# EFFECT OF BIOLUBRICANT AS A MILLING MACHINE COOLING FLUID ON SURFACE ROUGHNESS OF MILD STEEL PRODUCT

**Devita Maharani, Abdul Munir Hidayat Syah Lubis**
**Departement of Mechanical Engineering, Faculty of Engineering, Muhammadiyah University of Surakarta**

**Abstrak**

Kualitas permukaan pada proses milling dapat dipengaruhi oleh penggunaan cairan pemotongan. Penelitian ini mengkaji pengaruh penggunaan biopelumas sebagai pengganti cairan pemotongan komersial terhadap keausan dan kekasaran baja ringan setelah proses milling dengan kecepatan spindel 500 Rpm dan 930 Rpm dengan kedalaman pemotongan 0,3 mm. Penelitian ini dilakukan dengan 3 percobaan setup pada proses milling, yang pertama tanpa menggunakan cutting fluid, yang kedua menggunakan cutting fluid komersial dan yang ketiga menggunakan biolubricant. Minyak jelantah hasil trans-esterifikasi mengandung 57,12% asam lemak teresterifikasi dengan viskositas pada suhu 40°C sebesar 19 cSt, pada suhu 100°C sebesar 3,825 cSt, densitas sebesar 0,836 g/mL dan titik nyala sebesar 29°C. Hasil kekasaran permukaan pada tiga sampel baja ringan menunjukkan bahwa penggunaan fluida pemotongan mempunyai pengaruh terhadap kekasaran permukaan yang dihasilkan, ditandai dengan beberapa goresan dan tekstur. Nilai kekasaran tertinggi pada putaran 500 Rpm diperoleh dengan nilai 0,887 μm tanpa menggunakan fluida pemotongan dan pada putaran 930 Rpm diperoleh nilai 2,793 μm tanpa menggunakan fluida pemotongan. Sedangkan untuk nilai kekasaran permukaan terendah pada putaran 500 Rpm diperoleh nilai 0,637 μm dengan menggunakan biopelumas dan pada putaran 930 Rpm diperoleh nilai 0,300 μm dengan menggunakan biopelumas juga. Penggunaan biopelumas menghasilkan kekasaran permukaan yang lebih baik dibandingkan dengan menggunakan cairan pemotongan komersial atau tanpa menggunakan cairan pemotongan.

**Kata Kunci :** Biopelumas, Proses Milling, Cairan Pemotongan, Kekasaran Permukaan.

**Abstract**

Surface quality in the milling process can be influenced by using cutting fluid. This research examines the effect of using biolubricants as a substitute for commercial cutting fluids on the wear and roughness of mild steel after the milling process with spindle speeds of 500 Rpm and 930 Rpm with a cutting depth of 0.3 mm. This research was carried out with 3 experimental setup in the milling process, the first without using cutting fluid, the second using commercial cutting fluid and the third using biolubricant. The trans-esterified waste cooking oil is found to consist 57.12% esterified fatty acids with viscosity at 40°C is 19 cSt, at 100°C is 3.825 cSt, density of 0.836 g/mL and flash point of 29 °C. The surface roughness results on three mild steel samples show that the use of cutting fluid has an influence on the resulting surface roughness, characterized by several scratches and textures. The highest roughness value at 500 Rpm is obtained with a value of 0.887 μm without using cutting fluid and at

930 Rpm is obtained with a value of 2.793 µm without using cutting fluid. While for lowest surface roughness value, at 500 Rpm is obtained with a value of 0.637 µm by using biolubricant and at 930 Rpm is obtained with a value of 0.300 µm by using biolubricant as well. The use of biolubricants produces better surface roughness compared to using commercial cutting fluids or without using cutting fluids.
**Keywords :** *Biolubricants, Milling Process, Cutting Fluid, Surface Roughness.*

## 1. INTRODUCTION

Surface quality in the milling process can be influenced by using cutting fluid. The significant factors affecting surface roughness without cutting fluid are cutting speed, feeding speed, and tool geometry. Meanwhile, by using cutting fluid, the factors that affecting surface roughness are feed speed and tool geometry. By using cutting fluid in the milling process can reduce friction between the tool, chip and workpiece, resulting lower surface roughness compared to without the use of cutting fluid (Wang & Chang, 2004)

One of the causes the machine has difficulty when cutting materials is due to the high heat release in the cutting zone, thus affecting the tool wear rate. To increase tool life, reducing the cutting temperature and using cutting fluids for lubrication and cooling can be effective. Cutting fluids also reduce mechanical wear, including tool surface abrasion, which can impact the quality of the surface produced. Cutting fluids also help remove debris from the cutting zone on the tool or workpiece (Priarone et al., 2014).

Cutting fluid disposal is crucial for environmental protection, as it contains additives like emulsifiers, antioxidants, bactericides, and defoaming agents. These fluids have advantages but also significant environmental disadvantages, such as evaporation into the air and soil flow. Frequent contact with cutting fluids can increase the risk of cancer, respiratory, and skin diseases in production workers. Therefore, a more environmentally friendly alternative is needed (Youssef, 2008).

Biolubricant are produced from vegetable oils, such as canola, palm oil, jathropa, castor and rapeseed. Compared to synthetic base materials, biolubricant are less expensive and easily biodegradable. The high polarity of the entire base oil provides an intense bond with the lubricated surface, which makes vegetable oils highly efficient operate lubricants. Vegetable oils triglyceride structure gives them the ideal properties for lubricants. The strong bond between the long, polar fatty acid chains and metal surfaces results in a high-strength lubricating covering that lowers wear and friction (Lawal et al., 2012).

Waste cooking oil undergo three distinct sorts of reactions when they are fried: hydrolytic, oxidative, and thermolytic. These three reactions will continuously produce a unwanted products if the oil is used frequently. If the waste cooking oil is to be used as a feedstock, the amount of polar molecules in it, especially the free fatty acid (FFA), must be considered because it will have a major impact on the transesterification process. During transesterification, free fatty acids and water nearly invariably produce unwanted outcomes, such as the production of soap and catalyst consumption, which lowers the catalyst efficiency (Monika et al., 2023). Based on the description above, this research examine how the effect of using cutting fluid on the roughness of the mild steel processed by milling machine.

## 2. METHODS

### 2.1 Materials and Tools

The materials used in this research are: waste cooking oil, ethanol, KOH, hardened steel with hardness of 75,3 HRB and commercial cutting fluid. The tools used in this research are: hand gloves, hotplate stirrers, flash, beaker, separator funnel, thermometer, weighing scale, beaker, endmill, universal milling machine, surface roughness tester, GC-MS instrument, hardness tester, furnace, viscometer, pycnometer and flash point tester.

### 2.2 Transesterification Process

In this process, 20 mg of ethanol and 2 grams of KOH were weighed, then put into a 125 ml flask and heated to a temperature of 60C. Next, 200 mg of waste cooking oil was weighed and put into a 125 ml flask and then heated until temperature of 60 °C. After reaching a temperature of 60 °C, add the ethanol and KOH solution to the waste cooking oil solution and stir for 120 minutes at a temperature of 60 °C. Next move the solution into a separator funnel and let it sit overnight and remove the glycerol phase (bottom phase) and leave in a separate container.

## 2.3 Gass Chromatography – Mass Spectometry (GC-MS) Test

In this test, biolubricant samples were identified using a Shimadzu Gas Chromatography (GCMS-QP2010S) with an Rxi™ -1 ms column (30 m x 0.25 mm x 0.25 µm thickness). The initial temperature of the column oven at 80°C then increased by 5°C/minute to 200°C with a holding time of 2 min then raised to 280℃ with a holding time of 10 C/min and GC injector temperature set to 270°C. As a carrier gas, helium was used at a steady flow rate of 1 ml/min. The components are identified by analyzing each peak from the chromatogram with a mass spectro and compared with the library spectrum of the sample to determine the type of substance.

## 2.4 Viscosity Test

This test was carried out using a viscometer with the ASTM D445 standard test method.

## 2.5 Density Test

This test was carried out using a pycnometer to measure density of biolubricant.

## 2.6 Flash Point Test

This test was carried out using the Pensky-Martens Closed Cup Tester to measure the flash point of biolubricants with ASTM D93-20 standard test methods.

## 2.7 Quenching

In this test Wisetherm Furnaces is used to carry out quenching method on the mild steel.

## 2.8 Hardness Test

In this test Mitutoyo Rockwell Hardness Tester is used to determine the hardness value of hardened mild steel.

## 2.9 Milling Process

Set the endmill on the machine spindle and put the workpiece on the vise in milling machine. In the first experiment, no cutting fluid will be used. Set the zero point on the workpiece then enter the depth of cut of 0.3 mm then turn on the machine with a spindle rotation of 500 Rpm and after that using the spindle rotation of 930 Rpm on other side. The second experiment using commercial cutting fluid. Set the zero point on the workpiece then enter the depth of cut of 0.3 mm then turn on the machine with a spindle rotation of 500 Rpm and applying commercial cutting fluid during feeding process and after that using the spindle rotation of 930 Rpm on other side. The third experiment using biolubricant as cutting fluid during the feeding process. The application of biolubricant in this experiment used a peristaltic pump with a flowrate of 2.5 ml/min. Set the zero point on the workpiece then enter the depth of cut of 0.3 mm then turn on the machine with a spindle rotation of 500 Rpm and applying biolubricant during feeding process and after that using the spindle rotation of 930 Rpm on other side.

### 2.10 Surface Roughness Test

Turn on the SJ-210 surftest device by pressing the power button. Click the right arrow button then click calibration measurement on the menu. Place the precision reference specimen parallel to the device and make sure the detector needle touches the specimen then press the start button. Place the mild steel and the SJ-210 surftest device parallel to a flat place, make sure the detector needle touches the mild steel surface then click the start button. After the measurement process is complete, the value of Ra: average roughness will appear on the screen and then take note of those values for data analysis. When done, turn off the device by pressing the power button.

## 3. RESULT AND DISCUSSION

### 3.1 Gas Chromatography-Mass Spectrometry (GC-MS) test results

GC-MS test result shows that there is a chemical substance searched in biolubricant which is ester identified as 57.12%. The ester composition of the transesterification of waste cooking oil is not quite high, this is because the results of transesterification can be affected by several operational factors including FFA (Free Fatty Acid) content in waste cooking oil is high due to repeated use at high temperatures in frying, which increases the FFA content. The high FFA content in waste cooking oil can cause a saponification reaction in the transesterification process which can reduce the ethyl ester content in the biolubricant which is the main component in biolubricants.

### 3.2 Characteristic of Biolubricant

Table 1. Characteristic Of Biolubricant

| Viscosity | | Density at 24 °C | Flash Point |
|---|---|---|---|
| 40°C | 100°C | | |
| 19 cSt | 3.825 cSt | 0.836 g/ml | 29.5°C |

Based on table 1, it can be concluded that the viscosity at 40°C is 19 cSt indicating that the biolubricant has a medium viscosity and the viscosity at 100°C is 3.825 cSt indicating that the viscosity of the biolubricant decreases significantly as the temperature increases. Low viscosity at higher temperatures is typical of oils designed for lubrication. The density of a biolubricant is 0.836 g/ml, indicating that the lubricant is in liquid form. The lubricant in the liquid state allows the lubricant to flow and coat moving parts effectively, reducing friction and wear. The flash point of biolubricant is 29℃, this shows that the lubricant is very volatile and can burn at relatively low temperatures. So these biolubricants are not suitable for high temperature applications or environments where there is a risk of heat buildup

### 3.3 Hardness Result

The hardness test using the Rockwell method is carried out to determine the hardness value of several parts. Based on ASTM E92 standard, this test is carried out by applying pressure to the surface of the test specimen using a ball shaped indenter with a diameter of 1/16 inch. The load used in this test is 100 kgf with a pressing time of 5 seconds. The average hardness value on hardened mild steel sample is 75,3 HRB.

### 3.4 Surface Roughness Test Result

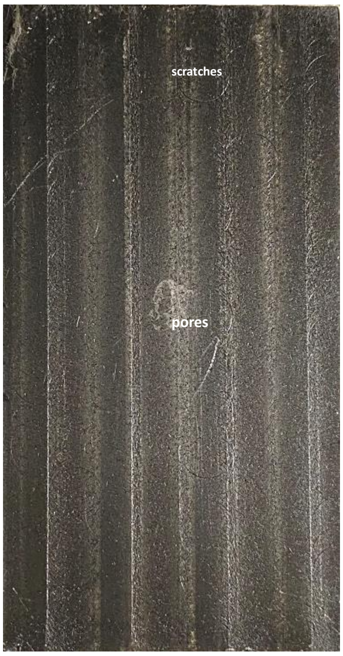
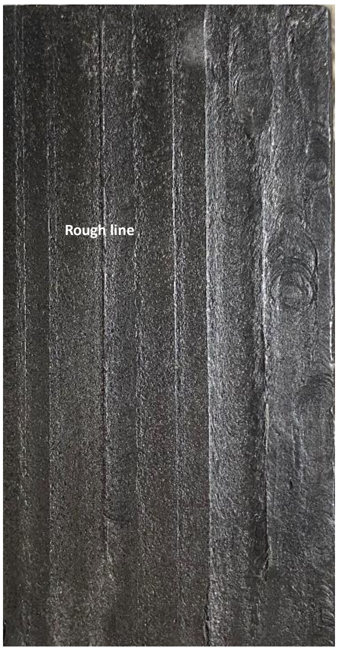
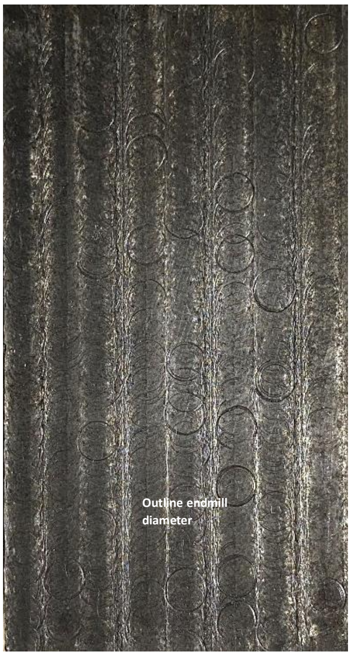
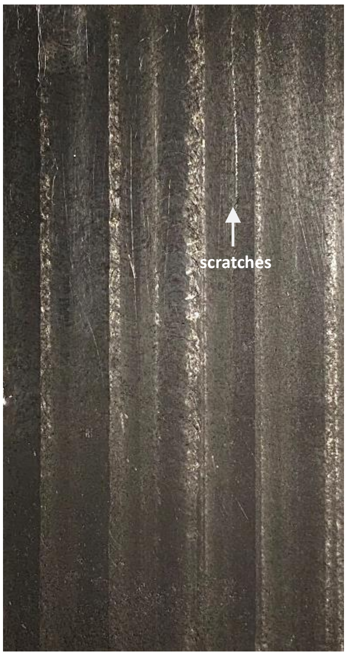
This surface roughness test uses the ISO1997 standard and the roughness value is represented by Roughness Average (Ra).

Table 2. Surface Roughness Test Results

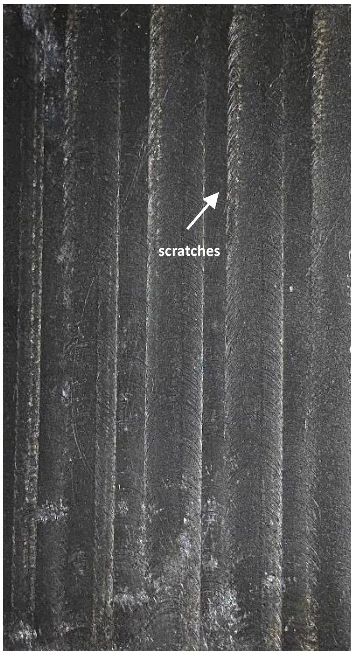
| No | N (Rpm) | f (mm/min) | a (mm) | Ra (µm) | | |
|---|---|---|---|---|---|---|
| | | | | **Without Cutting Fluid** | **Commercial Cutting Fluid** | **Biolubricant** |
| 1 | 500 Rpm | 50 | 0,3 | 0,887 | 0,862 | 0,637 |
| 2 | 930 Rpm | | | 2,793 | 0,798 | 0,300 |

Based on table 2 , the highest roughness value at 500 Rpm is obtained with a value of 0.887 µm without using cutting fluid, while at 930 Rpm the highest roughness value is obtained with a value of 2.793 µm without using cutting fluid. While for low value surface roughness, it can be seen that at 500 Rpm the lowest surface roughness value is obtained with a value of 0,637 μm by using biolubricant, while the lowest surface roughness value at 930 Rpm is 0,300 μm by using biolubricant as well.

Table 3. Milling Process Specimen

<table>
<tr><th></th><th>500 Rpm</th><th>930 Rpm</th></tr>
<tr><td>Without Cutting Fluid</td><td>
</td><td>
</td></tr>
<tr><td>Commercial Cutting Fluid</td><td>
</td><td>
</td></tr>
</table>

Biolubricant





Based on table 3 , the results of the milling process without using cutting fluid with a spindle speed of 500 rpm, the surface texture of the mild steel has several pores and at a spindle speed of 930 rpm it looks very rough with several rough lines and the outline of the diameter of the endmill used. Meanwhile, the milling process by using commercial cutting fluid, at a spindle speed of 500 rpm, there are several textures are from the endmill diameter and at a spindle speed of 930 Rpm there are several scratches at several points. In the milling process by using biolubricant, a rough surface texture was visible when using a spindle speed of 500 Rpm with a few small scratches at several points, whereas at a spindle speed of 930 Rpm there are a few smaller scratches.

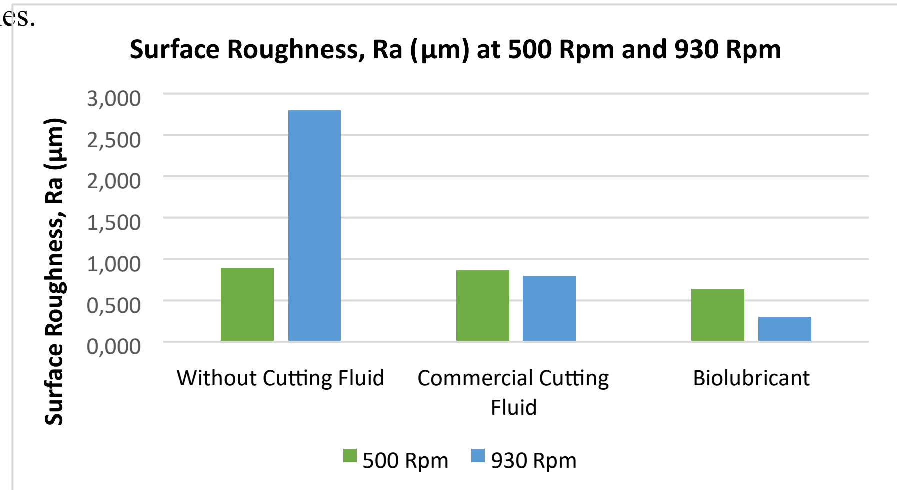



Figure 1. Surface Roughness at 500 Rpm And 930 Rpm

From figure 1 it can be concluded that the application of biolubricant is suitable for use at high speeds in the milling process because it produces lower surface roughness values compared to use at low speeds. The application of commercial cutting fluid is also suitable for use at high speeds compared to low speeds, because the resulting low surface roughness. Meanwhile, without using cutting fluid, it produces lower surface roughness when using low speeds compared to high speeds. The application of biolubricant as a cutting fluid in the milling process shows that biolubricant has better lubrication quality because the high polarity of oilbased cutting fluids provides a strong bond with the lubricated surface, which makes biolubricants very efficient in operation resulting in a high strength lubricant layer that reduces friction and able to reduce friction between the endmill and the workpiece by resulting a lower surface roughness value.

When lubricant pressure is unable to maintain the applied load or separate the surfaces, boundary lubrication happens at high loads and low speeds. The interacting surfaces will come into contact with one another. Many of variables, including material elasticity, hardness, fluid layer pressure, applied force, and surface roughness, affect how much contact happens. The interaction between two surfaces at boundary lubrication conditions is the roughness in contact with each other. At different roughness levels, this impact produces various consequences, including fracture, plastic deformation, and elastic deformation (Hsu & Gates, 2005).

The surface roughness value can be reduced by using cutting fluid during the milling process as a lubricant to reduce the friction that occurs between the workpiece and the endmill where the fluid enters the feed area, and some of the fluid can seep from the chip side as well to reduce friction. The roughness of the contacting surfaces is a factor that causes friction. Friction between two surfaces is greater on rougher surfaces, as they press more strongly against each other. Cutting fluid also used for cooling where it reduces the temperature of the and cools the workpiece and also cools the temperature of the endmill which makes the wear rate on the endmill reduced so it can affect the quality of the surface produced. The spindle rotation speed also affects the surface roughness of the workpiece. At high spindle rotation speeds the vibration on the endmill decreases, the vibration decrease on the endmill will reduce the surface roughness.

Table 4. New Endmill Area

| | No | Area ($cm^2$) |
|---|---|---|
| **New Endmill** | 1 | 0.012 |
| | 2 | 0.013 |
| | 3 | 0.022 |
| | 4 | 0.022 |

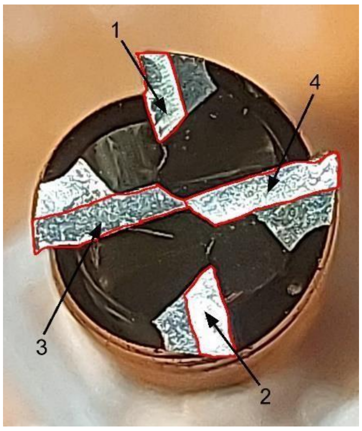



Table 5. Endmill Area Without Cutting Fluid

| | No | Area ($cm^2$) |
|---|---|---|
| **Without Cutting Fluid** | 1 | 0.016 |
| | 2 | 0.017 |
| | 3 | 0.023 |
| | 4 | 0.024 |

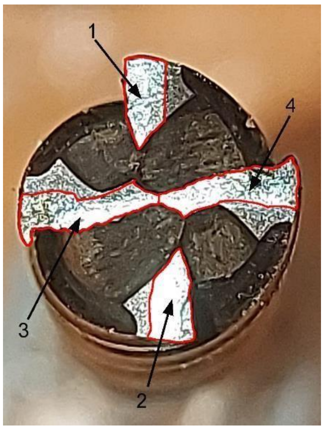



Table 6. Endmill Area With Commercial Cutting Fluid

| | No | Area ($cm^2$) |
|---|---|---|
| **Commercial Cutting Fluid** | 1 | 0.008 |
| | 2 | 0.007 |
| | 3 | 0.012 |
| | 4 | 0.016 |

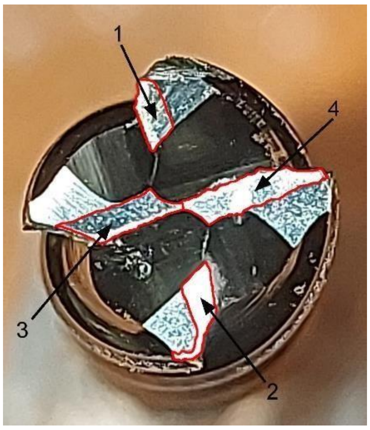
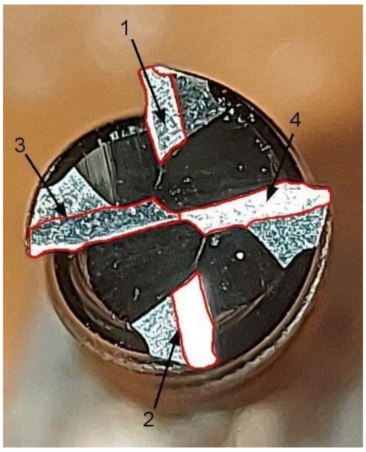


Table 7. Endmill Area With Biolubricant

| | No | Area ($cm^2$) | |
|---|---|---|---|
| **With biolubricant** | 1 | 0.012 |  |
| | 2 | 0.013 | |
| | 3 | 0.019 | |
| | 4 | 0.019 | |

It can be seen from the data in the table above by using application ImageJ to know about the area of endmill. This photo was taken using a cellphone camera with 8 times magnification. The area of the new end mill at point 1 is 0.012 $cm^2$, 2 is 0.013 $cm^2$ and at points 3 and 4 is 0.022 $cm^2$. The endmill area without using cutting fluid at point 1 is 0.016 $cm^2$, 2 is 0.017 $cm^2$ and point 3 is 0.023 $cm^2$, 4 is 0.024 $cm^2$. Meanwhile, the area of the end mill using commercial cutting fluid at point 1 is 0.008 $cm^2$, 2 is 0.007 $cm^2$ and point 3 is 0.012 $cm^2$, 4 is 0.016 $cm^2$. By using biolubricant, the area obtained at point 1 is 0.012 $cm^2$, 2 is 0.013 $cm^2$, points 3 and 4 is 0.019 $cm^2$. The change in area at the tip of endmill is caused by friction that occurs at the tip of the endmill with the mild steel surface. The reduction in endmill area is caused by wear that occurs at the tip of the endmill, this can be seen in the endmill data table using biolubricant and commercial cutting fluid. On the endmill that uses commercial cutting fluid has a decrease in area that is more than in the data table without cutting fluid, there is an increase in endmill area, this is because the endmill tip has been used up for the cutting process is broken, resulting in a reduction in endmill area.

The relationship between the data results in tables 4, 5, 6, 7, 8 and 9 is to show that the surface roughness value and defects of mild steel surface is influenced by wear that occurs on the endmill. Wear that occurs on the endmill can be reduced by using cutting fluid, where cutting fluid can reduce endmill temperature and friction that occurs during the milling process. The use of biolubricants as cutting fluids based on chemically modified vegetable oils can provide better lubrication compared to commercial cutting fluids based on mineral oil because chemically modified vegetable oils have better lubrication ability due to the improved chemical bonding of vegetable oils with metal surfaces.

Compared with conventional cooling methods, minimal quantity lubrication (MQL) is showing greater possibilities for producing a high-quality surface and better overall machining performance, where a small quantity of cutting fluid is used in a MQL-based machining process to provide cooling and lubrication between the cutting tool and surface. The cutting fluid used in the MQL (Minimum Quantity Lubrication) based machining process for cooling and lubrication between the cutting tool and the surface can be cut four times more when applying MQL than using wet machining. (Kumar et al., 2022).

## 4. CLOSING

### 4.1 Conclusion

1. Transesterification of waste cooking oil into biolubricant with a molar ratio of ethanol and waste cooking oil of 1: 10 using KOH catalyst has ester content of 57.12%.
2. The characteristics of the biolubricant show that the viscosity at 40°C is 19 cSt and at 100°C is 3,825 cSt. The density of a biolubricant is 0.836 g/ml and the flash point of the biolubricant is 29°C.
3. The hardness results of mild steel samples at five points obtained an average hardness of 75.3 HRB. The hardness value is quite hard based on the hardness value of mild steel in general because the quenching process has been carried out.
4. The surface roughness results on three mild steel samples show that the highest roughness value was obtained at 500 Rpm is 0.887 μm and at 930 Rpm is 2.793 μm without using cutting fluid. Meanwhile, lower surface roughness values were obtained at 500 Rpm is 0.637 μm and at 930 Rpm is 0.300 μm using biolubricant. Defects on the surface without using cutting fluid have many scratches and textures at 930 rpm , using commercial cutting fluid there are also scratches and textures from the endmill diameter at 500 rpm and by using biolubricant there are several scratches at several points. The use of biolubricants produces better

surface roughness compared to using commercial cutting fluids or without using cutting fluids.

5. Wear on the endmill affects the surface results produced. Wear can be determined by changes in the area of the endmill tip caused by friction between the endmill tip and the mild steel surface. There was an increase in the endmill tip area in experiments without using cutting fluid and a reduction in experiments using commercial cutting fluid and biolubricants.

**4.2 Recommendation**

1. Using oil with a low FFA content so that the ester content in the biolubricant produced is high.
2. Add a variation of the depth of cut, specimen and endmill material of milling process to obtain various sample results.
3. Focus and be careful when operating test equipment and collecting data.

**BIBLIOGRAPHY**

Helmi A. Youssef, H. E.-H. (2008). *Machining Technology: Machine Tools and Operations*. Taylor & Francis.

Hsu, S. M., & Gates, R. S. (2005). Boundary lubricating films: Formation and lubrication mechanism. *Tribology International*, *38*(3), 305–312. https://doi.org/10.1016/j.triboint.2004.08.021

Kumar, S., Kumar, R., Singh, S., Singh, H., Kumar, A., Goyal, R., & Singh, S. (2022). A comprehensive study on minimum quantity lubrication. *Materials Today: Proceedings*, *56*(December), 3078–3085. https://doi.org/10.1016/j.matpr.2021.12.158

Lawal, S. A., Choudhury, I. A., & Nukman, Y. (2012). Application of vegetable oil-based metalworking fluids in machining ferrous metals - A review. *International Journal of Machine Tools and Manufacture*, *52*(1), 1–12. https://doi.org/10.1016/j.ijmachtools.2011.09.003

Monika, Banga, S., & Pathak, V. V. (2023). Biodiesel production from waste cooking oil: A comprehensive review on the application of heterogenous catalysts. *Energy Nexus*, *10*(March), 100209. https://doi.org/10.1016/j.nexus.2023.100209

Priarone, P. C., Robiglio, M., Settineri, L., & Tebaldo, V. (2014). New production technologies in aerospace industry - 5th machining innovations conference (MIC 2014) milling and turning of titanium aluminides by using minimum quantity lubrication. *Procedia CIRP*, *24*(C), 62–67. https://doi.org/10.1016/j.procir.2014.07.147

Wang, M. Y., & Chang, H. Y. (2004). Experimental study of surface roughness in slot end milling AL2014-T6. *International Journal of Machine Tools and Manufacture*, *44*(1), 51–57.

https://doi.org/10.1016/j.ijmachtools.2003.08.011