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COMPARISON OF TOOL WEAR DURING DRILLING OF AN AUSTENITIC STAINLESS STEEL WITH A CONVENTIONAL CUTTING FLUID AND A VEGETABLE OIL[1]

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Abstract

In this work, the performance of a mineral and a vegetable-based cutting fluid during drilling operations in an AISI 304 austenitic stainless steel (ASS) is compared. The tests were made on ASS plates using a milling machine and HSS drills until the catastrophic failure of the drills. The wear of cutting edges was monitored periodically by observations in a stereomicroscope (SM). In addition, measurements of noise, temperature and current were taken. The results showed that tools lubricated with vegetable fluid had lower wear level than tools lubricated with mineral based oil. Power consumption remained without changes when the cutting fluid was changed while lubrication with the vegetable fluid reduced the noise level of the operation. These results are promising considering the machining performance and lower environmental impact that can be obtained with a vegetable-based cutting fluid.

Keywords: Mineral based oil; Vegetable based oil; Drilling; Austenitic stainless steel (ASS); High speed tool (HSS).

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1 INTRODUCTION

Cutting fluids are extensively used in metal machining process to reduce cutting forces, prevent wear between contact surfaces, drag chips away, clean, and dissipate heat generated during the cut operation.[1] Due to its chemical stability and its reusability, mineral-based oils are the most commonly cutting fluids used in metal machining process. However, the use of this kind of oils has negative environmental impacts related to its manipulation, transport, storage and final disposal.[2] It has been found that these cutting fluids also generate health problems as irritations, allergies and in extreme cases, cancer in human beings.[1,3] Therefore, the research concerning about vegetable-based cutting fluids (biolubricants) has been in constant development, as candidates to replace mineral-based oils. Vegetable-based cutting fluids are environmental friendly, almost entirely biodegradable, have low toxicity, reduce energetic costs and in some cases have good tribological properties since it reduces friction.[4,5]
Skerlos et al studied the behavior of cutting fluids obtained from canola, soybean and rapeseed and found that their performance is at least as good as conventional cutting fluids.[6] Similarly, the performance of vegetable-based cutting fluids in drilling austenitic stainless steel has been reviewed by Belluco and De Chiffre; their results show that all tested vegetable-based oils perform better than the commercially available mineral oil in terms of tool life improvement and reduction of thrust force. The better result showed that vegetable-based oil increases 177% the tool life and reduces 7% the thrust force.[7]
Tribological properties of cutting fluids strongly depend on the measurement method. Some standard tests for measuring properties and effectiveness of cutting fluids include Falex pin, Vee Block, Timken method and four ball test.[8-10] However, some authors have argued that the results obtained with these methods do not have a good correlation with performance of cutting fluids in machining process.[11] As established by these authors, drilling test offers an alternative to compare performance of cutting fluids since it is easy to setup and reasonably cheaper.
In this work, the performance of a mineral-based cutting fluid and a fluid obtained from a common vegetable plant in Colombia is compared using drilling tests in an austenitic stainless steel AISI 304 plate.

2 MATERIALS AND METHODS

2.1 Materials

Austenitic stainless steel AISI 304 plates with 19.05 mm (3/4 in) in thickness were used as machined material. The nominal composition of the plates was 0.8C, 2Mn, 18Cr, 8Ni, 0.75Si, 0.04P and 0.03S (wt-%). HSS drills with 15.08 mm (19/32in) diameter, 70.00° helix angle, 10.00° clearance angle and 130.00° point angle were used to drill AISI 304 plates.

2.2 Drilling Tests

A Fexac milling machine was used for drilling the plates and control the cutting conditions. The feed rate was 0.538 mm/rev. Drilling tests were carried out under two different conditions of lubrication: in the first one, the cutting operation was assisted with conventional mineral oil and the drills were called M. In the second condition, the

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cutting operation was assisted with a vegetable-based cutting fluid and the drills were called V.
During the test time, the noise level (dB) was measured every 5 seconds using a sonometer. The current (A) was also registered in each operation with a clamp and the power was calculated. After the drilling operation, the milling machine was stopped and the temperature on the surface of the drill was measured using a contact K type thermocouple. These measurements were taken after every drill operation until catastrophic failure of the tool.
In order to assess the tool wear, a Nikon stereomicroscope (SM), SMZ 1000 with a digital camera was used. A comparison between the wear level of M and V drills was established using images of the cutting edges and flanks. Images of the new drills and drills after each 20 holes were taken until the failure of one of them. Three zones were evaluated: flank 1, 2 and cutting edges. Figure 1 shows these zones.

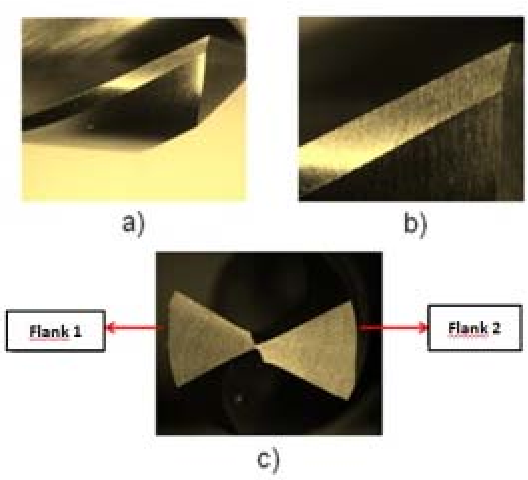

Figure 1. Wear evaluation zones. a) face 1, b) Closer image of face 1 and c) cutting edge. Stereo microscope images.

3 RESULTS

3.1 Tool Wear

Figure 2 shows images of drill M1 and drill V1 before start with drilling tests. Figures 3 to 6 show the evolution of tool wear after series of twenty holes. In these series of photos, flank 1 is shown in the first column on the left side of the (a) and (b) frames and flank 2 is shown in the second column. Cutting edges are shown in the third column on the right side of frames.
An initial phase of tool wear is observed in figure 3 for both lubrication conditions. Flanks in the drill lubricated with mineral oil (Figure 3a) shows some marks of adhesion and cutting edges exhibit some chipping marks in initial stages. Some oxides near the cutting edges shown that chipping marks formation could be assisted by friction and high temperature combined with cutting stresses.
Some wear marks where observed in the drill lubricated with vegetable-based fluid too (Figure 3b). However, little pits instead of adhesion marks were detected on the flanks. Some chipping marks were observed on the cutting edges, they seemed to be a little deeper but not so extended as in Figure 3a. Oxides could not be identified because a lubricant layer covered the edges, however this fact demonstrates that temperature increase in this zone too.

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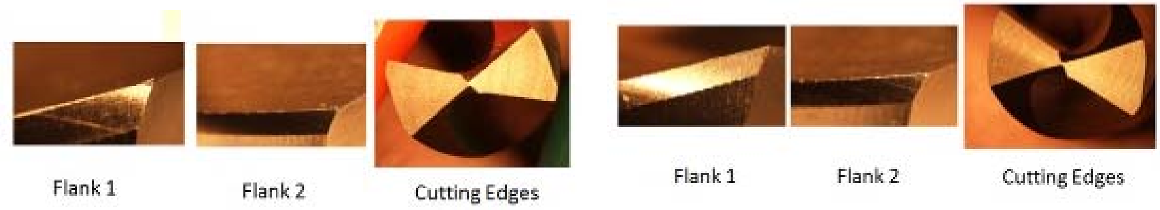
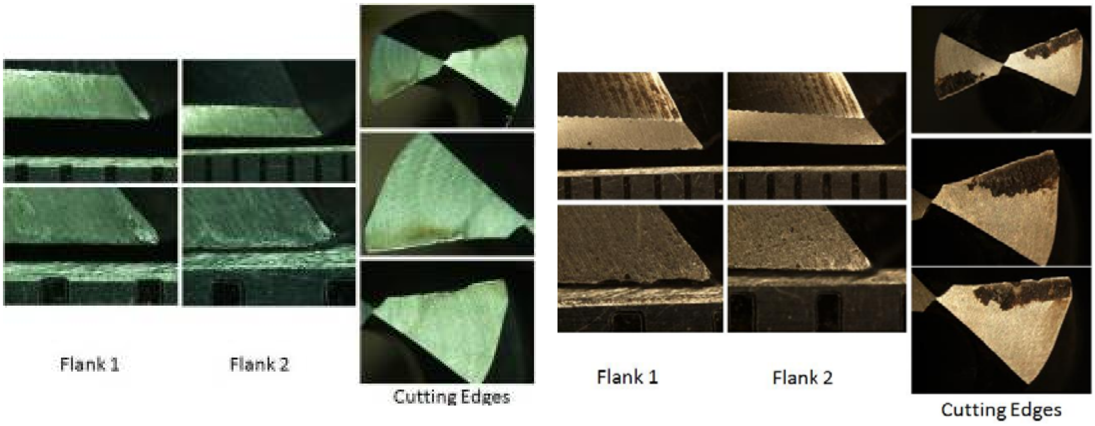


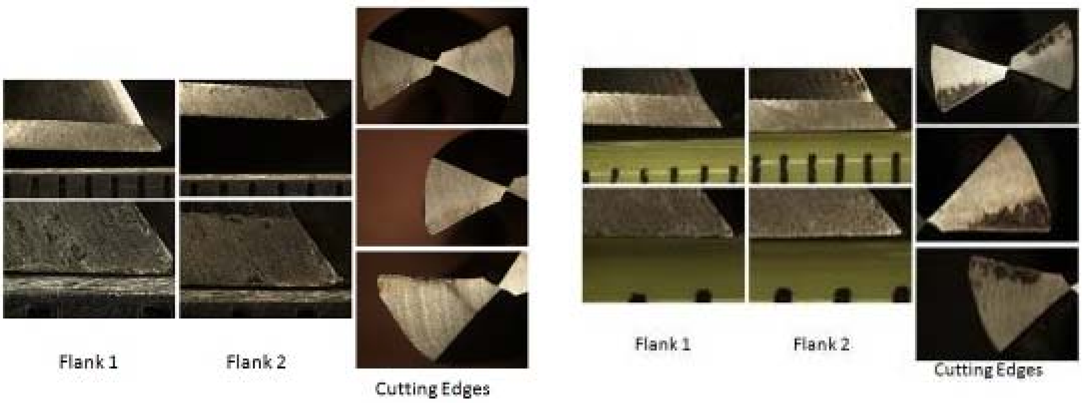
(a) (b)

Figure 2. Optical microscope images of (a) drill M1 (lubricated with mineral oil) and (b) drill V1 (lubricated with vegetable-based fluid) before drilling operations.



(a) (b)

Figure 3. Optical microscope images of (a) drill M1 and (b) drill V1 after 20 holes.



(a) (b)

Figure 4. Optical microscope images of (a) drill M1 and (b) drill V1 after 40 holes.

After 40 holes, both drills M1 and V1 show evolution of chipping marks and adhesion wear marks, however, the drill lubricated with vegetable-based fluid seems to be more free of wear marks in comparison with the drill lubricated with mineral oil. Increasing the number of holes up to 60, both drills conserve the geometry of the cutting edges, but it is remarkable the increase of wear on the flanks of the drill lubricated with mineral-based fluid. The other parts of the cutting edge do not show significant changes in geometry. Extensive adhesion and some marks of plastic deformation are observed.

Figure 5a shows optical microscope images of the drill M1 after 83 holes. The drill with mineral lubricant fails, whereas the drill used with vegetable-based fluid

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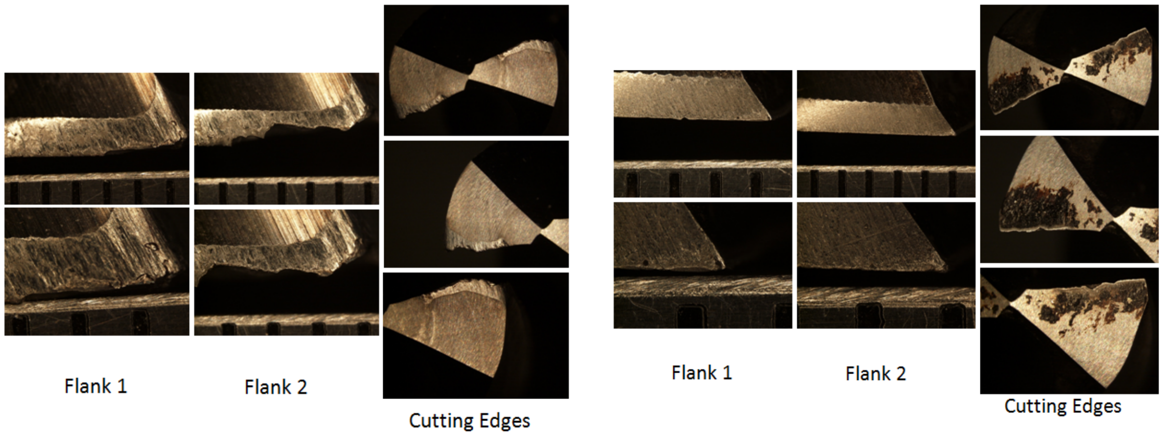
continues working out. Drill V1 did not failure but images where taking to establish a comparison (Figura 5b). Severe wear marks are observed in both flanks of the M1 drill. Chipping marks increased manifestly up to break up the cutting edge almost completely.

(a) (b)

Figure 5. Optical microscope images of (a) drill M1 and (b) drill V1 after 60 holes.



(a) (b)

Figure 6. Optical microscope images of (a) drill M1 and (b) drill V1 after machining 83 holes.

3.2 Noise, Temperature and Power

The quantity of noise level during drilling operation using the vegetable-based fluid was lower than detected using the conventional lubricant. Nevertheless, temperature measurements on the drill surface when mineral-based oil was used were always lower than the obtained using the vegetable-based fluid. Box-plot graphics and statistical tests were used to compare the average of noise level obtained in both lubrication conditions at the same stages of the test. In addition, a plot of number of drill holes and temperature was considered for the study of temperature behavior.

3.2.1 Noise

It was found that measurements of noise for vegetable-based fluid were lower in 58 drills of 83 carried out; this means that 70 percent of times the recording of noise for vegetable lubricant was lower. Box-plot graphics were obtained for 20, 40, 60 and

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80 drill holes. These graphs were used to determine if the two methods of lubrication were significantly different in average noise.

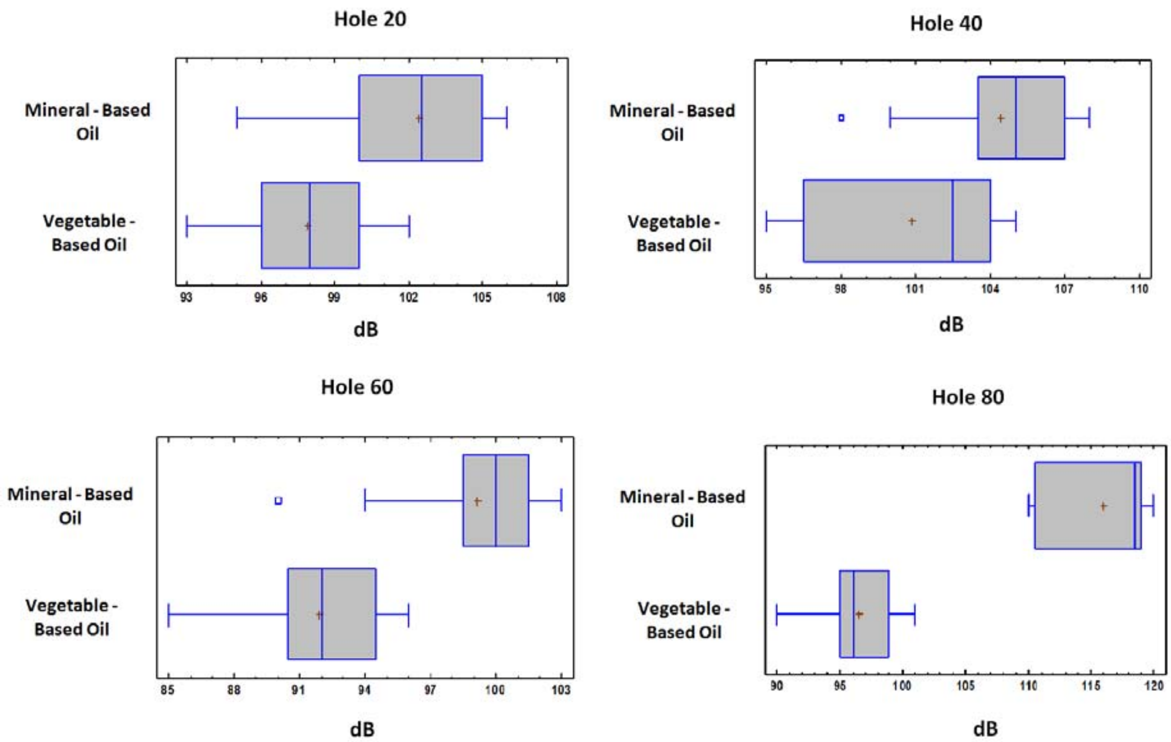

Figure 7. Box-plot graphics for mean comparisons.

Figure 7 shows results obtained for mean comparisons. For each drill hole was tested the hypothesis that the two types of lubricant exhibit the same mean of noise at the 0.05 level of significance. It was found that the measurements for each lubricant were approximately normal and the variances were assumed equal. The hypothesis test concluded for drill holes number 20, 60 and 80 that the average of noise of the two lubricants was significantly different. It was observed also that the average noise for drill holes 20, 60 and 80 with vegetable-based lubricant was considerably lower than the average noise found for mineral fluid. Table 1 summarizes general results of hypothesis test and the difference between means of noise of the two lubricants. Note that the difference between means increases as the drill holes increase in number.

Table 1- Results of hypothesis test

Number of drlls	Average of noise (dB)		Difference(dB)
	Vegetal	Mineral	
20	97.875	102.438	4.563
40	106.625	103.313	3.312
60	91.875	99.125	7.25
80	96.56	116	19.44

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3.2.2 Temperature

Figure 8 shows the average temperature measured after each perforation. It clearly shows that the average temperature of the drill when the vegetal lubricant is used is higher than the average obtained using the conventional mineral lubricant.

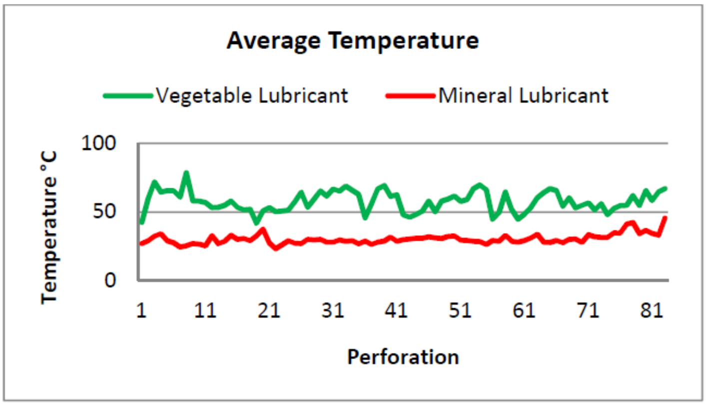

Figure 8. Average temperature on the drill surface as a function of holes for both lubricant condition, mineral and vegetable cutting fluid.

3.2.3 Power

Figure 9 shows the power values calculated for each drill hole. They have a similar behavior for both vegetable-based fluid and mineral lubricant.

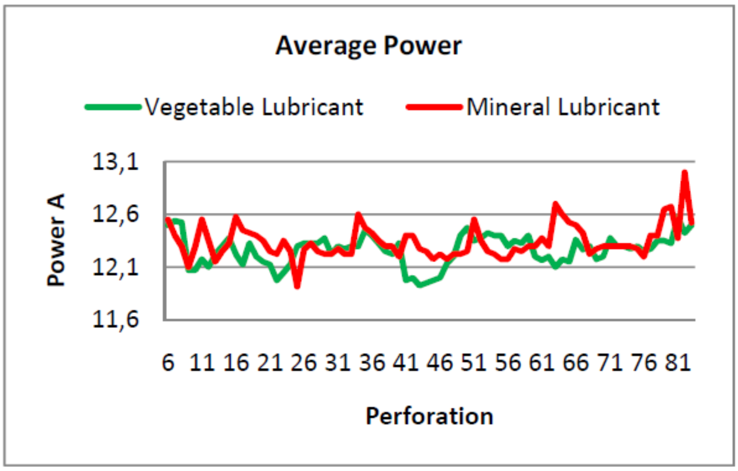

Figure 9. Average power as a function of holes for both lubricant condition, mineral and vegetable cutting fluid.

4 DISCUSSION

The observation of tool surfaces after tests allows identifying some wear mechanisms. Most of wear marks correspond to severe plastic deformation, but adhesion, some abrasion and chipping marks were observed too. Friction and temperature could have a main role in the wear process, considering that chipping marks are located in the outer zone of the edges, where these factors are commonly bigger. However, the high temperatures measured on the drills V, lubricated with the vegetable-base fluid, seems to indicate that under the test conditions used in this work, temperature elevation did not play a main role on the tool wear, and the lubrication condition dominated the process.

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Metal cutting operations are carried out under boundary lubrication condition, which is strongly affected by adsorbed layers on the contact surfaces.(1) It has been demonstrated that an efficient boundary lubrication regime can be established from the formation of adsorbed layers of polar molecules. According to Jahanmir, the molecules orient themselves with the polar end at the solid surface and form a close-packed layer that decrease friction, wear and improving the tribological response of the system.(12)

Mineral and vegetable esters are both assemblies of carbon and hydrogen atoms. However, their structure differs significantly, which determines the different performance showed by these kinds of fluids.(13) Vegetable oils are mixtures of triglycerides, which are glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages.(3) These molecules could provide desirable conditions for boundary lubrication since their fatty acid chains are long and polar, which could make possible the formation of an adsorbed film on the metal surface and generate high strength lubricant layers that interact strongly with metallic surfaces.

The results about noise level show that seventy percent of times, vegetable-based fluid presents values of noise lower than values obtained lubricating with conventional fluid; this response could be related with lower drill wear. In addition, when the drill hole numbers increase, noise associated with drilling with vegetable lubricant remains approximately stable between 92 and 106 dB, while the noise using conventional lubricant always showed a growing trend.

These results are promising. However, it is necessary further research that evaluate additives to impart other characteristics of a nontribological nature, such as oxidative stability, corrosion protection, and cooling properties.

5 CONCLUSIONS

Drills lubricated with vegetable-based cutting fluid showed a better performance than those lubricated with mineral fluid. Vegetable-based cutting fluid showed good anti-wear properties; nevertheless it did not exhibit good cooling characteristics.

The main wear mechanism identified on surface of drills was severe adhesion. However, the failure of the cutting edges was caused by formation of shipping marks.

The noise level registered using the vegetable-based cutting fluid is considerably lower than obtained using mineral fluid. It was noticed an increase of noise level near the failure of the drills, what indicate that noise could be used as a wear level signal.

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