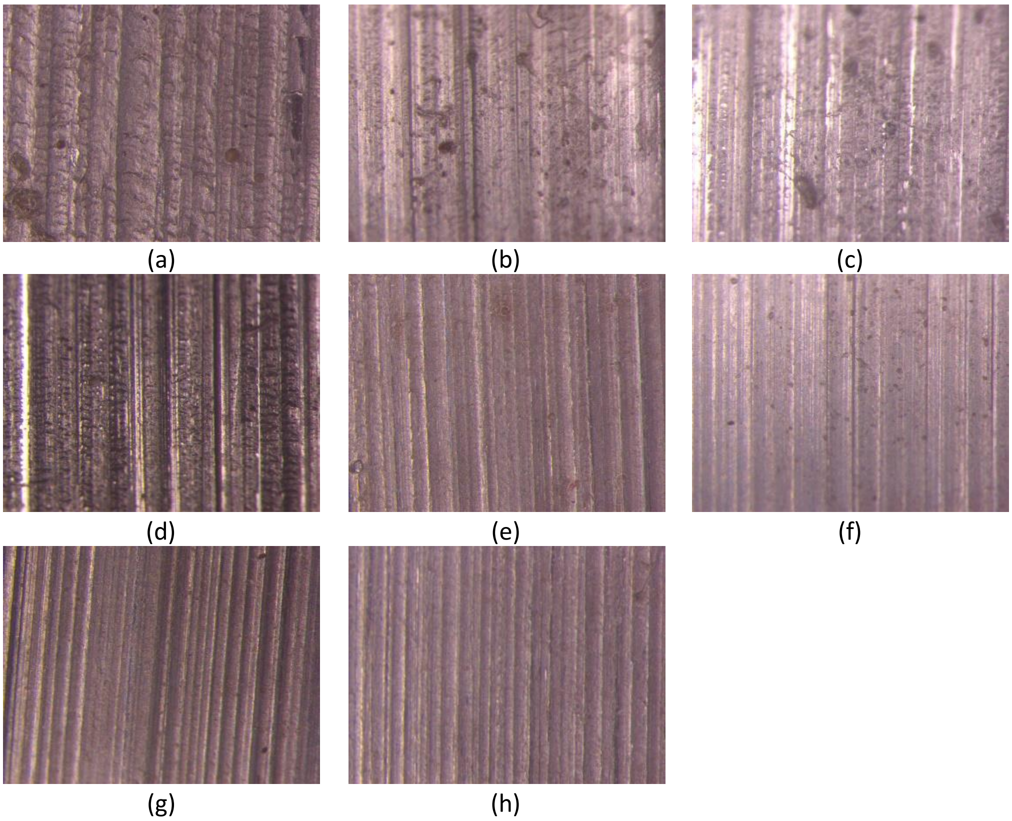

Fig. 2. Microstructures of cutting samples with different lubrication (a) Dry lubrication (b) Treated cooking oil (c) Treated cooking oil + 0.4wt% MoS_2 (d) Treated cooking oil + 0.8wt% MoS_2 (e) Treated cooking oil + 1.2wt% MoS_2 (f) Treated cooking oil + ZDDP and 0.4wt% MoS_2 (g) Treated cooking oil + ZDDP and 0.8wt% MoS_2 (h) Treated cooking oil + ZDDP and 1.2wt% MoS_2

4. Conclusion

A new formulated bio-lubricant for cutting of AISI420 martensitic stainless steel was successfully formulated through addition of ZDDP and MoS_2 nanoparticles into treated used cooking palm oil. The cutting of workpiece displayed the lowest average surface roughness Ra = 0.532µm and total roughness Rz = 4.006µm with the addition of 2wt% ZDDP and 0.8wt% MoS_2 nanoparticles. This new formulation may be the solution to treat excessive generation of waste cooking oil as well as an alternative to the use of readily available commercially petroleum-based lubricants.

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