Vegetable based cutting fluid – an environmental alternative to grinding process

Salete Martins Alves[1], João Fernando Gomes de Oliveira[2]

[1] Educational Society of Santa Catarina, Brazil e [2]Nucleus of Advanced Manufacturing, Dept. of Production Engineering, University of São Paulo, Brazil

Abstract

The development of lubricants like, cutting fluids was traditionally based on mineral oil as a base Fluid. This fact is related to the good technical properties and the reasonable price of mineral oils. The Report to the Club of Rome (1972) and the two oil crises of 1979 and 1983, however, elucidated that mineral oil is on principle a limited resource. Also mineral oil is its poor biodegradability and thus it's potential for long-term pollution of the environment and workers health. The growing demand for biodegradable materials has opened an avenue for using vegetable oils as an alternative to petroleum-based polymeric materials. Thus, this work presents a new water based grinding fluid formulation able to meet both the performance and environmental requirements for CBN grinding. The new fluid concept consisting of a high concentration (up to 40%) of sulfonate vegetable oil in water is proposed and tested. In this way it was possible to combine high lubricity, better heat conductivity and good environmental properties in one fluid. The results from practical tests using the new fluid show good performance on vitrified CBN grinding, which are comparable to the obtained with mineral oil.

Keywords: vegetable oil, cutting fluid, grinding process.

1 INTRODUCTION

Cutting fluids are used to reduce the negative effects of the heat and friction on both tool and workpiece. The cutting fluids produce three positive effects in the process: heat removal elimination, lubrication on the chip–tool interface and chip removal [1].

However, the advantages caused by the cutting fluids have been questioned lately, due to the several negative effects they have caused in the environment and worker health. When inappropriately discharged, cutting fluids may damage soil and water resources, causing serious environmental impacts. On the shop floor, the machine operators may be affected by the negative effects of cutting fluids, such as skin and respiratory problems. In order to make machining process more ecological, the Minimal Quantity Lubrication has been accepted as a successful near-dry applications because of its environmentally friendly characteristics [2][3][4]. But, depending of machining process, to reduce or to eliminate the cutting fluids use is not possible. For these cases is necessary to developed alternative solution in order to avoid environment and heath damages.

The use of vegetable oils may allow this mixture, to make possible the development of a new generation of cutting fluid where high performance in machining combined with good environment compatibility could be achieved. Interest in vegetable oil-based cutting fluids is growing. Compared to mineral oil, vegetable oil can even enhance the cutting performance, extend tool life and improve the surface finishing according to some recent analysis from industry [5]. Although, they have many environmental benefits, vegetable oils are more susceptible to degradation by oxidation or hydrolytic reactions. Therefore, the correct selection of the vegetable substance, the pH of the resulting solution and its control are important issues.

This work proposes a development of a vegetable based emulsion that can be used in grinding process to replace the commonly used mineral oil based emulsion. This product was tested in grinding process in order to verify the performance and environmental requirements for CBN grinding.

2 IMPORTANT CONSIDERATIONS AND DEVELOPMENT OF THE VEGETABLE BASED CUTTING FLUID

A sustainable environmental development is achieved considering some important factors like biodegradability and toxicity of lubricants. On the other hand, the lubricants should be stable during usage under different operating conditions [6].

Cutting fluids are consisting of base fluids and additives. Mineral oil, rapeseed oil and synthetic or native esters can be used as base fluids. If biodegradability should be considered, esters and vegetable oils are more indicate to formulate cutting fluids, because they are readily biodegradable in contrast to mineral oil. Also, the additive concentrations usually are below 10% w/w, this concentration is tolerated for eco-label "blue angel" [6].

In the use vegetable oil have some problems due to inadequate oxidative stability and problems associated with use in high or low temperature observed in this oil. The problem of poor oxidative stability can be mitigated by the structural modification of vegetable oil by chemical reactions. Sulphur and ozone modifications were used in theses reactions [7]

Some of the substances included in the fluids composition can lead to problems to the working environment and in their disposal [8]. Cutting fluids can also affect the operator's health due to the formation of mists and smoke. These aerosols may cause dermatological and respiratory irritations [9]. Then these substances, additives, should be chosen carefully. According to Bartz [10] there are groups of problematic substances that were included in cutting fluids formulas in the past, such as: nitrosamines, formaldehyde-condensate materials, organic chlorine-containing substances, organic phosphorous-containing substances, polycyclic aromatic hydrocarbons (PAH), such as benzopyrene - PAH and others. These substances should be avoided in the formulation of an environmentally adequate grinding fluid.

The use of vegetable oil in cutting fluid applications may alleviate problems faced by workers, such as skin cancer and inhalation of toxic mist in the work environments. This will also help to add value to a farm commodity, such as soy oil and other similar vegetable based oil [7].

The most important characteristic of vegetable oil is its biodegradability. According to Willing [11] biodegradability is the most important aspect with regard to the environmental fate of a substance. Biodegradability means that a substance is susceptible to biochemical breakdown by the action of microorganism (Fig. 1).

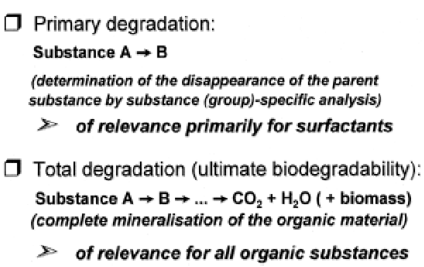

Figure 1: Biodegradation steps [11]

In the first breakdown step (primary degradation) the original molecule disappears. But considerable more important is the determination of the ultimate degradability of substances in CO_2 and H_2O. At the same time occurs biomass formation. Ultimate biodegradability guarantees the safe reintegration of the organic material in the natural carbon cycle. The evaluation if a substance is readily biodegradable or not is very important for its environmental classification, and the determination of its water hazard class [11].

The sustainability of the use of cutting fluids and other lubricants can be divided in two aspects. The first aspect regards the origin of the resources: fossil or renewable raw materials, such as, mineral oil and vegetable oil, respectively. The second aspect regards the environment pollution associated to use and discharge these products. The carbon cycle of mineral oil based products is not closed, but open. They lead to an increase of atmospheric carbon dioxide and thus contribute to global warming. In contrary to mineral oil based the carbon cycle of products of renewable resources is closed. The amount of carbon dioxide liberated during disintegration of organic chemicals equals the amount of carbon dioxide that was originally take up by the plants from the atmosphere (Fig. 2).

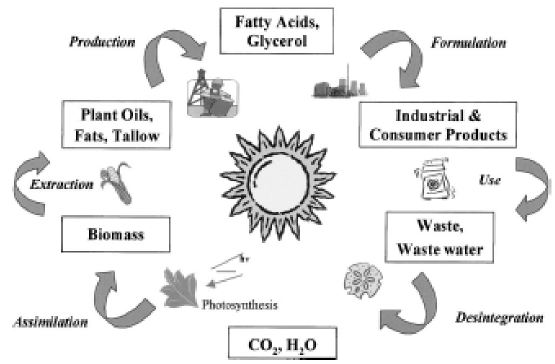

Figure 2: Life cycle of chemical products based on renewable resources [11].

Then it is very important to evaluate the replaced of mineral oil to vegetable and ester in order to became the lubrication process sustainable.

3 MATERIALS AND METHODS

3.1 Cutting fluid formulation and characterization

The general composition of water miscible cutting fluids can be characterized as an addition of base oil and emulsifier. Other components may be added to the fluid. such as: solution improvers, neutralization agents, corrosion and rust inhibitors, lubricating additives, biocides and fungicides, agents to improve stability in hard waters and foam inhibitors.

For the preparation of the proposed fluid, some steps were followed:

- **selection of components:** It is necessary to consider if the chosen components are not problematic, dangerous for the environment or health.
- **mixing:** Firstly add oil in water and mix for 2 min. After all substances are added, they are mixed together for 15 min. A test emulsion is prepared in order to verify, the mixture stability. It must repose for 24 hours without oil/water separation. In case the emulsion is not stable, the amount of emulsifier agent needs to be adjusted.
- **verifications:** Check some chemical and physical properties of the coolant, such as: PH, viscosity, corrosion and biodegradability and adjust the formulation.

The quality of new cutting fluid was evaluated by following analysis:

• *pH*

The cutting fluids pH was determinate by digital PHmeter. Always before the measurement, the PHmeter was calibrated with standard solutions. The cutting fluid pH should be between 9 and 11.

• *Viscosity*

A ball viscosimeter was used to determinate the viscosity of the cutting fluid. This method is very traditional and simple. The equipment consists of a tube with two marks, where the cutting fluid is put, and a ball that, depending on fluid viscosity, have a specific fall time. By Eq. (1) it is possible to calculate the fluid viscosity

$$\eta = t(\rho_1 - \rho_2)K \qquad (1)$$

where η is the dynamic viscosity (MPa s), ρ_1 the ball density (g/cm^3), ρ_2 the fluid density (g/cm^3), t the fall time of ball between of two marks of tube (s) and K is the ball constant (0.13MPa cm^3)/g.

• *Corrosion*

Corrosion is a reaction of a metallic material and the environment. This reaction causes measurable changes in the material surface properties. This test consists in measuring the corrosion grade of cutting fluid by its contact with cast iron. Some grams of cast iron chips, previously washed in acetone and dried, were placed on a piece of filter paper in a Petri dish. The chips were evenly spaced around the filter paper, prevented from contacting one another and humidified in 2ml of the test cutting fluid. The chips were left in the covered Petri dish for 2 hours. At the end of 2 hours, the iron chips were discarded and the filter papers were rinsed in acetone. The corrosion grade of the cutting fluid is measured by observation how many spots appeared in the filter paper surface. The objective of this analysis is to determinate the anticorrosive characteristics of soluble cutting fluids. Table 1 shows how the corrosion grade can be determinate.

Corrosion Grade	Mean	Filter paper surface
0	Without corrosion	No spots
1	Vestiges of corrosion	Three spots in the maximum
2	Low corrosion	Less 1% paper area with spots
3	Moderate corrosion	Between 1 and 5% paper area with spots
4	High corrosion	More 5% paper area with spots

Table 1: Identification of corrosion grade

• *Biodegradability*

The method used to investigate the cutting fluid biodegradability was Ready Biodegradability: 301B CO_2 Evolution Test adopted on 1992 (OECD), 1997. In this test a system of aeration of continue flux, in order to filter the air various flashes with sodium hydroxyl were used. The test was carried out in dark, under 20–25 ◦C and during 28 days. The cutting fluid biodegradability was evaluate by CO_2 evolution that was absorbed by $Ba(OH)_2$ solution during test period. The CO_2 evolution was determinate by titration with HCl.

3.2. Mechanical Performance Evaluation

The grinding tests were performed in a conventional surface grinder. The workpiece material was a SAE 8640, tempered and quenched, 52 HRc, in a prismatic shape. The dimensions were 18.0mm width, 40mm height and 170mm of length. In order to compare the performance of the new cutting fluid, other two types of fluids were tested: cutting oil and a semi-synthetic fluid. The concentration for semi-synthetic fluid was 15%. Preliminaries tests were made and it was verified that better concentration for new cutting fluid was 45%.

The grinding conditions applied in the tests were:

1. Cutting speed (vs) = 33 m/s.
2. Workpiece speed (vf) = 11.5 mm/s.
3. Grinding width (b) = 6.5 mm.
4. Grinding wheel penetration (a) = 25 μm.

The tests were performed using a Vitrified CBN wheel B181 concentration 125 (31.25%), dressed cross-axis using an electroplated diamond disc. The wheel speed in dressing (vs) was 33 m/s, the peripheral disk dresser velocity (vr) 38 m/s and dressing depth of cut ad =10 μm. Successive dressing strokes of 10 μm in diameter are performed until a uniform profile is obtained. In order to compare the performance of the different cutting fluids, some output parameters were chosen: the radial wheel wear and workpiece roughness.

The wheel wear was also measured reproducing the wheel surface profile in mild steel (SAE 1020). This procedure was named as printed profile technique. A plate was ground using the total grinding wheel width. The obtained profile was measured by a profillometer. The roughness measurements were performed using a cut-off of 0.25 mm. Each roughness value represents the average of four measurements in different points of the workpiece.

4 DISCUSSION OF RESULTS

4.1. Cutting fluid formulation and characterization

The resulting formulation of the proposed fluid is (% in volume): sulfonate castor oil (40%), water (35%), bactericide (derivate of triasine) (5%), anticorrosive (synthetic ester) (15%), emulsifier agent (polyglycol of synthetic ester) (5%). The amounts of bactericide and anticorrosive are not far from the values used in commercial products. The main difference in this proposed fluid is the higher concentration of vegetable oil. Therefore, the stability of the concentrate emulsion was the main concern in this research, leading to adjustments in the amounts of emulsifier and water. Another characteristic of this proposed formula is the reduction in the amount of additives, making easier the disposal and degradation of the mixture.

The selected vegetable oil (castor oil) is obtained from a plant called *mamona* in South America. The scientific name is *ricinus communis*, or castor-oil plant in English. This oil was selected for this research due to its abundance in South America and its stability. In order to improve the oxidative stability and others problems with use high temperatures (like temperatures reaching during grinding processes) the castor oil were structural modified. Castor oil was modified using sulfurization, the sulphur modification reaction was carried out by Miracema Nuodex company.

The new cutting fluid formula doesn't have any banned products in its composition, as for example, chlorine substances and nitrosamines. The components were easily mixed resulting in a transparent liquid similar to mineral oil. Some of the physical and chemical characterisation informations of the obtained concentrate solution are presented in Table 2.

aspect	oily
pH	10.77
absolute viscosity	129 cP
colour	chestnut
stable solution	yes

Table 2: Characterisation of new cutting fluid.

The high viscosity of the Castor oil gives the cutting fluid an oily aspect and good lubricant properties. For reference, the viscosity of a pure olive oil is about 90cP. The obtained concentrate solution still needs to be diluted in water before its use as a cutting fluid.

The amount of anticorrosive additive was adjusted based on corrosion tests. Figure 2 shows two results of the corrosion test before and after adjusting the amount of anticorrosive additive to the proper value. As no spots were observed after anticorrosive adding, it can conclude that this cutting fluid has good ability to inhibit the corrosion.

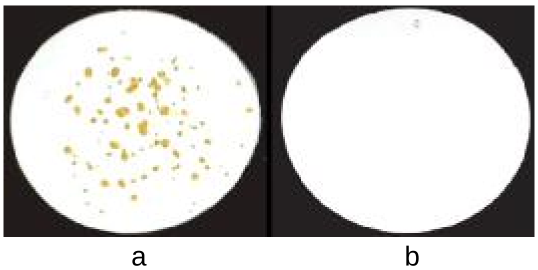

Figure 2: Result of the corrosion test before (a) and after (b) the increase in the amount of anticorrosion additive.

Biodegradation kinetics of the new cutting fluid and the reference substance sodium benzoate are shown in Fig. 3

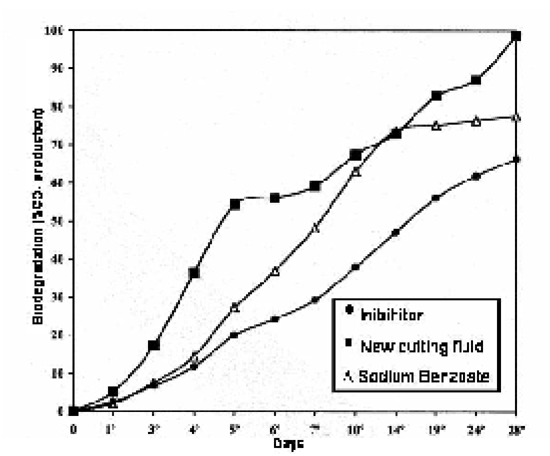

Figure 3: Biodegradation test of new cutting fluid.

In biodegradability test, the new cutting fluid exhibit high degradation rates, passing the level for ready biodegradability. Taking into consideration that the classification as readily biodegradable according to the OECD definition requires the fulfilment of an additional kinetic criteria, the so-called 10 day window. The level pass, 60% degradation, should be reach within 10 days after the onset of degradation. The onset degradation is defined as 10% degradation [11]. Mineral oil are degraded under these conditions to only 20-60%, so mineral oil can not be regarded as readily biodegradable. The excellent biodegradability shown by cutting fluid on vegetable oil to confirm that [12] said about lubricants based on renewable resources, that they are easily biodegradable under anaerobic conditions. From the ecological point of view this cutting fluid is not aggressive to the environment and its treatment and disposal can be easily made.

4.2. Mechanical Performance Evaluation

The mechanical performance of new cutting fluid was evaluated done grinding test and comparing with two known cutting fluids of market.

Figure 4 shows the obtained G ratios. It is possible to verify that the wheel wear can be significantly reduced if using a cutting fluid with high lubricant properties, as observed before [13,14]. The use of the mineral oil resulted in the highest G ratio. On the other hand, the lowest G ratio was measured in the grinding using semi-synthetic fluid (higher cooling ability and lower lubricant properties). The new formulation, with concentration of 45% showed the closest performance to oil, i.e. high G ratio value.

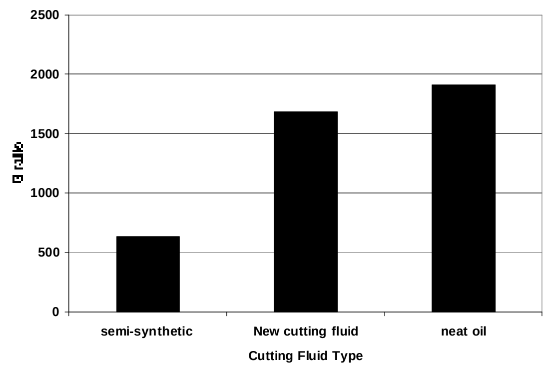

Figure 4: G ratio values for different grinding fluids.

Figure 5 presents the influence of the cutting fluid on the surface roughness. Each roughness value is an average of 4 measurements. The first column in Figure 4 refers to the Ra value after grinding half of the total stock (3000 mm^3/mm) and the second column the roughness after grinding 6000 mm^3/mm.

Normally it was expected that higher lubricant ability would result in lower roughness. However in these experiments high roughness values were found for the two cutting fluids with highest viscosity (neat oil and the new cutting fluid). This confirms some of the published results on CBN grinding where the surface roughness may increase with the use of oil [13]. The higher Ra value obtained with oil can be caused due to its low thermal conductivity that leads the chips to form at higher temperatures, making possible the formation of larger side burrs during each grain scratch.

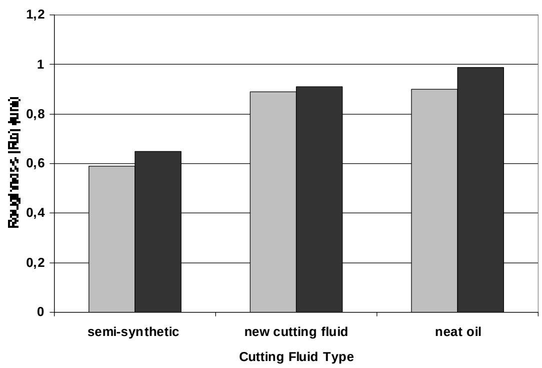

Figure 5: Roughness values for the tested grinding fluids.

The result shows that a fluid with very low lubrication properties can also deteriorate the roughness. The lowest roughness values were obtained when using the new cutting fluid at the concentration of 45% instead neat oil.

The tendency of increasing the roughness along the test was observed for all fluids. However the most uniform Ra behavior was observed for the new cutting fluid at 45%.

5 SUMMARY

Water based grinding fluids for vitrified CBN can perform as good as neat oil. Further developments in the formula using the castor oil may allow the development of other new combinations that could give even better results. Based on the presented results, the following conclusions can be also drawn:

- § The new cutting fluid is readily biodegradable and good corrosion inhibitor, also it presents a simple formula with few additives.
- § The proposed vegetable oil based soluble grinding fluid provided good results in the grinding tests similar to the obtained with the neat oil. Wheel wear, grinding forces and surface roughness were reduced when the new cutting fluid diluted at 45% was used.
- § The fluid proposed in this work has filled all environmental requirements and provided a good grinding performance. This opens new perspectives for the development of fluids for CBN grinding.

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