INFLUENCE OF VEGETABLE-BASED CUTTING FLUIDS ON MACHINING FORCES AND MICROBIAL CONTAMINATION WHILE TURNING ABNT 1050 STEEL

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Abstract. *The increasing technological advances achieved both in the development of new materials and in the machine tools technology has increased the demand for machining processes and consequently the use of cutting fluids increased. In addition, pressure from Environmental Protection and Health Agencies for all the products to be marketed more safely and without damaging the environment has also influenced the increase in the quality of the cutting fluids. The vegetable based cutting fluids has been increasingly used by the manufacturing industry, because, besides polluting less the environment, they cause less harm to the operator and can provide significant improvements in the tool life, but on the other hand it can be easily contaminated by microorganisms, since they have a wide range of nutrients that facilitate their reproduction. This study evaluated the machining performance of a vegetable-based cutting fluid, comparing it with a mineral-based fluid when turning an ABNT 1050 steel with coated cemented carbide tools. Cutting forces and the growth of fungi and bacteria during several weeks of usage are the basic parameters used for the comparison. The cutting speed (Vc), feed rate (f) and depth of cut (ap) were ranged and the influence of these parameters in the cutting forces had been verified. It was clear that the vegetable-based fluid provided lower cutting forces during the machining. Furthermore, the vegetable-based presented higher growth of microorganisms when used in its lowest concentration (3%), while the mineral based fluid showed the greater microbial growth in its higher concentration (10%). The microorganisms found were, in most cases, causatives agents of respiratory and skin irritation.*

Keywords*: vegetable-bases cutting fluids, microorganisms, turning, cutting forces.*

1. INTRODUCTION

During the machining processes the tools suffer high wear and heat that require constant changes of their cutting edges. Moreover, there is the warming of machined parts, which can cause two effects: changes in desired sizes and generation of internal stresses that may compromise their use. To minimize the wear of the tools and heating parts, several measures can be taken, including the use of a cutting fluid.

The cutting fluids help to cool the cutting region, especially at higher cutting speeds, to lubricate the cutting area, especially at low speeds and high shear stresses, reducing the cutting force, improving tool life, surface finish and the dimensional accuracy of the workpiece; help to break the chip and hence facilitating their transportation and protect the machined surface and the machine tool against oxidation (Trent and Wright, 2000; Machado et al., 2009).

Recently, great technological advances were achieved in both tool materials and in machine tools. This meant that the demand of cutting fluids grew considerably. High demand causes competitiveness which in turn causes an increase of product quality. Another factor that influences the increased quality of modern cutting fluids, is the pressure exerted by the Environmental Protection and Health Agencies, to which the products are marketed more safely and causes less harm to the environment (Machado. al., 2009).

In an internal report at UNICAMP in 2005, Diniz said that in most cases, cutting fluid causes undesirable effects: can cause allergies or other health problems to the machine operator by skin contact or by inhalation of its vapors; deteriorates because acquires fungi and bacteria, which requires regular treatment and still from time to time needs to be recycled, since it cannot be discarded anywhere. Large companies have recycling system; others need to deliver the cutting fluid for disposal for businesses certified by CETESB - Companhia de Tecnologia de Saneamento Ambiental, linked to Department of Environment of the State of Sao Paulo, which raises costs. "Therefore, the use of cutting fluid causes side effects in health, in the ecological and economic area." he completed. As a result, two research lines show up quite strongly: first, the development of new cutting fluids, environmentally friendly, which do not harm the health of the operator, which last longer in the machine and do not need to be changed so frequently; and second, the development of processes that do not require cutting fluids or that utilize a lesser amount (Sales et al., 2001).

It is known that nature can provide a much wider range for raw materials for the manufacture of lubricants that the petrochemical industry. This variety of raw materials, coupled with the new methods and modern refining processes, make it possible to eliminate the problems of old technology for vegetable oils, such as resinification, the viscosity increased and the development of acidity. The whole vegetable oils have several advantages, among them (Woods, 2005):

- *They are more compatible to human skin than mineral oils, and also have a reduced tendency to form steam, fog and smoke, besides having a higher flash point, reducing the risk for fire in the machinery.*
- *They have polar molecules that act such as magnets and align themselves to the metal surface, forming a lubricant film able to support large surface tension, improving the machining tool life. The molecules of mineral oils are not polar, and therefore its capacity is lower than that of vegetable oils. This is also an advantage when higher productivity is desired.*
- *As mineral oils, vegetable oils cannot be burned, although polluting less the environment. However, the main environmental advantage of vegetable oils instead of mineral base oils is that their raw material is biodegradable, causing much less pollution to the environment. They can also be reusable, like the mineral-based (Kuroda, 2006).*

By having a wide range of nutrients, the cutting fluid is easily contaminated by microorganisms that use these compounds as raw material in their physiological activities. As metabolic wastes are released in the environment the fluid becomes more active, promoting corrosion of parts in contact with the contaminated fluid. Therefore, the fluid undergoes a drastic reduction of its life, since this degradation occurs rapidly. Along with this fluid loss and possible damage to the parts in contact with it, microorganisms are also associated with the development of allergic reactions in workers exposed to aerosolized fluid (Thomé et al., 2007).

The fungal growth of *Penicillium* sp. in some samples was found by Thomé et.al. (2007), which did not verify the presence of bacteria called mycobacteria, but Gram negative bacteria, which can be explained by the fact that different specimens for bacteria compete for the same substrate, inhibiting somehow, the development of other specimens. As the fungal and bacterial population grows, the fluid loses its capacity to perform the functions of lubrication and cooling, in addition to being appointed as responsible for the rise of health problems for operators, such as pulmonary hypersensitivity, which is caused by mycobacteria and their endotoxins.

This study compared the performance of a vegetable-based cutting fluid with a mineral base one used in the form of stream or flood application, considering the machining forces and their relation to growth of fungi and bacteria during the turning of SAE 1050 steel, with coated carbide tools.

2. METHODOLOGY

The machining tests were made on a CNC lathe Multiplic 35D, manufactured by Industrias Romi SA, 11kW of power, maximum speed of 3000 rpm, using tools from T9035 series manufactured by OSG Tungaloy Sulamericana Ltda. The inserts had the following code ISO: DM SNMG120408 and support PSBNR 2525 M12. The material used for the experiments was a commercial available SAE 1050 steel, grade with a diameter of 55 mm and a length of 450 mm. Average of measured hardness of this steel is 255 HV.

The cutting fluids, manufactured by Castrol Industrial, were:

- CARECUT S100: soluble ester-based cutting fluid (vegetable), mineral oil free, bioestable with anti-corrosion and anti-foaming properties, free of boron, nitrite and phenols, suitable for grinding and conventional machining of carbon steels, alloy steels and stainless steel. This fluid has a density of 1.071 g/mL, pH approximately 9.1 at a concentration of 5%, and is not flammable because it is a water based product.

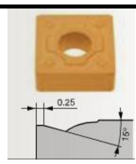
- CLEAREDGE 6515 BF: semi-synthetic machining fluid, mineral based, boron and chlorine-free, suitable for general machining of cast irons, carbon steels, alloy and stainless steels. The Clearedge 6515 BF has density of 1.060 g/cm3, pH 9.5 at concentrations of 3 and 5%, and, being a water based product, has no flash point (not flammable).

In order to avoid contamination in the cutting fluids, the reservoir and the cooling system was washed before placing the new cutting fluid.

Cutting conditions employed in this investigation are shown in Tab. 1. The components of machining forces were measured with a dynamometer (or Piezoelectric Platform) manufactured by Kistler Instrument, model 9265-B, with amplifier and signals conditioner, also manufactured by Kistler Instrument, Model 5019A, a signal acquisition card from National Instrument, model: NI PCI-6036E and software from National Instrument, Labview 7.6. Each test (combination of parameters) was replicated three times in random order.

Table 1. Summary of cutting conditions employed in this work

Workpiece material	SAE 1050 steel grade (Gerdau Aços Villares)
Dimensions	Ø55 mm x 450 mm
Cutting tool	Cemented coated carbide inserts ISO SNMG120408 DM T9035 (with chipbreaker)
Coating	CVD coating mainly composed of α-alumina and TiCN crystals; and an external layer of TiN
Tool holder	PSBNR 2525 M12
Cutting parameters	
Cutting speed, v_c (m/min)	From 10 to 350, ranging from 10 to 10 m/min
Feed rate, f (mm/rev)	From 0.05 to 4.00, varying each 0.05 mm/rev
Depth of cut (mm)	From 0.5 to 4.0, varying each 0.5 mm
Cutting fluid types	Carecut S100 (vegetable oil) Clearedge 6515 BF (mineral oil)
Flow rate (l/h)	257
Cutting fluid concentration	3% , 7% and 10%



Schematic of cutting tool

Approximately thirty 10 mL samples were collected of the two cutting fluids, directly from the machine reservoir , at a depth of 10 cm and at room temperature (about 25 ° C) on alternate days, always after using the machine for the force tests. Then the samples were placed in sterile tubes and subsequently appropriately transported to the Laboratory of Microbiology of the Federal University of Uberlandia, where the microbiological studies were carried out. The samples were inoculated in four different culture media: Mannitol Salt Agar (for the growth of Gram-positive bacteria), MacConkey agar (for growth of gram negative bacteria), Triptycase Soy Agar (for quantification of microorganisms) and potato agar dextrose (for fungal growth).

3. RESULTS AND DISCUSSIONS

3.1. Analysis of Cutting Forces (F_c)

In general, the forces were smaller when the fluid Carecut S100 (vegetable based) was used. However, the difference between the forces obtained when using the fluid Carecut S100 and the fluid Clearedge 6515 BF was very small. In Fig.1 it can be seen one of the tests being conducted, with the cutting fluid Carecut S100 at a concentration of 3%, and the piezoelectric platform.

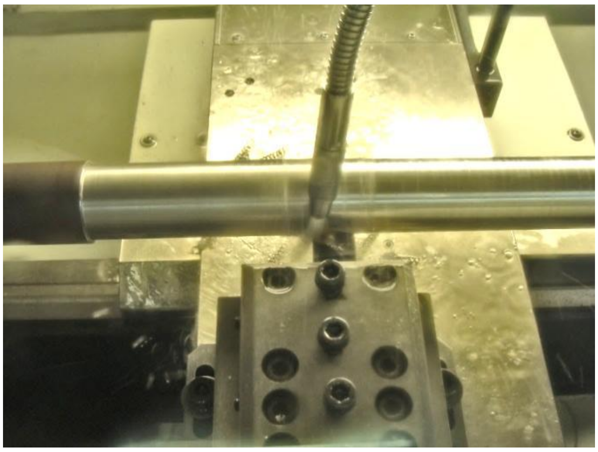


Figure 1. Application of cutting fluid during an experiment

In Figure (2) it is shown a graph with the cutting forces (F_c) obtained during the use of two cutting fluids in three concentrations, and varying the cutting speed (v_c). It can be observed the characteristic behavior of the curves of forces in machining steels (Machado et al. 2009; Trent and Wright, 2000), presenting the V-profile at low speeds (between 10 and 60 m/min), suggesting the presence of the built-up edge (BUE) in all conditions of application of the cutting fluids. In this speed range, the BUE grows to a maximum size, and then decreases until it disappears completely. The cutting force follows this size change of the BUE, decreasing with its growth, reaching a minimum point (where the maximum size of the BUE is – for these curves at speeds between 20 and 30 m/min) and then growing with decreasing of the BUE up to the point where it disappears completely. Presence of some oscillations in this region may be related to the lack of definition of the value of cutting speed at which this BUE completely disappears, and the cutting fluid may play a role in this definition. Comparing all the conditions, the cutting forces were higher when the Clearedge BF 6515 fluid was used at a concentration of 10% and were lower when using the fluid Carecut S100, also at a concentration of 10% and Clearedge BF 6515 to 7%. This ranking obtained by the fluid, unless other influences, could be explained by the cutting fluid ability of penetrating and lubricating the tool-chip interface. The cutting fluid, to be effective in its lubricating action, has to be present at the interface (just in the sliding zone, since at the seizure zone there is no chance for fluid penetration) and has to be able to interact with the workpiece material to form an effective lubricating film (Machado et al. 2009 and Sales et al., 2001).

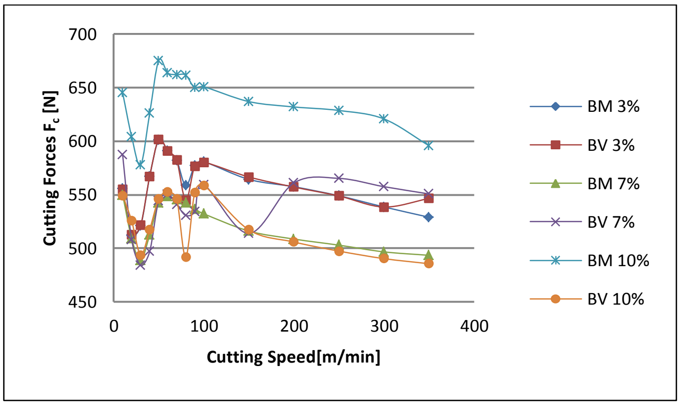


Figure 2. Cutting force (F_c) variation with the cutting speed, for a feed rate of 0.2 mm/rev and depth of cut of 1 mm – BM (Mineral Based Fluid) – Clearedge; BV (Vegetable Based Fluid) – Carecut.

As it is shown in the Figure (3), the behavior of the cutting forces (F_c) with the variation of the feed rate (*f*) is increasing and approximately linear, except for the fluid Clearedge 6515 BF 10%, where the forces were higher than the others. For the other studied fluids the values of the forces were very close to each other, and Table (2) confirms those values. Under these cutting conditions, therefore, it is not possible to identify the best fluid and better concentration, suggesting that all these fluids (except Clearedge 6515 BF 10%) had similar lubrication and cooling powers.

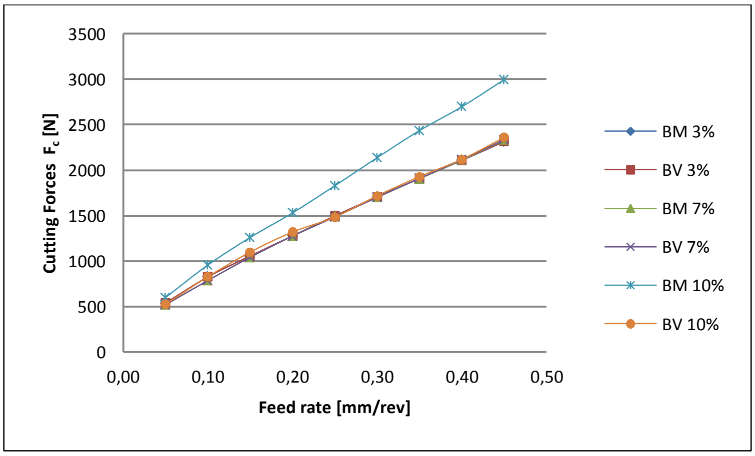


Figure 3: Variation of cutting forces (F_c) with the feed rate, for the cutting speed of 150 m/min and depth of cut of 1 mm

Table 2: Values of cutting forces (F_c) for the various feed rate and lubri-cooling condition tested

F_c [N] / f [mm/rev]	CLEAREDGE 6515 BF 3%	CARECUT S100 3%	CLEAREDGE 6515 BF 7%	CARECUT S100 7%	CLEAREDGE 6515 BF 10%	CARECUT S100 10%
0,05	533	540	519	519	600	526
0,10	827	827	787	787	957	828
0,15	1056	1056	1043	1043	1261	1099
0,20	1278	1277	1276	1275	1531	1320
0,25	1498	1497	1488	1486	1830	1485
0,30	1708	1708	1702	1703	2138	1719
0,35	1908	1909	1907	1910	2437	1930
0,40	2107	2111	2113	2118	2698	2120
0,45	2315	2317	2332	2337	2997	2361

The cutting forces (F_c) were also measured by varying the depth of cut, and the results can be seen in Figure (4).

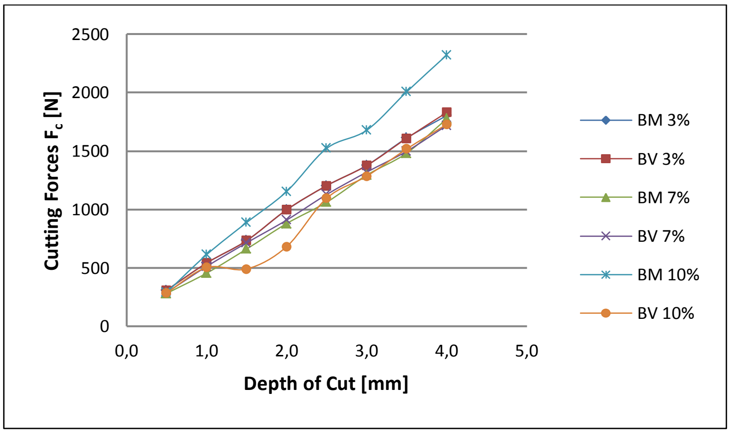


Figure 4: Variation of cutting forces (F_c) with the depth of cut, for the cutting speed of 150 m/min and feed rate of 0.2 mm/rev

Again, it is possible to verify that the use of Clearedge 6515 BF fluid at a concentration of 10% produced the highest cutting forces. The remaining fluids had very similar behaviors. In the region of depth of cut between 1 and 3 mm, the Carecut S100 fluid at a concentration of 10% showed slightly smaller forces.

3.2. Microbiological Analysis

The microbiological evaluation developed from the Carecut S100 Fluid collected from the reservoir showed that around 60% of samples had microbial growth, especially *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Bacillus* sp, coagulase-negative *Staphylococcus* and filamentous fungus, which is a causative agent of dermatitis. The growth was higher in the fluid with a lower concentration (3%), while the concentration of 10% had no growth.

In the Clearedge 6515 BF fluid a microbial growth in 53.3% of the samples collected was verified, and it was found the microorganisms: *Bacillus* sp, *Bacillus* sp anaerobic, *Staphylococcus aureus* and coagulase-negative *Staphylococcus*. At the concentration of 7%, 60% of the samples showed some growth, and at concentration of 10% this percentage was 83.3% growth. At 3% concentration no growth was observed.

It was observed that, in general, the vegetable-based fluids are more prone to microbial growth and the concentration in water has a strong influence. In the vegetable-based fluid the highest concentration decreased the microbial growth, while the growth in mineral-based fluids in the lowest concentration reduced this microbial growth.

The presence of organic compounds and minerals in the formulation of the fluid are a source of nutrients for these microorganisms to develop themselves. The temperature and pH of the fluid systems are also fundamental aspects to be considered for the development of microorganisms, because room temperatures and/or higher ones (if the machine is turned on for a long time) and pH around 9 encourage microbial growth (Passman , 1988).

In this study in the reservoir of the machine were found microorganisms such as *Bacillus* sp., *Staphylococcus aureus*, *Pseudomonas aeruginosa* and filamentous fungi, which are already described in literature as common organisms present in cutting fluids and they should be avoided because of the quantity of problems that may be caused by the lack of control and care. It is believed that the main source for the existence of these microorganisms is the air, which is in constant contact with the fluid. And, as these machines are located at a site that usually contains many machining materials, many people working and many experiments being performed, there is a high probability of having microorganisms in the air such as *Staphylococcus aureus*.

4. CONCLUSIONS

- ✓ In general, the condition of lubrication and cooling which provided the lowest forces was the use of Carecut S100 fluid at a concentration of 10%, and with the Clearedge BF 6515 fluid at a concentration of 10% the highest cutting forces was observed.
- ✓ In the detection of microorganisms in the fluid allocated in the machine reservoir the following microorganisms were found: *Bacillus* sp., *Staphylococcus aureus*, *Pseudomonas aeruginosa* and filamentous fungi, and in general, vegetable-based fluids showed higher growth of these microorganisms, and curiously, a higher growth of microorganisms was observed in the fluid Clearedge BF 6515, at a concentration of 10%.

5. ACKNOWLEDGEMENTS

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