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Development of new cutting fluid for grinding process adjusting mechanical performance and environmental impact

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Abstract

Many problems are identified with the use of cutting fluids, such as health and environment hazards. There has been a high demand for better adequacy of industrial grinding processes in order to meet the present requirements of safety and protection to the environment. In this scenario new combinations of fluids and grinding wheels have been tested in research projects. The application of grinding wheels using cubic boron nitrite (CBN) abrasives is a strong tendency in grinding. An environmentally friendly fluid has to accomplish some main requirements, such as should not be toxic, biodegradable and should produce low emissions when in use. But also an ideal fluid has to provide good process performance and allow low costs in the application of CBN based tools. This work presents a new grinding fluid formulation able to meet both the performance and environmental requirements. The proposed fluid is based on a sulfonate vegetable oil with high concentration in water for grinding with CBN in high speed. This way it is possible to get high lubricity and good performance on CBN grinding. The tests show that the application of the proposed formula in CBN grinding results in process performance equivalent to the obtained using mineral neat oils. The parameters evaluated were radial wheel wear and workpiece roughness. Chemical analysis shows the new fluid as to be non-toxic and have easy biodegradability.

Keywords: Grinding; CBN; Cutting fluid; Environment

1. Introduction

A large interest by environmental conscience of the industry has been observed due to pollution increase, development of preventive legislation and the increase interest by "green" products and process. The recent industry efforts to decrease the environmental impacts had two focuses: development of good recycling processes, especially for metals and plastics and replacement of chemical products in manufacturing processes, making them "clean process".

Due to the growing need to adapt current safety requirements to operators and environment, new combinations of grinding wheel types and cutting fluids are being sought. As a result, the grinding process is being optimized by adopting grinding strategies that lead to a decrease in the energy expended during the cutting process and its rapid dissipation out of the grinding zone. These strategies include the use of cubic boron nitrite (CBN) wheels, which allow a larger amount of heat to be removed from cutting area through a the grain and the wheel core [1]. In addition, adopting a suitable cutting fluid reduces the coefficient of friction and specific grinding energy between grain and workpiece. In CBN grinding, a significant improvement in the process is observed, regarding the reduction of thermal damage and workpiece temperature.

This paper presents a short review about environmental impacts of cutting fluids and a study for the development of a new concept of grinding fluid to be applied in CBN grinding processes. This cutting fluid is based on a water/vegetable–oil combination. Aspects, such as biodegradability and good mechanical performance were considered. The performance of the new cutting fluid during the grinding operation was evaluated by considering the roughness and wheel wear. Different dilutions were tested to verify which one gives the best work conditions.

2. Environmental impacts of cutting fluids, legislation and current trends

The considerations about environmental aspects of cutting fluids are focused in impacts to health and to water resources [2]. Many chemical used in cutting fluid composition, such as biocides, anticorrosive, antifoam and others, can have bad effects on man and nature. The biocides are extremely harmful to operator

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health and have high costs [3]. With the technological evolution, many new synthetic products are exposed in market and for these products there are not adequate toxicological tests, and with hard work to control them, the American Environmental Agency recommends preventive actions.

The Occupational Safety and Health Administration (OSHA) regulated some substances to be controlled in formulations of cutting fluids, such as ethanolamine, diethanolamine, hexylene glycol, morpholine, *p*-chlorine-*m*-cresol, alkaline poly chlorines from C10 to C13, nitrodiethanolamine, glycol ether, Stoddard solvent, nitrites, polycyclic aromatic hydrocarbons (PAH), chlorinated paraffin oils of short chains, barium composites, oil mist and copper composites.

The fluid that contains any one of these elements cannot be considered "clean", although no specific effect can be verified regarding the use of these substances (EPA, 1995). However, some harmful effect had been associated to these components, thus, there is a recommendation for precaution.

According to Ignácio [4], there are many problems involved which the use of cutting fluids, which can determine the life of theses products and also increase the company responsibilities. Beyond of existing causes in the preparation, the use of cutting fluids in machining processes becomes them susceptible to the attack of microorganisms, bacteria and fungi. The incorrect use, for example, can produce undesirable results that can range from process problems, operator's health issues to the premature discarding of the product. In order to guarantee lesser impact of cutting fluids to the operator's health and to the quality of the environment, managers and operators must know all the procedures that are indispensable in its application, following the instructions given by the manufacturer and environmental agencies. With this is possible to prevent the occurrence of undesirable results.

In the last decades, the environmental agencies and the public authorities have worried in making possible the harmony between industrial activities and the environment, due irrational consumption of natural resources, air pollution and industries waste. On the other hand, to the competitiveness, globalization of the economy and more rigid environmental legislation have done pressure to industries in order to adjust its processes searching to take care of the three more important aspects for its survival: technological, economic and environment.

In Brazil, there is no legislation for cutting fluids, but there are two laws related to lubricants in general: CONAMA 362/05 and DECREE 50.877/61. These laws only classify the lubricants as dangerous waste and give instructions about disposal and recycling.

Currently, there is a world-wide trend, mainly in Europe, for reducing the cutting oil use, due to the high cost, but mainly for the risks to operator health and environment. This set of situations becomes undesirable the use of refrigeration systems in the production. Some alternatives have been studied to substitute the traditional methods of refrigeration, such as minimal quantify of lubricant, dry machining and the use of environmental friendly cutting fluids (air, polymeric fluid, biodegradable fluid, etc.). In grinding the last option is the most realistic since the process requires a high refrigeration in order to avoid part and tool damage. Following is presented a new fluid that search for a balance in meeting the technological and environmental requirements.

3. Methodology

3.1. Formulation of the new cutting fluid

For the preparation of the cutting fluids, some steps were followed:

1. Selection of components: it is necessary to consider if the chosen components are not problematic, dangerous for the environment or health.
2. Mixing of components: firstly add oil in water and mix for 2 min. After the additives are added, all components are mixed together for 15 min, in order to verify if the emulsion form a solution. The emulsion must repose for 24 h, to verify if the emulsion is stable.

Materials used in the formulation:

1. Sulfonate castor oil 80%.
2. Water.
3. Bactericide derivate of triasine.
4. Anticorrosive—composition of synthetic ester.
5. Emulsifier agent—polyglycol of synthetic ester.

3.2. Physical and chemical characterization

Some analysis, chemical and physical, were made to evaluate the quality of new cutting fluids. Following are described all 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 (0.13 MPa cm^3)/g.
- Corrosion

  Corrosion is a reaction of a metallic material and the environment. This reaction causes a 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 2 ml of the test cutting fluid. The chips were left in the covered Petri dish for 2 h. At the end of 2 h, 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.
- 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.

Table 1
Identification of the corrosion grade

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

3.3. Grinding test

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 18.0 mm width, 40 mm height and 170 mm 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%. Also, three different dilutions of the new cutting fluid were tested being possible to verify which dilution is best to grinding process.

The grinding conditions applied in the tests were:

1. Cutting speed (v_s) = 33 m/s.
2. Workpiece speed (v_f) = 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 (v_s) was 33 m/s, the peripheral disk dresser velocity (v_r) 38 m/s and dressing depth of cut a_d = 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.

Table 2
Composition of new cutting fluid

Bactericide
Emulsifier agent
Rust inhibitor
Sulfonate castor oil
Water

Fig. 1 shows the experiment setup of the grinding and the dressing tests.

4. Results and discussions

4.1. Formulation and characterisation of the new cutting fluid

To elaborate the new cutting fluid the selected materials should not include banned products in their composition, as for example, chlorine substances and nitrosamines.

Also, it was proposed simpler formula that the one proposed by Hübner [5], with fewer additives. This facilities the treatment and disposal of cutting fluid after used. The composition is present in Table 2.

The amount of sulfonate castor oil was around 40%. This high concentration of oil is the most innovative feature of this fluid. The components were mixed easily and the solution has a transparent aspect similar to cutting oil, this fact can be observed during the preparation of the cutting fluid. The physical and chemical characterisation is present in Table 3.

The high viscosity gives the cutting fluid an oiliness aspect and lubricant properties. The water presence increases the cooling capacity. This way the new formulation makes possible the presence of the two main cutting fluids characteristics: good lubricant and good coolant, in only one product.

In order to evaluate the quality of the formulated cutting fluid, corrosion and biodegradability analysis were made.

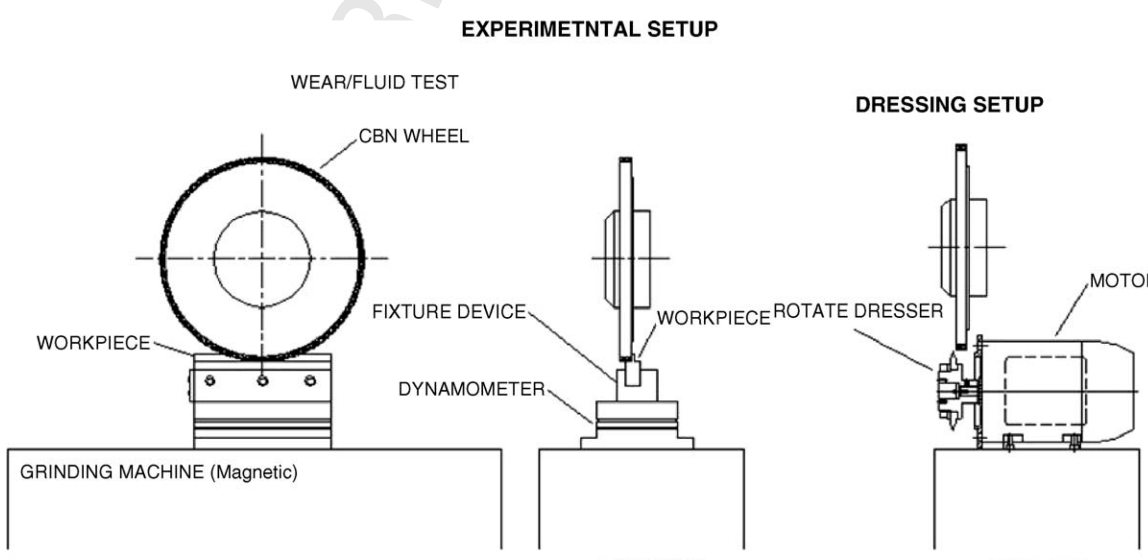

Fig. 1. Experimental setup of grinding tests.

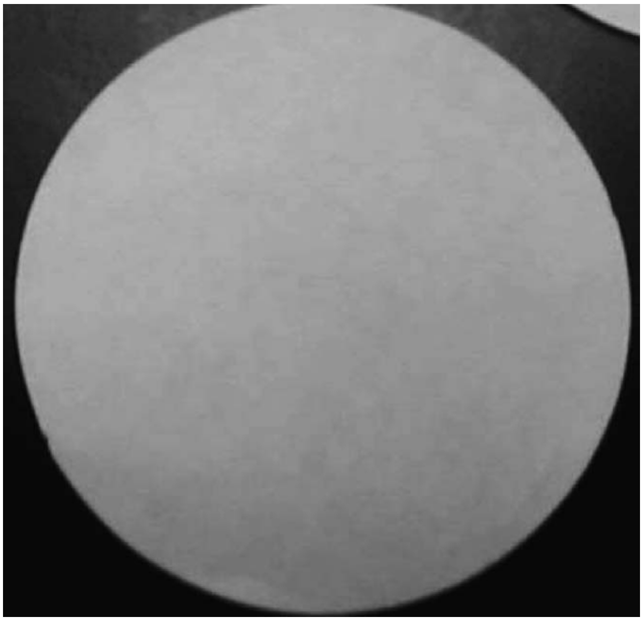

Fig. 2. Corrosion test.

The corrosion inhibiting ability of the new cutting fluid was assessed. No incidents of corrosion were observed. Fig. 2 shows the paper filter where the corrosion grade of cutting fluid was analysed. It can be verified that there are not corrosion spots. Then it is possible conclude the new cutting fluid have corrosion grade 0, so it has corrosion inhibition characteristics.

The result of the biodegradability analysis allows concluding that the new cutting fluid is easily biodegradable. 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. Grinding tests

The grinding performance of cutting fluid was analyzed by radial wheel wear and workpiece roughness. The comparison between the new cutting fluid and other existents in market was made.

4.2.1. Radial wheel wear

The radial wheel wear values were measured by the described printed profile technique. The *G* ratio (material removed volume/wheel worn volume) was used to compare the different cutting fluids.

Analyzing the radial wheel wear results presented in Fig. 3, the influence of the type of cutting fluid in the radial wear of CBN wheel can be noticed. It was also possible to verify that the wheel wear can be significantly reduced if using a cutting fluid with high lubricant properties, as also observed by Hitchiner [6]. The use of the cutting oil caused the lowest wheel wear (high *G*). On the other hand, the higher wheel wear was observed in the grinding test using the semi-synthetic cutting fluid (higher cooling ability and lower lubricant properties), approximately 8 μm in the radius. The new formulation in different concentrations tested presented an intermediate behavior. The concentration of 21% showed similar performance to the cutting oil, with high value of *G*. At high concentration (32%) the new cutting fluid was not good. In this concentration chips agglomeration was observed, increasing the friction between workpiece and wheel, consequently increasing the wheel wear.

The concentration 15° Brix gives good results, but not as good as cutting oil and concentration 21° Brix. When cutting fluids with high lubricating ability are used the friction wear is reduced and the other mechanisms are much less significant.

Table 3
Characterisation of new cutting fluid

Oiliness aspect	Yes
pH	10.77
Dynamic viscosity (Cp)	105.56
Colour	Chestnut
Stable solution	Yes

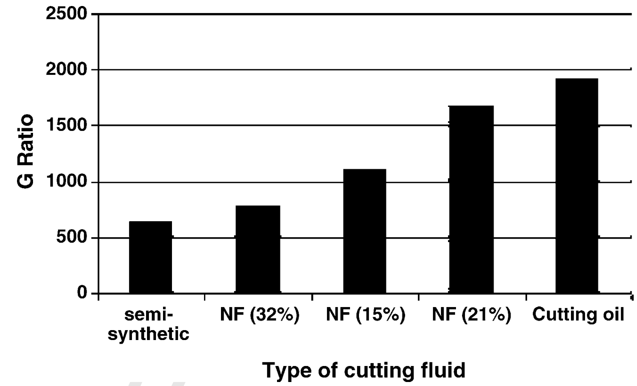

Fig. 3. Radial wheel wear values for the different cutting fluids.

4.2.2. Roughness

The workpiece roughness results for the grinding test using different cutting fluids are presented in Fig. 4. The cutting fluid type influenced the roughness values. Normally the higher the lubricant ability the lower is the roughness, but in these experiments a high roughness values for the two cutting fluids with high viscosity (cutting oil and the new cutting fluid at 32%) were observed. This fact can be caused due to the

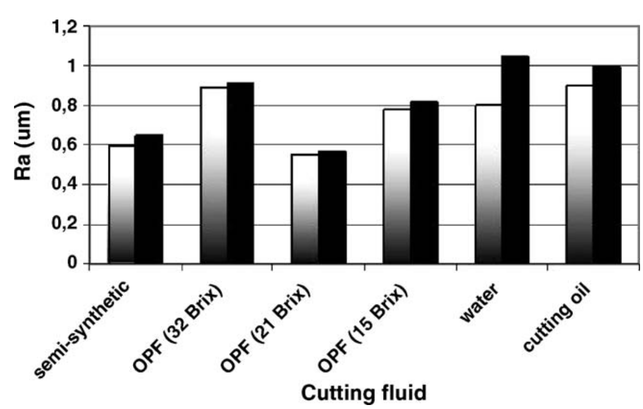

Fig. 4. Roughness values (R_a) for the different cutting fluid.

chips' agglomeration described above. The attrition between workpiece, chips and wheel may be the factor that causes the increase in the roughness values. At low concentration (15 and 21%), the new cutting fluid causes a decrease in the roughness.

The best performance was observed when using the new cutting fluid 21%, where the roughness was lower than 0.60 μm. In Fig. 4, the first column of each fluid corresponds to a roughness value after the grinding of half of total removed material and the second column is the roughness after the grinding process was concluded. The tendency of the increase roughness value with the increase of the removed material was observed for all cutting fluids, but not so expressive.

The new cutting fluid at 32% and the cutting oil presented a similar behavior, with trend of increasing the roughness values, with the increase of the volume of removed material and the roughness ranges around 0.90 μm. The semi-synthetic fluid presented good results with roughness around 0.6 μm. In this test it cannot be confirmed that the lubrication ability of fluids is a major factor in the performance.

5. Conclusions

Based on these experimental results, the following conclusions can be drawn:

- The lubrication properties of the cutting fluid is the key factor for its performance and can have high influence on the radial wheel wear. The wheel wear was reduced when cutting oil and new cutting fluid at 21% were used.
- The same influence was not observed in roughness, cutting fluids with high lubrication ability may give roughness values which are not as good.
- The wheel wear and workpiece roughness were reduced by using the new cutting fluid. The best result was obtained with new cutting fluid diluted at 21%.
- It was possible formulate a cutting fluid with vegetable oil based and less quantity of additives and to obtain results similar to the cutting oil.
- The cutting fluid developed in this work has filled all environmental requirements as well as has a good grinding performance.

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