Effect of vegetable oils as cutting fluid on wear of carbide cutting tool insert in a milling process

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Abstract. This research focuses on the effect of vegetable oils, i.e. crude palm oil (CPO) and coconut oil (CO), used as the cutting fluid on the wear of carbide cutting tool insert in a face milling process. The performances of the tool, in term of wear and the surface roughness of the workpiece, were investigated and compared to those resulting from a similar milling process but using conventional cutting fluid, which is a commercial soluble oil emulsion (SOE). The results show that at the spindle speed of 360 rpm and the feed rate of 80 mm/min, the tool wear was smaller in the case of CO than that in the case of CPO cutting fluid, which is 0.16 mm² compared to 0.40 mm², respectively. The tool worn area in these cases are still larger than that in the case of SOE, which is 0.09 mm². However, at higher spindle speed of 490 rpm and feed rate of 80 mm/min, the smallest tool worn area occurred for the case of CO cutting fluid, which is 0.04 mm², compared to 0.1 mm² and 0.11 mm² for the case of CPO and SOE cutting fluids, respectively. As for the workpiece, the achieved surface roughness, Ra, were relatively similar for all the evaluated cases.

1. Introduction
Cutting tools and cutting fluids are the most important factors in a machining process because they determine the final product quality. The cutting fluid prevents the tool from overheating, reduces friction, keeps a cool working condition, provides a tolerable surface finish, acts as cleaner, increases chip removal, and prevents corrosion [1,2,3]. Therefore, it is desirable for a cutting fluid to have properties such as high thermal conductivity, good lubricity, high flash point, stable oxidation, and corrosion resistance. Cutting fluids also affect the tool wear, influencing the finished quality of the workpiece. Less tool wear will result in longer tool’s life and improves the dimensional accuracy of the workpiece [4,5].

Straight oils and soluble oils are often used as cutting fluids in a machining process. Soluble oils, also refer to as emulsions, comprise of water, mineral oil, emulsifiers and additives. Soluble oils improves cooling capabilities and lubrication but tends to promote corrosion due to water content. Straight oils are excellent in lubricity, rust protection, and easily maintained but have poor heat...
dissipation, smoking and misting problem, oil film production on the finished workpiece, and poor cutting operation [5,6].

The use of conventional cutting fluids in industries has a negative impact on environment. Particularly, if they are not disposed properly, they will cause harm to both environment and public health [7,8,9]. The wasted fluids contain lubricating oils, additives, metal particles, and surfactant [10]. Additives in mineral oils contain sulphur, chlorinated paraffin, phosphorous compound, fatty material, and metal chlorides [11,12]. High concentration of oils and additives containing corrosion inhibitors, stabilizers, and antibacterial agents also prevents the waste from direct disposal to the treatment plants [13]. Due to this environment concerns, it is important to consider a human safe and environment friendly cutting fluids. Vegetable oils are excellent candidate for this application because they are sustainable, eco-friendly, less toxic, and most importantly, bio-degradable [14].

Vegetable based cutting fluids has advantages such as high viscosity index [15], higher flash point [16], and better lubricity due to larger molecular weight [17]. Vegetable based cutting fluids are also reported to have a better thermal conductivity, specific weight, storage stability, corrosion prevention and provide improved performance in terms of cutting force, feed force, and workpiece quality [17]. The performances of several vegetable oils have been investigated, such as coconut oil, palm oil, olive oil, sesame oil [14], aloe vera oil, cotton seed oil [18], canola based oil [19], and groundnut oil [20]. Coconut oil is reported to have a good performance to be used as cutting fluid for stainless steel because it produces uniform thickness and low toll wear compared to palm oil, olive oil, sesame oil [14] or groundnut oil [20]. Aloe vera oil provides a better surface finish and lower tool wear compared to conventional fluid. Canola oil has a good performance due to its lubricity. It is also reported that cotton seed oil gives a better performance compared to conventional SAE40 oil although the friction coefficient was relatively similar [19]. Those results indicated that vegetable oils have a great potential as the replacement of conventional cutting fluids to save the environment.

In this research, the tool wear and the quality of the finished workpiece in term of surface roughness, Ra, in a milling process were investigated using three kinds of cutting fluid, i.e. crude palm oil (CPO), coconut oil (CO), and commercial emulsion fluid, i.e. soluble oil emulsion (SOE). Although the performance of palm oil as cutting fluid has been reported before, in this case, it was used in the form of non-refined crude palm oil, which is cheaper than refined palm oil. The performance is compare to those of coconut oil and soluble oil emulsion fluids.

The objective of this research is to find out the effect of vegetable oils used as cutting fluid on cutting tool’s wear and the surface finish quality of the workpiece. The investigation was conducted...
using the insert carbide cutting as the tool and grey cast iron as the workpiece in a face milling process.

2. Methodology
A machine tool was used in this research (Figure 1). This machine tool can perform several milling processes: peripheral milling, face milling and end milling. In this research, the face milling process was used in investigating the effect of vegetable oil used as cutting fluid on the wear of insert carbide cutting tool.

Schematically, a process of face milling is shown in Figure 2. The spindle rotates at a certain revolution speed, rpm, in a fixed position while the workpiece moves in the direction of motion at a certain velocity; feed rate, mm/min. Normal milling process uses three cutting tools, as indicated in Figure 2. However, in this investigation, only one cutting tool was used. This is done so that contact occurs only at one cutting tool and the wear can be directly related to the particular surface interaction. The operation parameters used in this research are given in Table 1. There are a total of four tests conducted at various spindle revolution speed and feed rate.

![Figure 2. Schematic diagram of the face milling process](image)

The cutting tool used in this research is the insert carbide cutting tool \((\text{solid carbide})\) series TPKN 22 VC2. The material has a hardness of 1300 - 1800 (Vickers) and heat resistant of 1000º C. The geometry and dimension of the cutting tool is given in Figure 3. The workpiece used in this study is the grey cast iron. The mechanical properties of grey cast iron is given in Table 2.

| Spindle rev., (rpm) | Feed rate, mm/min |
|--------------------|-------------------|
| 360                | 60                |
| 360                | 80                |
| 490                | 60                |
| 490                | 80                |
Figure 3. Cutting tool geometry and dimension

| Table 2. Material properties of grey cast iron |
|---------------------------------------------|
| Property                     | Value          |
| Density                      | 7.34 gr/cm³    |
| Elasticity Modulus           | 162 GPa        |
| Shear Strength               | 610 MPa        |
| Poisson ratio                | 0.33           |
| Hardness, Vickers            | 321            |

Table 3. Properties of cutting fluid

| Cutting fluid                        | Viscosity, Ns/m² | Viscosity, Ns/m² |
|--------------------------------------|------------------|------------------|
|                                      | 27°C             | 80°C             |
| Crude Palm Oil (CPO)                 | 48.7             | 3.5              |
| Coconut Oil (CO)                     | 3.19             | 2.2              |
| Soluble Oil Emulsion (SOE) composed of dromus : water (1:5) | 0.13             | 0.09             |

The cutting fluid is the most important factor in this investigation. The fluids used are bio-oils, which are crude palm oil (CPO), coconut oil (CO), and conventional soluble oil emulsion (SOE) composed of commercial dromus and water with a ratio of 1:5. The properties of the fluids are given in Table 3.

The wear evaluation is done by examining the area lost at the cutting tool after the cutting process. An optical microscope, GX-71, was employed for the evaluation. An example of worn cutting tool is given in Figure 4. Figure 4(a) indicates the wear of the cutting tool at two different locations; A and B. The wear of the tool is calculated as the accumulation of all area losses; in this case the sum of area A and B.

3. Results and Discussion
3.1 Effect of spindle speed and feed rate on the tool wear
Figure 5 shows the microscopic image of the tool cutting before (Figure 5(a)) and after (Figure 5(b)) the cutting process. In this case, the spindle speed was 360 rpm and the feed rate was 60 mm/min. The test was conducted using SOE cutting fluid. From the figure it can be seen that wear occurred during...
the process. Some areas of the tool have been removed in the process at location A and B, which are 26936.73 μm² and 34705.51 μm², respectively. Thus, the total area loss in this case is 0.06 mm². It seems that the tip of the cutting tool was chipped over during the cutting process. It also seems that some wear have occurred along the tip of the cutting tool from A to B. However, this wear could not be evaluated due to limitation in the analysis equipment.

![Figure 4](image-url)  
**Figure 4.** Tool wear showing worn area; before machining process (a), after machining process (b)

![Figure 5](image-url)  
**Figure 5.** Tool wear of the tool at 360 rpm spindle speed, before the machining process (a), after the machining process (b)

The total area losses of the cutting tool for other cutting conditions at spindle speed of 360 rpm are given in Figure 6. At the feed rate of 60 mm/min, the highest tool wear occurred for the test condition with CO used as the cutting fluid, with a total area loss of 0.4 mm². This is significantly higher than those using SOE and CPO, which are 0.06 mm² and 0.08 mm², respectively. Here, the wear of the tool was relatively similar for the condition in which SOE and CPO was used as the cutting fluid.

A similar trend occurred for the feed rate of 80 mm/min for the same spindle speed of 360 rpm, as also shown in Figure 6. At this condition, the total area losses for the SOE, CPO, and CO were 0.09 mm², 0.16 mm², and 0.4 mm², respectively. The total worn area of the cutting tool increased by half for the case of SOE and doubled for the case of CPO as the feed rate increases. However, the total area loss of the tool was the same for the case of CO cutting fluid.

Figure 7 shows the effect of feed rate on the total area loss for the spindle speed of 490 rpm at two different feed rates; 60 mm/min and 80 mm/min. At 60 mm/min, the largest area loss occurred for the case of CPO, which is 0.22 mm², followed by that of CO, which is 0.17 mm². The smallest area loss for this condition is for the SOE cutting fluid, which is 0.12 mm². At 80 mm/min feed rate, as also shown in Figure 7, the smallest area loss occurred for the case of CO, which is 0.04 mm². Whereas for the case of SOE and CPO, the area losses are 0.11 mm² and 0.1 mm², respectively.
Figure 6. Effect of feed rate on total worn area of the tool at spindle speed of 360 rpm

Figure 7. Effect of feed rate on total worn area of the tool at spindle speed of 490 rpm

From Figure 6 and Figure 7, it can be seen that total area loss of the cutting tool insert is affected by both the spindle speed and the feed rate. This is obvious because higher spindle speed means more interaction between the tool and the workpiece. Figure 6 implies that CO is not quite suitable for cutting fluid at the particular condition because it caused heavy wear on the cutting tool. However, the CO worked well at spindle speed of 490 rpm especially at the feed rate of 80 mm/min. Particularly, at this spindle speed and feed rate, CO has a better performance as the cutting fluid compare to CPO or SOE.

Up to this point, the particular reason of better tool wear properties in the case of CO at higher spindle speed is still not clear thus requires further analysis and investigation. However, one possible explanation is the fluid’s viscosity. Particularly at higher spindle speed, the temperature at contact interface may increase significantly and change the viscosity of the oil. At lower spindle speed, CO and CPO have a lower performance compared to commercial SOE possibly because their viscosity are comparatively higher, as shown in Table 3. However, due to temperature increase at higher spindle speed, the viscosity of CO or CPO reduces, resulting in improved cooling effect performance thus improving the tool wear properties. As it is shown in Figure 7, at spindle speed of 360 rpm, the vegetable oils, particularly CO, has a relatively lower performance compared to that of the SOE.
However, these performances improved at the spindle speed of 490 rpm. At this speed, both CO and CPO have a better performances compare to commercial SOE fluid.

![Figure 8. Effect of various parameters on surface quality of the workpieces](image)

From this analysis, it can be argued that CPO and CO fluids can be applicable as the cutting fluids for milling process, in term of the tool wear properties. This is particularly true for the case of carbide cutting tool insert working on grey cast iron workpiece. Since both fluids are renewable vegetable oils, their application can be beneficial for environment and sustainability.

In this analysis, it was observed that wear of the carbide cutting tool insert are in types of flank wear and crater wear. Thus, a more suitable parameter for wear evaluation is term of volume loss. However, this has not been conducted in this analysis due to limitation. Nevertheless, the results shown in this analysis have clearly indicated the potential of bio-oils, coconut oil and crude palm oil, as the cutting fluids.

### 3.2. Effect of spindle speed and feed rate on the surface roughness of the workpiece

One of the most important factor determining the final quality of a milling process is the surface roughness of the product. Here, it is the surface roughness of the workpiece. Commonly in a machining process, the surface roughness is affected by various factors such as the spindle speed, the cutting rate, the cutting depth, the properties of both the tool and workpiece, and the lubrication. In this case, only two parameters were taken into account for the evaluation; the spindle speed and cutting rate. Figure 8 shows the images of the finished workpieces as the result of milling process at various spindle speeds, feed rates, and cutting fluids. By physical observation, the finished quality of the workpiece in the case of CO cutting fluid matches the quality of that in the case of SOE. In order to better compare the results, the roughness of each workpiece was evaluated by using a surface profilometer taking the parameter of arithmetic average value of the roughness profile, Ra, μm.

The results are given in Figure 9 and Figure 10. It is obvious from the figures that smoother surface roughness were achieved at higher spindle speed and/or cutting rate. The effect of cutting fluid on the surface roughness of the workpiece is more obvious at the feed rate of 60 mm/min. For the spindle speed of 360 rpm, the smoothest surface was achieved for the case of SOE fluid, which is $Ra=0.89$ μm. The highest roughness occurred for the case of CPO fluid, which is $Ra=1.99$ μm, followed by that of CO fluid, which is $Ra=1.56$ μm. The surface roughness decreases at the spindle speed of 490 rpm, as shown in Figure 10. At the feed rate of 60 mm/min, it seems that CPO is the least favourable fluid because it produced a relatively rough surface compare to the other fluids.

On the other hand, the difference among the surface roughness of the workpiece is less observable for the case of feed rate of 80 mm/min for both spindle speed of 360 rpm and 490 rpm. At spindle speed of 80 mm/min, the roughness of the workpiece for the case of SOE fluid and that of CO fluid
are Ra=0.6 μm and Ra=0.64 μm, respectively. For the case of CPO, the roughness is Ra=0.7 μm. The roughness of the workpiece for the three condition decreased as the spindle speed increases, as shown in Figure 10. The largest decrease occurred for the case of SOE fluid, which is 50%. This is obvious since the commercial SOE is the cutting fluid that has been optimized for the machining process.

![Figure 9](image_url) Effect of feed rate on the surface roughness of the workpiece at spindle speed of 360 rpm

![Figure 10](image_url) Effect of feed rate on the surface roughness of the workpiece at spindle speed of 490 rpm

The results of this investigation is comparable to previous results reported in various literatures. It was reported that improvement of wear up to 67% was achieved when using vegetable oil in the case of minimum quantity lubrication condition, as well as improvement of the workpiece surface roughness up to 31% [21]. Here in this research, the improvement of tool wear was achieved particularly at higher spindle speed. However, improvement in surface roughness of the workpiece was not clearly observed in this research, thus requires further analysis and investigations.

4. Conclusion
The investigation on the effect of vegetable oils as cutting fluid on the wear of the carbide cutting tool insert and the surface roughness of the grey cast iron workpiece in a face milling process has been conducted. The results indicates that coconut oil has a better performance as a cutting fluid compared
to crude palm oil or commercial soluble oil emulsion, particularly at higher spindle speed and feed rate since it gave the smallest wear of the tool. However, their effects on the surface roughness of the workpiece are less observable. The results imply that coconut oil is highly potential to be used as cutting fluid in machining processes, especially at higher spindle speed.

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