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Comparative performance analysis of *Tung* and *Jatropha* emulsions for development as cutting fluids

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Keywords: reichert test, CGI gray cast iron, *Tung* and *Jatropha* emulsions, flank wear

Abstract

This work was based on a comparative analysis of the action of *Tung* and *Jatropha Curcas* emulsions as cutting fluids for a CGI gray cast iron, where machining parameters, tool wear and fluid efficiency were analyzed. The results that followed the Reichert Test, milling with TiN coated carbide inserts, weight loss and pins temperatures measurements for each fluid.Given the operating conditions, the main wear mechanism presented by CGI gray cast iron machining, using Tung and Jatropha emulsions as cutting fluid, was flank wear, with adherence to the flank surface and the tool outlet. Therefore, substrate peeling was observed followed by chipping and breaking of the cutting edges of the tool with higher incidence in machining with emulsified Tung fluid.The tool wear zone occurred mainly near the radius of the tool nose on the flank side, with plastic deformation independent of the cutting speed.

1. Introduction

Tribological tests are initial alternatives for analysis at the cutting fluid product development stage, as they allow greater flexibility for formulation change where lubricity information is obtained in the test phase.

Equipment widely used in the study of these phenomena are tribômeters, which are devices whose main function simulate friction and wear situations under controlled condition.

These devices can simulate various characteristics of a wear or friction problem without causing any difficulty to experiment on real equipment. Vegetable oils are tasked with acting as anti-wear fluids and friction modifiers due to their strong interactions with the surfaces with which they interact [1].

The tribological test frequently is the Reichert Test, specified by DIN 50–347 (wear test apparatus) due to the higher repeatability of the results. This method consists of a pin-on-ring tribometer configuration used to test the strength of the lubricating film under the application of a shear force.

Some authors state that friction is not always reduced, and often the increasing coefficient of friction is acceptable, as this is associated with a significant reduction in wear [2]. Although standardized small-scale tribological assays are preferred for their practicality and material selection capability, full-scale assays are required to confirm small-scale results [3].

For the development of a study and improvement of a new cutting fluid, it is relevant to understand the tribochemical and tribophysical processes that occur between the material and the cutting tool in machining [4].

Wear and tear is the main causes of cutting fluid component deterioration due to surface fatigue. It is rarely catastrophic, but reduces the efficiency of operation, which can result in dimensional changes of components or damage to the surface [5].

The mechanisms involved in cutting tool wear, especially in general machining, are complicated and may consist of different interaction effects, complexly related, because they depend on cutting conditions, tool composition and geometry, cutting temperature, cutting forces and pass frequency [6].

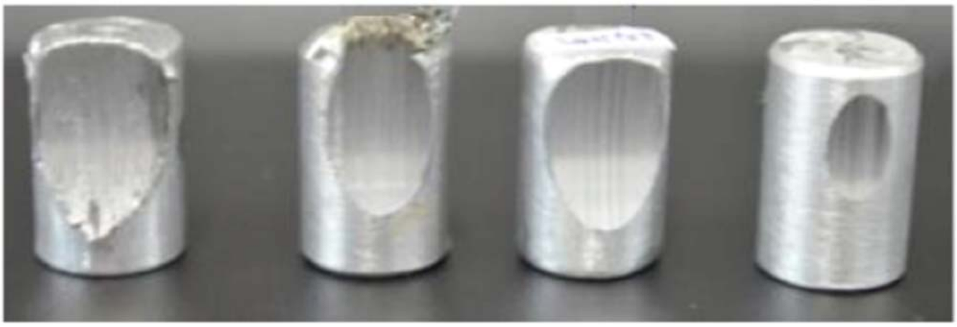

Figure 1. Type of characteristic wear according *Reichert Test.*

According to the principle of metal cutting, there are three deformation zones during material removal process: shear deformation zone, contact zone of tool-chip, and contact zone of tool-workpiece what are areas where the heat is generate [7].

Tung stands out as a species that has high oil content in its composition, arousing great interest of the industry for the production of biodiesel, while Jatropha has no high oil content.

In metal machining, the tribological aspects that should be highlighted are: contact area, stress distribution and wear temperature [8]. However, in order to choose a cutting fluid for machining, it must be based on performance characteristics and cost effectiveness.

Cutting fluids are of fundamental importance in the roughing and grinding processes, aiming to improve the finishing properties, since their fluidity, quality and tendency to reduce the coefficient of friction stand out [9].

Tung oil is mainly used due to its drying power, having many industrial applications, such as: in the manufacture of varnishes, resins, artificial leather, its production and marketing structured [10].

Jatropha emulsion have an oil content of up to 45 to 60%, and from an environmental point of view, it has advantages for its high biodegradability, low environmental pollution and low toxicity [11, 12].

Therefore this work aimed at alternatives of vegetable cutting fluids, comparing it with the fluids usually used. Also, to avoid toxicity problems, vegetable based compounds are used at different levels, that is, the emulsifier is replaced with a vegetable oil, where vegetable based cutting fluids are for sustainable machining [13].

Some oil species (Soybean, Sunflower, Castor bean, Cotton, Rapeseed and Palm), for example, are already technological; They have a history of research in the areas of production of oils for the metalworking and agroenergy industries.

Already the emulsified Jatropha and Tung are species that still require further studies, and for this reason this study on their action as a potential plant-based lubricant was verified along their application to the metal-mechanical sector [14].

Of the various types of cutting fluids we can classify that most are cutting oils or water miscible fluids. Flank wear is present in every machining operation and reaches the tool clearance surface, and is caused by abrasion usually due to high hardness or fouling of the materials, or when the cutting temperature reaches high values, which lead the tool material to lose hardness [15]. Like this the emulsification does not change process parameters and flank wear during machining [16].

2. Materials and methods

To perform the test through the *Reichert Test*, it was used the application of different fluids: Jatropha and Tung emulsified vegetable fluids. *Jatropha Curcas L.* and *Tung* oil were chosen to be compared, because in a preliminary study carried out earlier, it was observed the good lubricity potential that both vegetable oils played with the best role of lubricant, even being in the state, without any form of additive in its composition. The tests were performed with constant time, load, speed and amount of lubricant for all fluids according to ASTM G 99–95a (Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus)[17], where the pins wear are similar to the one shown in figure 1.

To evaluate the lubricity of the fluids by the tribologycal test, the ellipse area left by the pin surface wear was measured. In this way, we also observed the lubrication properties between the fluids, the loss of mass, image evaluation of the worn pin surface and its appearance without the presence of material residue on the pin surface after the completion of the test. Figure 2 shows the *Reichert Test* tribometer with adaptations for temperature acquisition and space for specimen, ring and counterweight adaptation.

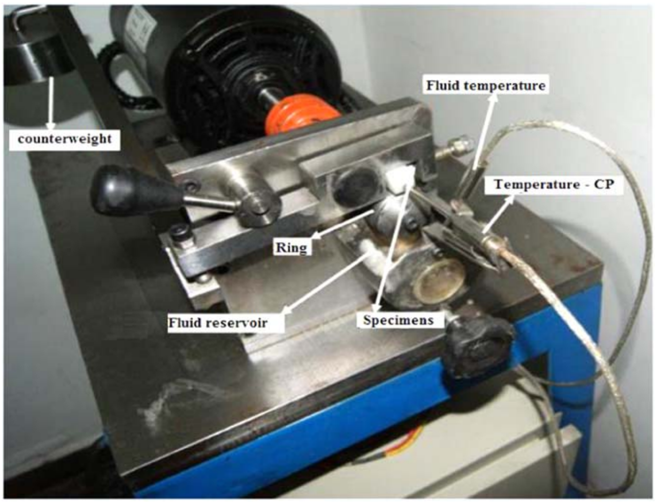

Figure 2. Tribometer with thermocouple adaptations for fluid specimen temperature acquisition.

Table 1. Cutting parameters used in the gray cast iron CGI studied.

Parameter	Tung	Jatropha
Cutting speed (Vc) m min^{-1}	70	70
Advance (fz) mm $tooth^{-1}$	0.05	0.05
Cutting depth (ap) mm	0.5	0.5
Rotation (n) rpm	1400	1400

Table 2. Physical and chemical properties of vegetable bases used in machining tests.

Physical and chemical properties	Characteristics datas	
Vegetable base	*Jatropha*	*Tung*
Solubility	Soluble in ether and fats	Soluble in ether
Solubility in water	Soluble in water	Soluble in water
Density (20/40 °C):g/cm^3	0.8903	0.920–0.938
Refractive index (25 °C–40 °C)	1.468	1.516–1.526
Flash point	240 °C	>275 °C

The cutting fluids used in the experiments for machining CGI gray cast iron were selected from two different emulsificable vegetable bases: Jatropha oil and Tung oil. After the pre-tests, three edge repetitions were determined for each fluid, in order to obtain the best performances for Jatropha oil and Tung, and increase the reliability of the test results. Image analysis and monitoring of flank wear generated by machining CGI cast iron were used with a Dino-Lite Pro model AM-313T portable digital microscope with magnification up to 200 × with the aid of Dino Capture 2.0 measuring software. For machining were on factors as shown in table 1.

However for the analysis of the tool wear mechanisms, a Zeiss Scanning Electron Microscope (SEM), model EVO-MA15 and Energy Dispersive x-ray (EDX) analysis were used to determine the chemical compositions.

Below in the table 2, we present the important properties of both worked fluids in terms of their physicochemical characteristics.

The cutting fluids used should facilitate the machining processes involved to ensure compatibility with GGI gray cast iron, particularly from a tribological point of view [18].

Table 3. Mass loss averages (g) of the pins A_1 and A_2.

Number of repetitions	Jatropha-A1	Jatropha-A2	Tung-A1	Tung-A2
1	0.03	0.04	0.03	0.05
2	0.04	0.02	0.03	0.02
3	0.04	0.04	0.02	0.03
4	0.03	0.04	0.03	0.02
Total	0.14	0.14	0.12	0.12

Table 4. Sample temperature (°C) averages for pins A_1 and A_2.

Number of repetitions	Jatropha-A1	Jatropha-A2	Tung-A1	Tung-A2
1	27.36	35.08	24.22	33.83
2	28.37	30.46	24.76	33.66
3	29.93	30.77	25.17	34.27
4	29.20	31.08	25.50	34.84

3. Results and discussions

The main direction of the tests led to wear tests through the *Reichert Test*, where emulsified vegetable-based oils were used to evaluate the behavior, and the rate of wear was the main criterion of comparison between the fluids in question [19].

Friction and wear are events that occur unexpectedly in engineering projects and waste is a contaminant that becomes an environmental problem. Thus, the addition of nanoparticle additives in vegetable oils becomes an important alternative to minimize these risks [20].

The results of the acquisition of mass losses, ellipses areas, specimen temperatures and fluid temperatures for the Jatropha emulsion, and Tung, where in the tables 3 and 4 show respectively the average values of mass losses and specimen temperatures and fluid temperatures for the repetitions of emulsion tested in pins A_1 and A_2 for Jatropha and Tung emulsions.

It is possible to observe the alternations between the values with each repetition performed with the Tung and Jatropha emulsions in the mass losses. However despite the variations, there is a certain balance in the results between the fluids, and there is a slight tendency to reduce mass losses from the third repetition, for Tung oil emulsion for pin A_2 particularly, and the total mass loss for Tung emulsion was less than 0.02 grams.

Based on table 4 we can see a linear growth trend for the temperatures for both fluids and in the pin A_1 and A_2, however, with slightly higher values for the Jatropha emulsion for pin A1, which leads us to suggest that the Tung emulsion presented better performance in terms of cooling capacity compared to Jatropha emulsion, 2.1% more efficient for pin A_1 only.

For Tung emulsion, although reaching values higher than those of Jatropha for pin A_1, it is possible to verify equilibrium during repetitions in a linear way, perhaps leading to an equilibrium tendency in the machining temperature variation.

In the evaluation of the lost masses, for the Tung and Jatropha emulsions, both fluids obtained an average of 0.03 g of lost mass, therefore, the emulsified fluids presented the same behavior.

In the evaluation of the specimen temperature (pin A_1), Tung obtained an average of 24.91 °C, while Jatropha obtained an average of 28.72 °C, therefore a higher result of 3.81 °C for Jatropha emulsion compared to Tung emulsion. In the fluid temperature evaluation (pin A_2), with emulsified fluids, the Tung obtained an average of 34.15 °C, while for Jatropha the average was 31.85 °C; therefore a higher result of 2.30 °C for the Tung emulsion compared to the Jatropha emulsion. This shows that when the cutting temperature reaches higher average values, the tool material has been shown to lose hardness nad wear more.

3.1. Tribological wear mechanisms

The wear mechanism only outlines the way wear occurs and the way the wear rate varies over time. The dynamics in which the wear particles move determine the surface fatigue or friction [21].

Usually in machining, grinding and other operations, the materials used are abrasives, and the heat and temperature reached are paramount to tool life [22].

Therefore, we present the results of the scanning electron microscopy (SEM) of the worn surface, both pin and ring, for all contact conditions studied, where was used the Tung oil and emulsified Jatropha.

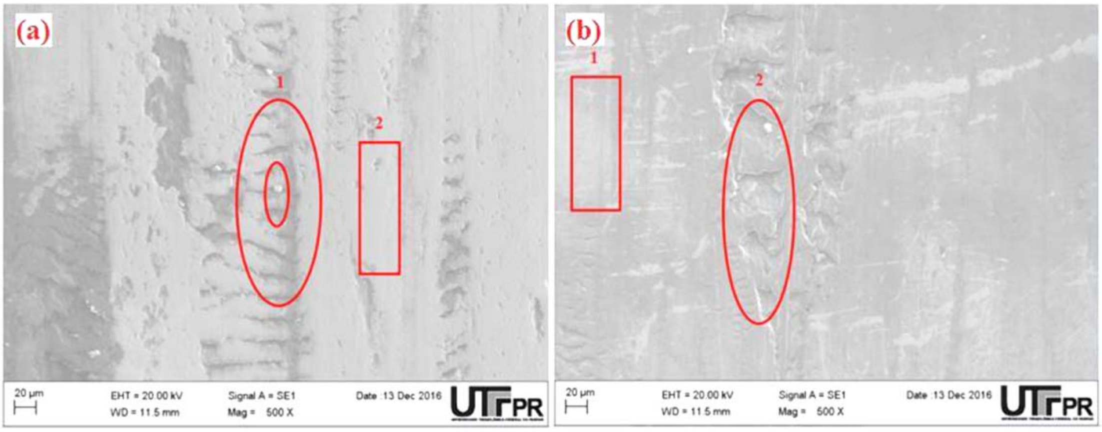

Figure 3. Images of the wear region in the emulsified Tung oil tests, (a) pin A_1 surface, (b) A_2 pin surface with wear details.

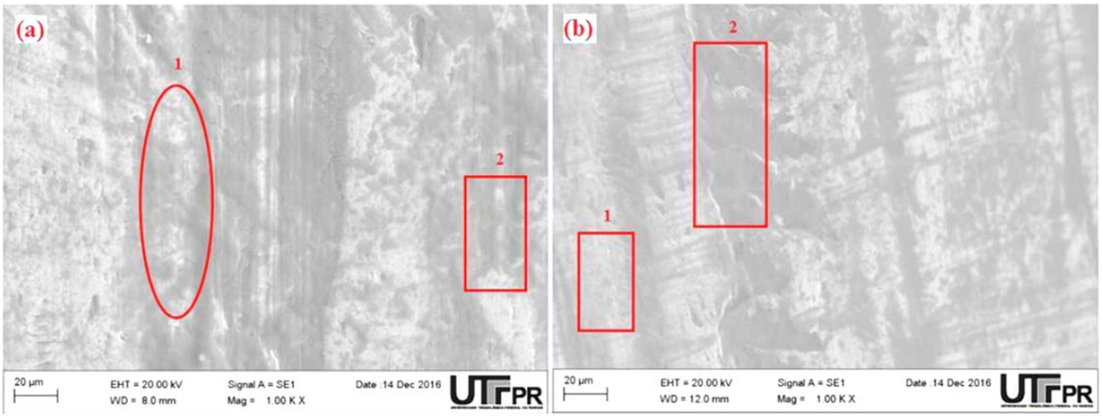

Figure 4. Images of the wear region in the emulsified Jatropha oil tests, (a) pin A_1 surface, (b) A_2 pin surface with wear details.

In detail 1 of figure 2(a) where we have the image of the pin A_1 and A_2 tested with emulsified Tung oil, a large reduction in surface deformation is noted; the frayed region is reduced and thus it can be stated that the friction occurred moderately, indicating the good performance of the fluid, with the surface behaving more homogeneously.

In detail 2 of figure 3(a) presents a surface with reduced deformation, with evidence of surface covered with a film supposedly of origin of the fluid itself, forming an oxidized surface, followed by a decrease of wear, moving to a stabilization regime where we have the presence of a smooth surface.

In details 1 and 2 of figure 3(b), there is an alternation between smooth surface and rough surface, but with evidence of tribochemical or corrosive wear caused by friction between two solid surfaces that react with a corrosive environment, albeit in reduced volume. It is also noticed the occurrence of wear particles incorporated into the surface (detail 2). By analyzing the images, it can be said that the lubrication and cooling actions of Tung emulsion presented satisfactory behavior.

In figure 4(a) in the details 1 and 2 has the micrograpy of the abraded surface with the presence of cleaned areas with few bumps, showing the sharp reduction of friction, this can be confirmed by the image in detail 1 in the same figure, the surface is smooth, with few deformation regions or fragments on the worn face.

In its turn in the details 2 of figure 4(a) is also possible to verify a very significant reduction in the volume of material on the surface, that may be associated with the cooling and lubrication behavior, showing good fluid performance.

In turn in figure 4(b) in details 1 and 2 it is possible to observe a very clean surface, smooth finish, without evidence of rough regions or deformation caused by friction, with points that show slight deformation and surface wear. This surface was caused by the abrasive wear mechanism by microscreening and formation of edges provoked by particles from the wear action, concluding that the emulsion of Jatropha showed satisfactory performance in lubrication and cooling in the friction region.

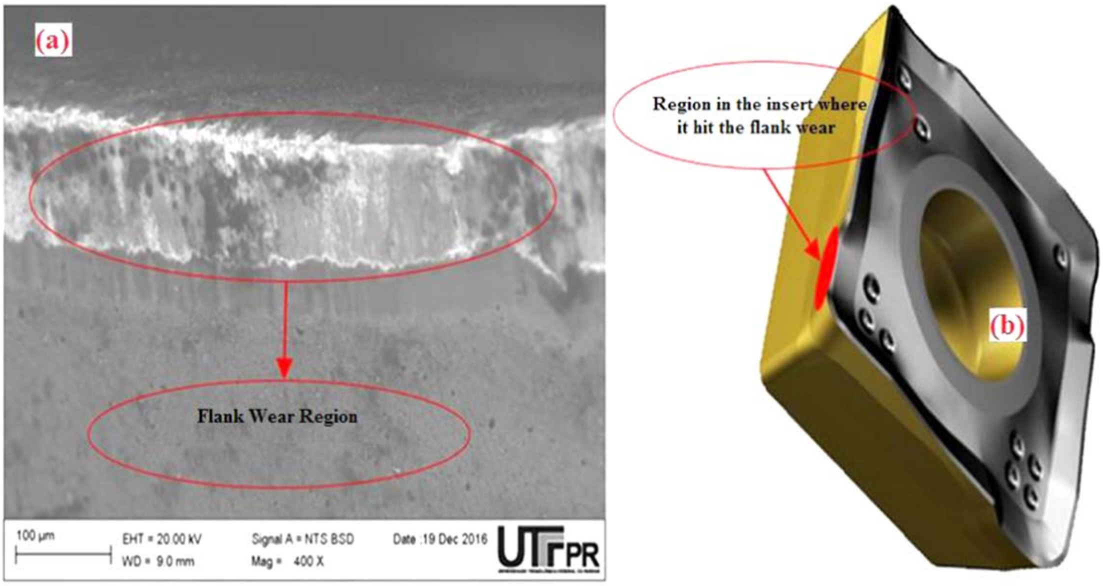

Figure 5. (a) Flank wear tool used in the tests, (b) new tool where the wear has affected.

Table 5. Flank wear average values (mm)—Edge 1.

Interval 1	Interval 2	Interval 3
0.176	0.190	0.221
0.181	0.195	0.226
0187	0.198	0.237
Average = 0.181	Average = 0.194	Average = 0.228

3.2. Tool wear

This is the ability of the coating to protect against abrasion. Although a material may not be hard, elements and processes added during production may aid in the breakdown of cutting edges or forming lobes. A high coefficient of friction causes increased heat, leading to a shorter coating life or coating failure, but on the other hand a lower coefficient of friction can greatly increase tool life.

Figure 5 shows the tool used in the experimental tests for Tung and Jatropha vegetable-based cutting fluids.

The amount of heat generated when machining can be reduced by a surface that has no thickness or irregularities, and this smooth surface allows chips to slide more easily from the face of the tool, generating less heat.

In the tribological study we must define:

- Wear: Localized volume loss of a surface, leading to a decrease in local size.
- Wear mechanism: The mechanism by which the volume loss occurs.

We define (VB_{Bmax}) as the progression of maximum flank wear with machining time in minutes and at different cutting speeds, and that flank wear increases with increasing cutting speed, which is usually the most significant factor affecting tool life during machining [23].

Higher surface lubrication can also allow higher roughing speeds compared to uncoated versions, which should further prevent wear on the work material.

Tables 5–7 show the dimensional values of wear, machined length and the average of the flank wear values for each measuring range for edges 1, 2 and 3.

In addition, the figure 6 show the average flank wear was compared between Tung and Jatropha emulsions as a function of machined length (length of cut) using the same parameters. In this condition, it was noted that the two fluids upon reaching the third edge wear measurement range, with a maximum machined length of 2.16 m for edge 1, achieved their maximum edge wear. For this reason, it can be said that there was an equivalence between the two fluids. After the third measurement interval, a wear was noted for the 0.223 mm Tung and 0.288 mm Jatropha emulsion.

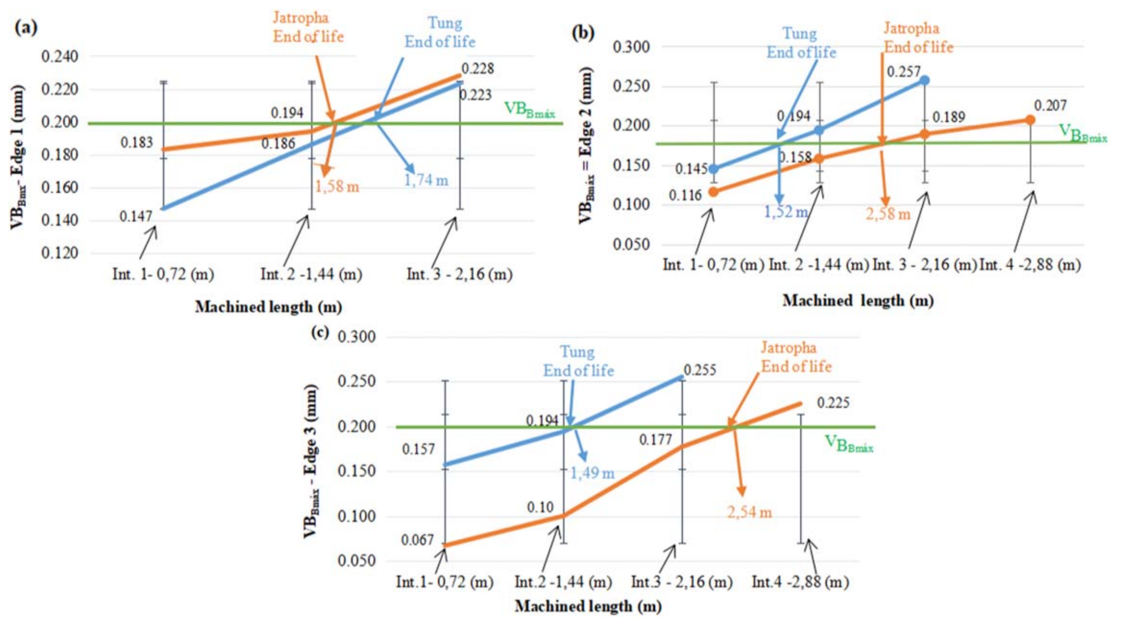

Figure 6. Evolution of tool flank to the three wear edges (a)1, (b)2 and (c)3.

Table 6. Flank wear average values (mm)—Edge 2.

Interval 1	Interval 2	Interval 3	Interval 4
0.092	0.145	0.178	0.200
0.126	0.158	0.189	0.207
0.130	0.171	0.200	0.215
0.092	0.145	0.178	0.200
Average = 0.112	Average = 0.158	Average = 0.189	Average = 0.207

Table 7. Flank wear average values (mm)—Edge 3.

Interval 1	Interval 2	Interval 3	Interval 4
0.062	0.093	0.170	0.201
0.068	0.103	0.176	0.228
0.070	0.105	0.186	0.247
0.062	0.093	0.170	0.201
Average=0.066	Average = 0.100	Average = 0.177	Average = 0.225

Tool wear was performed until it reached its maximum limit of VBBmax = 0.2 mm on the tool flank, determining its end of life and the data acquired at each 0.72 m range of machined material. Figure 6(a) shows the average flank wear to the edge of the tool 1 comparing between Tung and Jatropha emulsions as a function of machined length using the same parameters.

However we can verify that for the length of cut with the predefined wear of 0.20 mm, it is noted a small advantage for the Tung emulsion that machined 1.74 m of material against 1.58 m for the emulsion of Jatropha, which corresponds to a efficiency of 10% for the Tung emulsion.

On the other hand, when comparing the final machined length 2.16 m with respect to wear, a slight difference can be seen, which shows that the fluids perform very closely.

Figure 6(b) shows the total machined length and number of repetitions for both fluids that are compared to each other, always using the same cutting parameters. At the end of each interval, the wear dimensions were evaluated until they reached the maximum wear of 0.2 mm, otherwise the measurement intervals would continue until the proposed objectives were reached.

Thus, there is a maximum length of 2.16 m of material machined for the Tung emulsion, and 2.88 m for the Jatropha emulsion on edge 2, thus with efficiency of 33% for Jatropha.

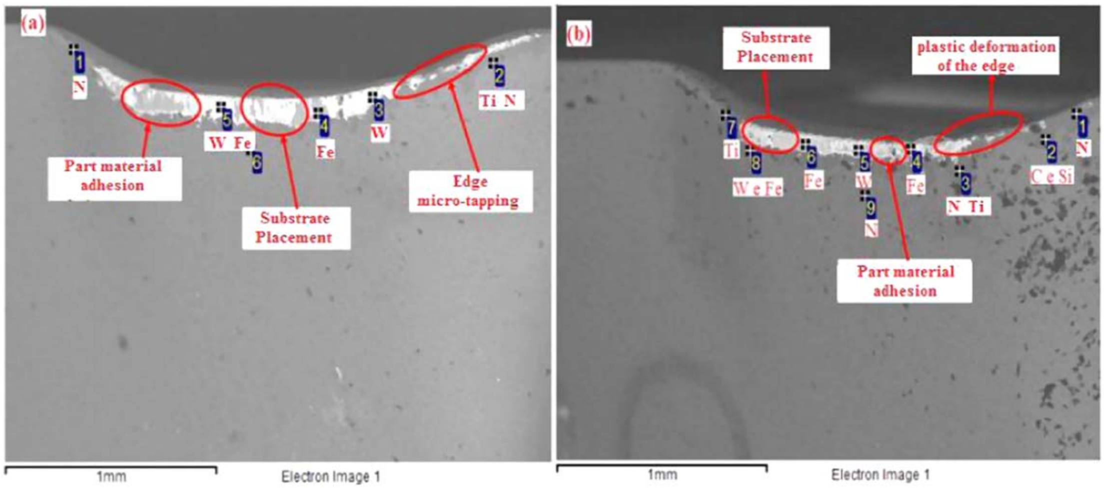

Figure 7. Analysis of EDX composition, flank wear, (a) third edge measurement range 1, (b) fourth edge measurement range 3, coated cutting tool using Jatropha emulsified cutting fluid.

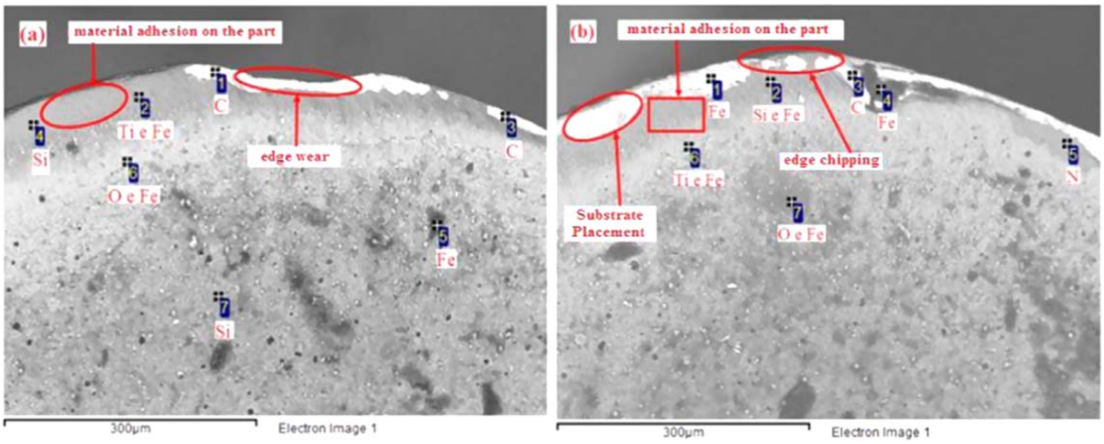

Figure 8. Analysis of EDX composition; output surface, (a) third measuring range edge 1, (b) fourth edge measurement range 3, coated cutting tool using Tung emulsified cutting fluid.

However, when interpolated the graphs, it can be observed that the maximum flank wear of 0.2 mm for the Tung was achieved by machining a length of 1.52 m, while the Jatropha to reach the same values of flank wear, machined a length of 2.58 m. In this sense, it has a much better performance for Jatropha, with 70% efficiency compared to Tung emulsion.

Figure 6(c) shows the total machined length for the two fluid conditions and the number of intervals for both fluids that are compared to each other, always using the same cutting parameters.

Thus, there is a maximum length of 2.16 m for machined material for Tung emulsion, and 2.88 m for Jatropha emulsion for edge 3, totaling a 33% higher efficiency for Jatropha emulsion.

However, it can be seen that the maximum flank wear of 0.2 mm for Tung emulsion was achieved by machining a length of 1.49 m, while the Jatropha emulsion to reach the flank wear value machined a length of 2.54 m.

Comparing the flank wear at the end of life of the first 0.72 m range of machined material, significant wear differences are noted, where the Tung emulsion had a flank wear of 0.194 mm, while the Jatropha emulsion of the same machined length reached 0.100 mm, with a 94% higher efficiency than Tung emulsion.

As shown in figure 7, both flank wear, substrate placement wear and plastic deformarion of the edge were observed for all the inserts tested under all cutting conditions. The tool wear zone occurred mostly near the tool nose radius on the flank side. For coated inserts, the coating layer from the cutting edge (flank portion) was worn within the first interval of machining [24].

In the EDX analysis, of the specimens, the figure 7(a) identified high tungsten values (points 3 and 5), demonstrating that the substrate is exposed and does not have the aid of the end-of-life cutting cover. It is still possible to identify micro-bearings at the cutting edge that can lead to the propagation of cracks caused by mechanical and/or thermal fatigue, which weakened the substrate coverage.

Figure 7(b) shows the presence of plastic edge deformation and tool flank wear. This plastic deformation of the edge occurs at high temperatures, and the material drains subject to machining forces and is favored by the presence of hard metals such as C, Si and Ti.

Horewer in figure 8(a) it is possible to state that the main wear mechanisms and/or breakdowns identified at the cutting edges were Titanium Nitride (TiN) coating peeling, thermal and abrasive cracking [25].

On the other hand, in figure 8(b) identified significant values of iron, silicon and carbon, elements that make up the specimen, showing the occurrence of adhesions of the machined material on the cutting edge. In the lighter regions, on the tool outlet surface, it is possible to identify strong occurrences of Titanium Nitride (TiN) coating peeling, presenting the substrate exposure, making the surface vulnerable to adhesion of specimen materials [26, 27].

4. Conclusion

For mass losses, Tung and Jatropha emulsions showed the same behavior, with a final average of 0.03 g for both fluids.

However, in relation to the temperatures of the specimens, the average difference for pin 1 was 3.81 °C higher when machining for Tung emulsion, which was reversed in pin 2, where the slightest difference of 2.30 °C for Jatropha emulsion, which represented a better performance.

The main wear mechanism presented by CGI gray cast iron machining, using both Tung and Jatropha emulsions as cutting fluid, was abrasion wear, and the predominant type of wear was flank wear, which negatively affects surface roughness and is the dominant factor in tool life. Adhesion was also noticeable in both the flank and the tool outlet surface, with substrate peeling followed by chipping and breakage of tool cutting edges, observed with higher incidence in machining using emulsified Tung fluid.We observed from the optical micrographs and SEM micrographs of the worn surfaces of the cutting tool that flank, chipping and substrate displacement wear occurred on all inserts and cutting conditions. The tool wear zone occurred mainly near the radius of the tool nose on the flank side, with plastic deformation independent of the cutting speed.

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