Performance of commercial and palm oil lubricants in turning FCD700 ductile cast iron using carbide tools

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HIGHLIGHTS

➢ The tool life for the commercial lubricant was longer than palm oil based lubricant.
➢ Better surface roughness was obtained using the palm oil based lubricant.
➢ The Ra measured was affected by the wear on the cutting tool.

ABSTRACT

In a machining operation, cutting fluids are widely used as coolants to reduce the effects of heat, and also as lubricants to reduce the interface friction between the tool chip and tool workpiece. This paper presents the performance of both inorganic commercial lubricants and environmental friendly organic palm oil based lubricants, when turning FCD700 cast iron using carbide tool. Two sets of turning parameters were tested: i) cutting speed of 120 m/min, feed rate of 0.3 mm/rev, and depth of cut of 0.6 mm, and ii) cutting speed of 220 m/min, feed rate of 0.2 mm/rev, and depth of cut of 2 mm. The results show that for both turning conditions, the tool life for the commercial lubricant was longer than the palm oil based lubricant by more than double. Better surface roughness was obtained using the palm oil based lubricant by about 1μm, due to the oxygen in vegetable oil compound, which creates a stronger bonded layer of lubricant on the metal surface. The Ra accuracy can also be affected by the dirt or imperfection of the machined surface produced when the cutting tool begins to wear out.

Keywords:
| Turning process | Commercial oil lubricant | Palm oil lubricant | FCD700 cast iron | Carbide tool | Tool life | Surface roughness |
1.0 INTRODUCTION

The recent trend of high speed machining is becoming common in almost manufacturing and automotive industries. High speed machining is an ideal method meet to the demand for a shorter production times for the manufacture of an automotive component. This would therefore improve productivity and reduce manufacturing cost. During high speed machining, as with conventional machining, it is imperative to obtain optimal chip control. Also, the need to transfer heat from the cutting interface is crucial to produce a successful machining performance. Due to this, the application of cutting fluid is still important, and in drilling holes, an application of cutting fluid is a must. The fluid that cools and lubricates the cut also helps to evacuate chips from the hole, the workpiece and the fixture. When cutting dry, only the spindle’s motion will work to evacuate chips.

Coolants and lubricants function differently in the machining processes. Coolants control the heat generated in the machining process by quenching with water or oil based coolants that usually contain sulphur, chlorine, or other additives. Lubricants reduce friction in machining, thus minimizing heat build-up (Palmer, 2009). They are also used to remove heat in machining operations. Excessive heat can damage the microstructure of metals. The proper use of coolants can make higher metal removal rates possible. Coolants can also help improve part quality (surface roughness) and dimensional accuracy.

In manufacturing automotive components, grey cast iron continues to occupy a notable place in the area of materials. Cast iron is in direct competition with cast aluminium, although the mechanical properties of the former find their place in the market, for making certain components such as cylinder blocks, and cylinder heads to a lesser extent (Álvarez et al., 2004). Cast iron machinability varies greatly depending on the type of iron and its microstructure. Ferritic cast irons are easiest to machine, while white irons are extremely difficult to machine. Other grades of cast iron, such as malleable, ductile, compacted graphite, and alloyed cast irons are also difficult to machine. Additionally, hard spots in castings, formed during rapid cooling and in the presence of excessive levels of carbide forming elements can seriously degrade machinability (Kennametal, 2010). Ductile iron frequently known as nodular or spheroidal graphite (SG) cast iron also called Ferrum Casting Ductile (FCD), is a recent member of family of cast iron. It contains nodules of graphite embedded in a matrix of ferrite or pearlite or both. The graphite separates as nodules from molten iron during solidification because of additives cerium (Ce) and magnesium (Mg) introduced in the molten iron before casting. The nodules act as crack arresters and impart ductility to the material (Kennametal, 2010). By contrast, neither white iron nor grey iron shows a significant amount of ductility. Ductile iron is of higher purity and is stronger than grey iron (Susumu et al., 2008). However, improving the performance of the metal cutting
operation in high speed machining and in the case of machining hard material such as FCD700, is still a major problem.

It was found that the efficiency of the metal cutting operation depends to a large extent on the effectiveness of the cooling/lubrication provided (Kovacevic et al., 1995). A conventional wet coolant directed to the cutting area is the most common method of applying the cutting fluid. However, this method loses effectiveness at high cutting speeds and causes pollution. Uses of coolant for the machining processes is harmful to both the environment and human health (Shaw and Mitsuro, 2000). The chemical substances in coolants cause serious health problems to workers who are exposed to the coolant in both liquid and mist form. The cost of using coolant is increasing, as the number and the extensiveness of environmental protection laws and regulations increase. Vegetable oils can offer significant environmental advantages with respect to resource renewability and biodegradability (Gawrilow, 2003). Furthermore, the advantages gained include non-toxicity, affordable application cost, good lubricity and a high viscosity index (Gawrilow, 2003). This study compares the performance of both commercial and the proposed palm oil based lubricants. The proposed palm oil based lubricant is easier and costs less to dispose, due to its biodegradable property, as compared to the commercial straight oil lubricant.

2.0 MATERIALS AND METHODS

Due to the current trend in the manufacturing and automotive industry, which demands more environmental friendly machining environment, other cooling methods such as chilled air application and biodegradable cutting fluids are proposed. This study evaluates the performance of the biodegradable palm oil based as an alternative to the application of the straight oil lubricant. In this study, all the machining experiments were carried out using a Colchester Tornado 600 CNC lathe. The workpiece material in the experiment used was FCD700 cast iron. It was selected to represent the major group of workpiece materials used in the automotive industry. The specimen was in the form of a cylindrical bar 115 mm in diameter and 200 mm in length (measured from chuck to tail stock). A pre-cut with a 1 mm depth of cut was performed on work piece prior to the actual turning tests using an uncoated carbide tool. This was done in order to remove the rust layer from the outside surface and to minimize any effect of inhomogeneity on the results of the experiment. The length to be machined was set at 80 mm for each run. This allowed 30 mm held in the chuck for supporting, and 10 mm clearance between the end of the machined surface, and for the chuck to avoid any interference with the chip flow. Table 1 shows the composition of the cast iron grade FCD700 used in the experiment and Table 2 shows the mechanical properties of the coated carbide insert AC700G respectively.
Table 1: Composition of cast iron grade FCD700 (SIRIM, 2009)

<table>
<thead>
<tr>
<th>Element percentage (%)</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
<th>Mo</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>3.32</td>
<td>2.68</td>
<td>0.46</td>
<td>0.028</td>
<td>0.018</td>
<td>0.85</td>
<td>-</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Table 2: Geometry and coating of coated carbide insert

<table>
<thead>
<tr>
<th>Nose radius, r&lt;sub&gt;e&lt;/sub&gt;</th>
<th>Clearance Angle, β</th>
<th>Rake angle, α</th>
<th>Main coating material</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>3°</td>
<td>-5°</td>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; + TiCN</td>
</tr>
</tbody>
</table>

Surface roughness of the turned surface was measured regularly after every cut using a portable surface roughness tester Mpi Mahr Perthometer. The performance of both commercial and the proposed palm oil based bio lubricants was evaluated according to the turning parameters as shown in Table 3. Both lubricants used were water-based (emulsion). These parameters were found to give the longest tool life when turning in dry chilled air conditions in a previous study (Azmi et al., 2010; Kamal, 2009).

Table 3: Turning parameters used in the experiment

<table>
<thead>
<tr>
<th>Exp no.</th>
<th>Cutting speed, V (m/min)</th>
<th>Feed rate, f (mm/rev)</th>
<th>Depth of cut (mm)</th>
<th>Type of lubricant</th>
<th>Lubricant application (60 l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>120</td>
<td>0.30</td>
<td>0.6</td>
<td>Commercial oil</td>
<td>Flood</td>
</tr>
<tr>
<td>P1</td>
<td>120</td>
<td>0.30</td>
<td>0.6</td>
<td>Palm oil</td>
<td>Flood</td>
</tr>
<tr>
<td>D2</td>
<td>220</td>
<td>0.20</td>
<td>2.0</td>
<td>Commercial oil</td>
<td>Flood</td>
</tr>
<tr>
<td>P2</td>
<td>220</td>
<td>0.20</td>
<td>2.0</td>
<td>Palm oil</td>
<td>Flood</td>
</tr>
</tbody>
</table>

3.0 RESULTS AND DISCUSSION

When machining using carbide tools under typical cutting conditions, the failure of the cutting tools was due to the gradual wear on the flank and rake faces (Che Haron et al., 2001). However, assessing the failure on the flank wear was preferred due to the gradual wear progress and easily monitored (Paldey and Deevi, 2003). In this study the tool life was limited by the flank wear, when the flank wear (VB) = 0.3 mm. Table 4 showed tool life and surface finish obtained for both commercial and palm oil based lubricants.
Table 4: Tool life and surface finish obtained for both commercial and palm oil based lubricants

<table>
<thead>
<tr>
<th>Exp no</th>
<th>Cutting speed, V (m/min)</th>
<th>Feed rate, f (mm/rev)</th>
<th>Depth of cut (mm)</th>
<th>Type of lubricant</th>
<th>Tool Life (min)</th>
<th>Final VB (mm)</th>
<th>Roughness, Ra (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>120</td>
<td>0.30</td>
<td>0.6</td>
<td>Commercial oil</td>
<td>122.0</td>
<td>0.326</td>
<td>4.010</td>
</tr>
<tr>
<td>P1</td>
<td>120</td>
<td>0.30</td>
<td>0.6</td>
<td>Palm oil</td>
<td>71.75</td>
<td>0.30</td>
<td>3.187</td>
</tr>
<tr>
<td>D2</td>
<td>220</td>
<td>0.20</td>
<td>2.0</td>
<td>Commercial oil</td>
<td>28.33</td>
<td>0.318</td>
<td>2.329</td>
</tr>
<tr>
<td>P2</td>
<td>220</td>
<td>0.20</td>
<td>2.0</td>
<td>Palm oil</td>
<td>9.61</td>
<td>0.304</td>
<td>1.287</td>
</tr>
</tbody>
</table>

Results in Table 4 show that longer tool lives were achieved when turning cast iron using commercial oil lubricant than palm oil lubricant. The tool life was drastically shortened at high cutting speed of 220 m/min and high depth of cut of 2 mm. At low turning parameters of 120 m/min, 0.3 mm/rev and 0.6 mm depth of cut, the tool life for the commercial oil lubricant was about 1.7 times more than palm oil lubricant. But as the cutting speed increased to 220 m/min and at 2 mm depth of cut, the tool life for the commercial oil lubricant increased to 3 times more than the palm oil bio lubricant. A previous study (Lawal et al., 2011), found that the ability for the palm oil lubricant to conduct heat away from the work zone was better than the commercial oil lubricant at all ranges of cutting speed, i.e. the wettability of palm oil lubricant was better than the commercial oil. Furthermore, the viscosity for the palm oil lubricant was bigger than the commercial oil i.e. 4.79 (cSt) and 7.64 (cSt) respectively. This indicates that the palm oil lubricant perceived better thermal stability due to its higher viscosity. Findings from the previous study (Lawal et al., 2011) showed that the palm oil-based lubricants should be able to prolong the tool life at all the cutting speed used in the experiment. Unfortunately, the results obtained in this study are the opposite. The main reason for these contradictory results may be due to the additive added to the commercial oil that had helped it perform better than the palm oil-based lubricant. More attention should be given in the future to the additive elements to improve the performance of the palm oil-based lubricant.

Figure 1 shows the Flank wear land vs. cutting time. The flank wear experienced on the flank face is similar to a typical wear curve (Groover, 2011) of gradual wearing of the cutting tool. Therefore, the turning conditions used in this study are suitable to be applied in turning cast iron in real manufacturing industry. The wear behavior can be predicted, as it started with rapid initial wear, uniform wear rate and accelerating wear rate (Groover, 2011) as shown in Figure 1 for test D1.
The useful life of a cutting tool may be limited by a variety of wear processes such as crater wear, flank wear or abrasive wear, built up edge, depth of cut notching and nose wear (Paldey and Deevi, 2003). The important types of tool wear are flank wear, nose wear, crater wear and notch wear. The development of cutting tools material mostly focus on minimizing the flank wear, crater wear and notch wear. In a study it was found that the flank wear in carbide tools initially occurs due to abrasion and as the wear process progresses, the temperature increases causing diffusion to take place (Bonifacio et al., 1994).

There was a gradual deterioration of the surface finish with prolonged machining as the wear at the cutting edges increased. Relatively high surface roughness values were recorded as the wear progressed primarily due to the severe wear which altered the geometry of the cutting edge. Figure 2 shows the Ra values vs. the cutting time. It is clearly observed that the Ra values increases with the cutting time or the flank wear land. But in some cases, low Ra values are measured at the end of the cutting tool life. This may due to the Ra, i.e. average deviation from the mean surface is highly controlled by the mathematical equation used in the talysurf unit (Thwaite, 1984). Furthermore, the reading can also be affected by the dirt or imperfection of the machined surface produced.

Machining with D1 and P1 conditions resulted in bigger Ra values as compared with conditions D2 and P2. This is due to the bigger feed rate used in the D1 and P1 machining conditions as similarly observed by other researchers (Li and Low, 1994; Byrne et al., 1997; Jaharah et al., 2009; Jaharah et al., 2010). Ra measured for D1 (using commercial oil lubricant) is higher by about 1 μm as compared with the P1 (using palm oil-based lubricant) at a low cutting speed of 120 m/min, high feed rate of 0.3 mm/rev and low depth of cut of 0.6 mm. On the other hand, at a high cutting speed of 220 m/min, a low feed rate of 0.2 mm/rev, and high depth of cut of 2 mm, the measured Ra at the
beginning of the cut is about the same, but as the wear progresses, cutting using commercial oil show significant increases in Ra as compared to the palm-oil based. This may due to the vegetable oil compound that consists of oxygen and creates a stronger bonded layer of the lubricant on the metal surface (Wood, 2005), and good adhesion to the metal surface (Gawrilow, 2003). Therefore, the palm oil has a better lubrication property than the mineral oil. Consequently, the cutting fluid with good lubricating properties will produce a better surface finish. Furthermore, according to Bongfa et al., vegetable oils have good friction reduction abilities in their study of unrefined castor oil as crankcase oils application. According to Farhanah and Bahak, the better the lubricant can protect the moving surfaces from direct metal-to-metal contact occur; produce better surface finish.

![Graph](image.png)

**Figure 2:** Surface roughness, Ra (μm) vs. cutting time (min)

**CONCLUSION**

Cutting using the commercial oil lubricant produced a longer tool life than the palm oil-based lubricant. At the cutting speed of 120 m/min and 220m/min, the tool lives for commercial oil lubricant were respectively 1.7 times and 3 times more than the palm-oil based lubricants. More attention should be given in the future to the additive elements to improve the performance of the palm oil-based lubricant in order to prolong the tool life at all the cutting speed used in the experiment. The advantages of better wettability and viscosity index of the palm oil lubricant should be utilized as a future lubricating oil. In addition, the Ra measured for commercial oil lubricant was higher than palm-oil based
which was due to the good adhesion of palm oil compound to metal surface and oxygen content hat create a stronger bonded layer of lubricant on the metal surface.

REFERENCES


