

# Development of Environmentally Friendly Fluid for CBN Grinding

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## Abstract

Environmentally friendly water based fluids have been offered recently by many suppliers. On the other hand the G ratio values obtained for CBN grinding with water based coolants are much lower than with neat oil. This work presents a new water based grinding fluid formulation able to meet both the performance and environmental requirements for CBN grinding. The existence of a reaction between CBN grains and water is evaluated in grinding tests and also in a chemical reactor. The results show that the reaction between CBN grains and water is not significant when compared to the measured volumetric wheel wear in a grinding operation. Based on this fact, a 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 show performance comparable to the obtained with neat oil.

**Keywords:** Grinding, Cubic boron nitride, Fluid

## 1 INTRODUCTION

Cutting fluids play important roles in machining processes. A CIRP keynote paper in 1999 by Brinksmeier et al. shows a comprehensive study on the main effects of coolant type, composition and application in grinding [1]. The correct selection and use of grinding fluids normally results in enhanced process performance, better workpiece quality and longer tool life.

On the other hand, some of the substances included in the fluids composition can lead to problems to the working environment and in their disposal [2]. 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 [3].

Grinding fluids should ideally be formulated to meet both cooling and lubrication requirements. They normally consist of a basic fluid, water based or not, mixed with other products such as EP additives, antibiotics, anti-corrosion, and emulsifying agents (the last for the water soluble fluids only). The chemical effects of cutting fluids in machining and grinding processes are well discussed in a recent CIRP keynote paper on chemical aspects on machining processes, including the interactions which occur between the various participating surfaces [4].

There is a common sense that CBN grinding performs generally better when oil is used instead of water based fluids [1]. Wheel wear and surface finishing values are lower when grinding with vitrified CBN wheels and oil. The main reasons for the lower performance in the application of water based fluids in CBN grinding are frequently attributed to the chemical affinity between CBN and water. However, there are some controversies regarding the relevance of the major factors leading to this low performance. Some explanations include the occurrence of thermal shocks, higher friction or film boiling [5]. Even grinding with graphite or dry grinding can result in lower wear rates in comparison with water based coolants as shown by [6]. However, the higher thermal conductivity of water can bring some benefits such as the higher compressive stresses in the ground part, as observed by Brinksmeier [1], or the improved adequacy to the environment when using a proper composition.

Since the available choice of grinding fluids nowadays are divided between high lubrication ability products (mineral or synthetic oils) or high thermal conductivity (water with 2 to 15% of oil), grinding users are subjected to the

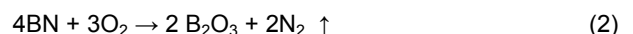
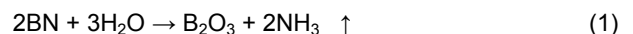
limitations of these two extremes. Therefore, a grinding fluid combining high thermal conductivity and good lubrication properties would be desirable. This can be achieved by mixing higher amounts of oil in water (near 40% in volume for example).

The use of vegetable oils may allow this mixture, to make possible the development of a new grinding fluid where high performance in grinding combined with a good environmental compatibility could be achieved. 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 [7]. 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 formulation for water based grinding fluid able to meet both the performance and environmental requirements. The following sections present some analysis, procedures, tests and results related to the development of the new formulation.

## 2 EVALUATION OF CHEMICAL REACTIONS BETWEEN CBN AND WATER IN GRINDING

It is known that the G ratio of CBN grinding is lower when water based coolants are applied, leading to higher tool costs. The chemical decomposition of CBN is frequently associated with its interaction with high temperature steam in grinding. This interaction can be similar to the phenomena described in [8] where CBN grains can be destroyed in the wheel firing process where several constituents of the bond are chemically reactive with the grains. These oxidation reactions (equations 1 and 2) result in the formation of Boron oxide ( $B_2O_3$ ) on the surface of CBN grains, a protective layer that prevents further oxidation.



However, this oxide layer is soluble in high-temperature water steam (equation 3) and can allow further oxidation of the CBN grain. According to [9], there is limited direct evidence to confirm that this chemical reaction leads to

CBN degradation. These reactions, although very slow, can cause wear flats on the CBN edges and, thus, shorten wheel life.



A water based grinding fluid would not be successful in cases where the described reactions are relevant to the process performance. So, the study of these phenomena should be the first step before trying to develop a water based fluid for grinding. In order to verify the relevance of the oxidation reactions in a CBN wheel, two different wear tests are proposed:

- **reaction between CBN grains and steam in a chemical reactor:** a fixed amount of steam continuously flows at 600°C for 2 hours through the CBN grains. The grains were positioned on quartz net where the steam was injected.
- **grinding tests using water:** A small amount of pure water is used as fluid in a CBN surface grinding operation.

The resulting CBN grains from the chemical reactor test were evaluated qualitatively using X-Ray diffraction spectroscopy and the water samples from grinding tests were analyzed quantitatively by Inductively Coupled Plasma-Optical Emission Spectroscopy. While the objective of the first test was to verify the existence of the described reactions, in the second test the concentration of Boron in water was determined.

CBN is chemically very inert but it can be hydrolyzed by steam resulting in  $\text{B}_2\text{O}_3$  and  $\text{NH}_3$ . However the temperature for this reaction is not well known. Since grinding temperatures can reach 600°C in normal conditions the test was performed using 600°C as maximum value. Figure 1 shows the obtained spectrum (black line) for the CBN grains after the test in the chemical reactor at 600°C. The expected peaks for the presence of Boron Oxide are indicated with blue lines. The red lines are the expected peaks for CBN. It is observed that the measured curve does not match to the peaks expected for the  $\text{B}_2\text{O}_3$ . Therefore the reaction did not happen in significant scale at common grinding temperatures.

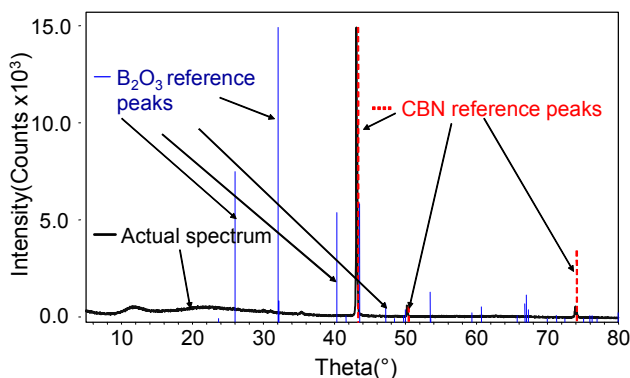


Figure 1: X-Ray diffraction spectrum of CBN grains after reaction with steam at 600°C.

For the grinding test the selected tool was a vitrified CBN wheel, B181 concentration 125, dressed with a diamond disc. The conditions were: grinding speed  $v_s = 33$  m/s, workpiece speed  $v_w = 660$  mm/min, grinding width  $b = 6.5$  mm, grinding wheel penetration/pass  $a = 25\mu\text{m}$ . Dressing depth of cut  $a_d = 10\mu\text{m}$ , dressing overlapping ratio  $U_d = 4$ . The workpiece material was a SAE 8640 at 52 HRC. This grinding condition is considered quite gentle. It is well known that CBN performs better at high speed and can grind at higher stock removal rates. However, in this case,

at lower contact zone temperatures the measured wear will be more influenced by the friction which is the basic hypothesis of this research. The reaction at higher temperature has already been tested in the reactor.

Two water samples were collected before and after the grinding tests and analyzed by the inductively coupled plasma-optical emission spectroscopy system. An absolute increase of 9.75 mg in the level of Boron in the water after grinding was measured. This value was calculated considering the Boron concentration increase (0,15mg/l) and the tank capacity (65 liters). The obtained value is not significant regarding the measured volumetric wear of the grinding wheel of  $0.0485\text{ cm}^3$  during this grinding test, corresponding to 88.949 mg of CBN. Therefore the increase of boron detected in the water by the chemical analysis corresponds to about 11% of the amount of wear during the grinding process. It is important to point that the amount of boron found in the water could be from the eventual very small particles of CBN in suspension, and not necessarily from diluted Boron Oxide.

These results confirm the hypothesis that the CBN wear is mostly caused by the influence of friction and thermal shock (this last in heavier grinding conditions). Therefore, water based grinding fluids with high lubrication properties may still result in good performance in CBN grinding.

### 3 DEVELOPMENT OF THE NEW GRINDING FLUID

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.

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.

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 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 or 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 (sulfonate castor oil) is obtained from a plant called *mamona* in South America. The scientific name is *ricinus communis*, or castor-oil plant in English. The castor oil was one of the first oils produced for engines with the brand name Castrol in 1909 (Castrol is a contraction of Castor and Oil). This oil was selected for this research due to its abundance in South America and its stability.

The new cutting fluid formula don'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 information of the obtained concentrate are in Table 1.

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

Table 1: 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. Several dilutions will be tested in the grinding experiments.

The commonly used test of contact with cast iron was applied for the measurement of the anticorrosive characteristics. Some grams of cast iron chips are placed on a disk of filter paper in a Petri dish, humidified in 2 ml of the cutting fluid and left covered for 2 hours. At the end of the period, the iron chips are discarded and the filter paper is rinsed in acetone. The corrosion grade of the cutting fluid is measured by counting the number of stain spots on the filter paper surface. The absence of spots means a corrosion inhibiting characteristic. The amount of anticorrosive additive was adjusted based on repeated corrosion tests. Figure 2 shows two results before and after adjusting the amount of anticorrosive.

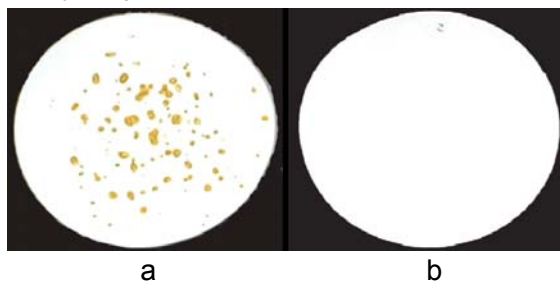


Figure 2: Result of the corrosion test before (a) and after (b) the increase in the amount of anticorrosion additive.

The method used to test the biodegradability of the new fluid was the ready biodegradability 301B CO<sub>2</sub> adopted in 1992 by the OECD (Organization for Economic Cooperation and Development). This test is compatible with the ISO10708 procedure. The test was carried out in the dark, at 23°C and during 28 days. The biodegradability was evaluated by the CO<sub>2</sub> release that was absorbed by a Ba(OH)<sub>2</sub> solution during the test period. The CO<sub>2</sub> release value was found by the titration

with HCL. According to this method, the result of the biodegradability analysis allowed concluded 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 EVALUATION OF GRINDING PERFORMANCE

The grinding tests were performed in a surface grinder. The workpiece was SAE 8640, tempered and quenched, at 52 HRC, in a prismatic shape. In order to compare the performance of the new cutting fluid, two other types of known substances were tested as references: cutting oil and a semi-synthetic fluid. The concentration used for the semi-synthetic fluid was 15%. Three different dilutions of the new fluid in water were tested making it possible to verify which would be the best for grinding.

The tool and cutting conditions were the same used in the grinding test with water described in the section 2. The measured output parameters were the radial wheel wear, grinding forces and workpiece roughness. The total amount of material ground for each fluid was 6000 mm<sup>3</sup>/mm. The radial wheel wear values were measured by the printed profile technique and the G ratio was then calculated.

Figure 3 shows the obtained G ratios. The proposed fluid is designated with the letters NF (new formula) and the concentration (in volume) is beside the fluid name. 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 [1,11]. 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, tested in different concentrations, presented intermediate behaviors. The concentration of 45% showed the closest performance to oil, i.e. high G ratio value. At high concentration (70%) the new fluid was not as good. In this case chip agglomeration in the wheel porosities was observed, increasing the friction and consequently increasing the wheel wear. The concentration 35% gives an intermediate result, but not as good as the neat oil and the NF at a concentration of 45%.

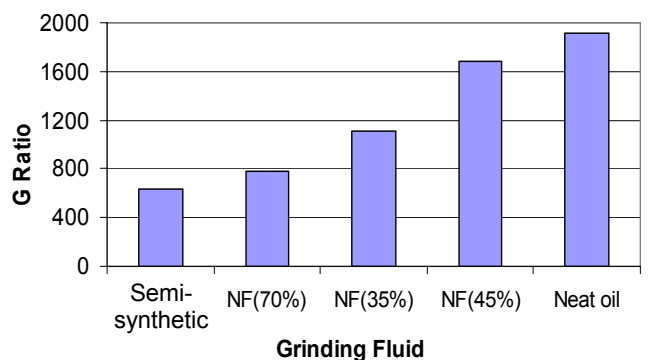


Figure 3: G ratio values for different grinding fluids.

Figure 4 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<sup>3</sup>/mm) and the second column the roughness after grinding 6000 mm<sup>3</sup>/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 at 70%). This confirms some of the published results on CBN grinding where the surface roughness may increase with the use of oil [1]. 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.

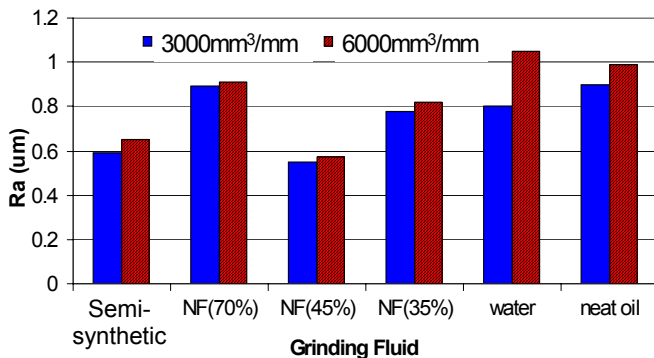


Figure 4: Roughness values for the tested grinding fluids.

The high roughness for the new formula at 70% can be explained by the agglomeration of chips in the wheel porosities as described earlier. The attrition between workpiece, chips and wheel may be the factor that causes the increase in the roughness values. At lower concentration (35% and 45%), the new fluid provided a reduction in the roughness. The roughness values obtained in the grinding with pure water, as described in section 2, are also included in the graph for reference. 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 fluid at the concentration of 45%. 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 formula at 45%.

It can be seen in Figure 5 that in most of the experiments the grinding forces remained almost constant. Only for the semi-synthetic fluid there was a large oscillation of the normal force after the removal of 2000 mm<sup>3</sup>/mm. The lowest force values were measured for the new formula at 45% and for the neat oil. The combination of high lubricity and good thermal conductivity presented in the new fluid allows the maintenance of the wheel sharpness providing wheel wear rates similar to mineral oil and surface finishing similar to water based fluids.

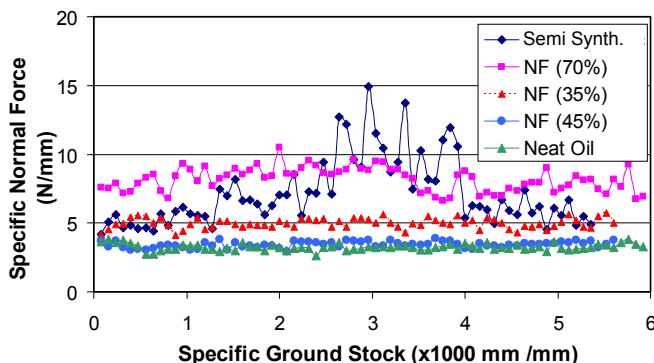


Figure 5: Normal grinding forces for the tested fluids.

## 5 SUMMARY

From all the presented results it is possible to confirm that the presence of water in the fluid was not a negative factor regarding the wheel wear. Also, the use of a grinding fluid with intermediate properties can open new perspectives in the development of such products. 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 also be drawn:

- The chemical reactions between CBN grains and water are not a significant factor in the wheel wear mechanism in the tested conditions.
- The proposed vegetable oil based soluble grinding fluid provided good results in the grinding tests similar to the ones 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 fulfilled all environmental requirements and provided a good grinding performance. This opens new perspectives for the development of fluids for CBN grinding.

## 6 ACKNOWLEDGMENTS

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