# ANALYSIS OF THE CUTTING FLUID INFLUENCE ON THE DEEP GRINDING PROCESS WITH CBN GRINDING WHEEL

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***Abstract.*** *The application of cutting fluid in a deep grinding process is becoming more and more important, mainly where the cutting fluids are used as an "external" agent to the grinding conditions. The role of the fluid in grinding operations is refrigerating the workpiece, to remove the shavings, to lubricate the grinding zone, to refrigerate and to clean the wheel. The efficiency of a cutting fluid will depend mainly of the type of fluid that will be used. In this work will be analyzed the influences of the type of cutting fluid used in a deep grinding process of the steel VC131 using CBN grinding wheel. Were used three different types of cutting fluids: a vegetable emulsion, a synthetic solution and a neat oil. The variables analyzed during and after the grinding process were the grinding force, the superficial roughness, the acoustic emission (EA), the temperature of the piece and the G ratio (relation between the volume of material removed of piece and the volume worn of grinding wheel). The neat oil showed the best performance with relation to the following output variables: EA, cutting force and G ratio. The vegetal emulsion was the fluid that best dissipated heat from the cutting region.*

***Keywords****. Machining, Grinding, CBN wheel, Cutting fluid.*

## 1. Introduction

Grinding is a machining process employed for the attainment of tight tolerance (two-dimension tolerance between IT4 e IT6 and compatible geometric tolerance) and reduced roughness values (Ra from 0.2 to 1.6μm) (Diniz et al., 2000), becoming one of the most complexes machining process so far, due to the great number of variables involved.

The search for productivity and quality in the late years has led to great advancements at machining processes. Such advancements occur at the conventional operations as well as at the simplification of a component manufacturing sequence with the exchange from intermediate operations to finishing operations.

In the plunge grinding process, the workpiece is fixed upon a magnetic plate, which remains held on the grinding machine's table. The workpiece has a pendulous longitudinal movement with velocity $\mathbf{v_w}$. The grinding wheel with outer diameter $\mathbf{d_s}$ [mm], has cutting velocity $\mathbf{v_s}$, and penetrates into the workpiece with depth (a), the way it is (schematically) shown by Fig. (1).

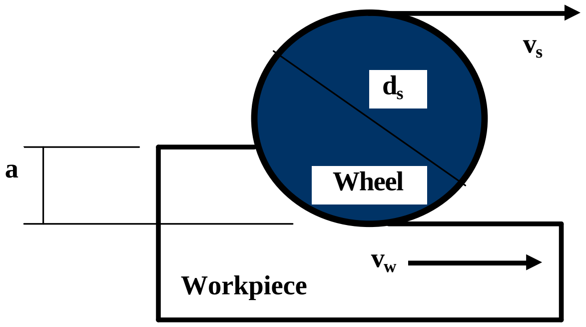

Figure 1. This figure shows the plunge grinding process.

According to Webster & Ciu (1995), the employment of fluids in machining processes is becoming even more important due to the high removal rate, high quality and long lasting grinding wheel, and furthermore, the fluid correct employment at the cutting zone, may be so important as the grinding wheel specification choice.

The cutting fluids are employed as an “outer agent” to the machining conditions, the roles the fluids play at the machining operations are: to refrigerate the workpieces, to remove the chips, to lubricate the machining zone, to refrigerate and to clean the grinding wheel, among others. A great variety of oils and cutting fluids are available in the market for the different machining processes, and the choice might be influenced by factors such as viscosity, technical features, cost among others.

This paper has as its main purpose to analyze the influence of the type of cutting fluid employed in the grinding operation with high depth of cut (depth of cut “a” of 70μm), with CBN superabrasive grinding wheel (Cubic Boron Nitride) manufactured with vitrified bond.

In this work, the type of material to be ground, the fluid pressure and flow rate, the machining condition and the grinding wheel will be fixed. Only the cutting fluids will not. This way we will attempt to verify the influence of some types of cutting fluids on the cutting tangential force behavior, on the workpiece superficial roughness, on the acoustic emission (EA), on the temperature and on G ratio (relation between the volume of material removed of piece and the volume worn of grinding wheel).

## 2. Cutting fluid

### 2.1. Classification of cutting fluid

Each basic type of cutting fluid shows features, advantages and specific limitations. However, the features that distinguish the different classes not always are easily seen, remaining small differences concerning their classification (Motta & Machado, 1995). According to Runge & Duarte (1990) and ASM (1991), the cutting fluids may be grouped into four basic types:

- cutting oils (neat oil or emulsified);
- water-soluble cutting fluids:
  - conventional emulsifiable;
  - semi-synthetic emulsifiable;
  - solutions (synthetic fluids);
- gases;
- pastes;

### 2.2. Functions of a cutting fluid in the grinding process

In order to be actually effective, the cutting fluid should not only provide good workpiece cooling by convection, but especially it should perform at the chip formation mechanism, furthering the cut (chip formation) instead of the plastic deformation with no material removal (plowing). As result, there is a reduction on the required grinding specific energy for the machining process (Malkin, 1989).

Table (1) shows some characteristics of the main employed cutting fluids for machining processes in industries. According to Diniz et al. (2000), water-base fluids have two meaningful disadvantages as follows: low lubricating content and easier promotes oxidation of workpieces and machine. However, the cutting oils seem to provide better lubricating power than the water-base fluids (solutions and emulsions).

Table 1. Characteristics of the most important fluid types (Webster, 1995).

| | **Synthetic** | **Semi-Synthetic** | **Soluble Oil** | **Mineral Oil** |
|---|---|---|---|---|
| **Removed heat** | Excellent | Outstanding | Good | Bad |
| **Lubrication** | Bad | Good | Outstanding | Excellent |
| **Maintenance** | Outstanding | Good | Bad | Excellent |
| **Filterability** | Excellent | Outstanding | Good | Bad |
| **Environmental damages** | Excellent | Outstanding | Good | Bad |
| **Cost** | Excellent | Outstanding | Good | Bad |

## 3. Material and method

### 3.1. Types of employed cutting fluids

Three types of fluids will be employed: a vegetal emulsion, a synthetic solution and neat cutting oil. Next, the outlines of each type of fluid are found:

**CutMaxCF 10:** Neat cutting oil free from chlorine. Its basic contents are: paraffin mineral oil, grease, extreme-pressure additive and anti-oxidizer.

**Hocut 4110:** Synthetic cutting fluid solution formative.

**Hocut 2010:** Water-soluble cutting fluid, biologically decomposed, vegetal emulsion formative, which basic contents are: vegetal oil free from mineral oil, nitrites, heavy metals and phenolic compounds.

The water-soluble cutting fluids were prepared at 5% concentration and the pH measurement was performed before the beginning of each test, and all employed cutting fluids showed pH levels between 7.2 and 10.8.

### 3.2. Type of employed grinding wheel

Was employed a CBN B76R125V12 superabrasive grinding wheel, with 350 mm diameter and 20 mm width vitrified bond. The truing operation was performed through a truing device fixed to the machine's table, placed at the horizontal position underneath the grinding wheel, lined up with its gravity center. As the grinding wheel runs, a transversal rectilinear movement was performed relate to the grinding wheel, in order to remove the toll's irregular layer, this way generating new cutting corners for each proposed test performance.

### 3.3. Workpieces

The samples were manufactured with VC 131 tempered steel and retempered with hardness of approximately 60 HRC. The samples approximately dimension were 200 mm length, 20 mm height and 5 mm thickness. Three holes of 2 mm diameter by 5 mm away from one another were made, in order to fix the thermocouple.

### 3.4. Machining conditions

In sequence will be shown the machining condition adopted for the tests performance:

Fluid flow rate = 10 l/min;
Grinding wheel velocity = $\mathbf{V}_s$ = 65 m/s;
Table velocity = $\mathbf{V}_w$ = 0.04 m/s;
Optimized nozzle with fluid output diameter = 8 mm;
"a" is the cut depth = 70 µm;
$h_{eq}$ is the cut equivalent thickness = 0.1 µm.

Initially the workpiece was fixed on the grinding machine's table according to Fig. (2) and afterwards all machining conditions (cutting velocity, table velocity and grinding wheel's penetration into the workpiece) were set.

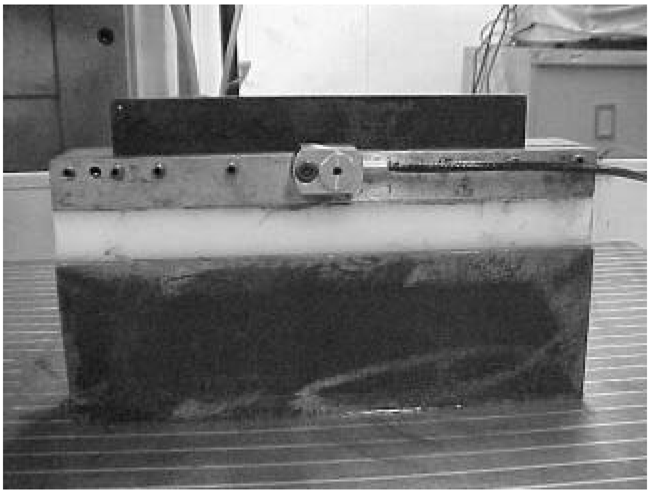

Figure 2. Fixing the workpiece on the plane grinding table.

Then, the tests started, measuring the cutting force, EA and the temperature at real time. The grinding wheel diametric wear was marked on a workpiece at the end of each test and the roughness measured each 25 moves of the grinding wheel.

#### 3.4.1.Thermocouples fixed to the workpiece

The thermocouples were fixed to the workpiece through instantaneous glue, where only the tips were glued to the workpiece. The thermocouple tips were attached through a solder performed with acetylene flame.

The thermocouples were connected to the A/D plate, where it was possible to visualize temperature at real time through a digital display.

### 3.4.2. Acoustic emission sensor

For the acquirement of the acoustic emission at real time, an equipment of Sensis Manufacturer, model BM12 was employed, and the sensor was fixed next to the piece case.

### 3.4.3. Superficial roughness measurement

The superficial roughness of the parameter workpiece $R_{a,}$ was taken each 25 grinding wheel moves, employing a roughness measurement instrument of TAYLOR HOBSON, model Surtronic 3+. The measurements were performed at three different positions from the workpiece (side and center) and three successive times at each position. The cut off was of 25µm.

### 3.4.4. Measurement of G ratio

At the end of each test, the grinding wheel was marked on a workpiece, which was fixed to the grinding table, in such way to remain at perpendicular position to the grinding wheel's face. With the aid of an electronic displacement measurer - TESA; model TT10, with accuracy of 1?m, three measurements at the grinding wheel wear and at the sides regions were performed. G ratio, which expresses the grinding wheel performance, was obtained through the division of the removed material volume by the volume of the worn grinding wheel.

### 3.4.5. Cutting tangential force

For the cutting tangential force, the measurement at real time was performed through the grinding wheel rotation **n** and the electric power $\mathbf{P_c}$ spent by the actuation motor of the abrasive tool, during cut. In that purpose, a signals conditioning circuit was employed, which allows the acquirement and the transformation of values from the electric current, electric tension and motor rotation into signals of compatible electric tension, to be sent to a data acquisition system (A/D board). Employing the LabVIEW data acquisition software, previously determined calibration equations as well as the tension values read by the data acquisition plate, then the cutting tangential force $\mathbf{Ft_c}$ could be calculated by the Eq. (1), once $\mathbf{d_s}$ is the grinding wheel diameter:

$$Ft_c = 60*P_c / (2*3.1415*n*d_s) \qquad (1)$$

### 3.5. Initial parameters

### 3.5.1. Type of nozzle to be employed

An optimized nib with an 8 mm diameter nozzle was employed, as shown by Fig. (3), in order to show a better flow rate-pressure set.

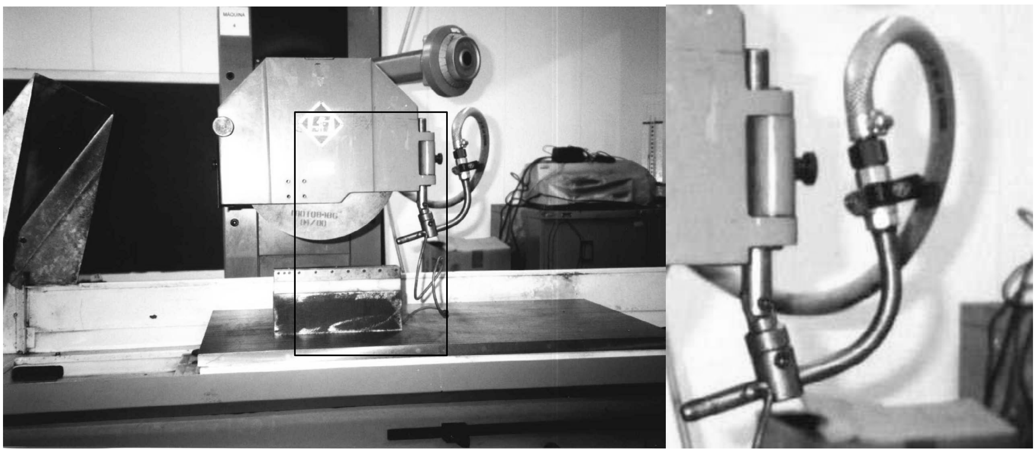

Figure 3. Nozzle used.

## 4. Results and discussion

The obtained results for the tested fluids will be presented, analyzing the output variables: roughness, cutting tangential force, acoustic emission, temperature and G ratio.

For the cutting force and EA, an average was calculated for each grinding wheel move, in other words, two points expressing the beginning and the end of the workpiece grinding were selected, coming up to 90 averages. The choice of the points was made manually, once the data acquisition was made only toward the table displacement (incompatible movement between workpiece and grinding wheel), and the acquired data would not happen at equal time intervals. When the table retook on the opposite movement, the computer program was stopped and an advancement of 70 ?m was made for a new grinding wheel move.

### 4.1. Results for the average superficial roughness

The roughness was obtained after 25 grinding wheel moves, where three measurements at the border and at the middle of the workpiece were performed. Then, the roughness average by along the workpiece in function of the number of moves was calculated. The Fig. (4) shows roughness for the tested fluids.

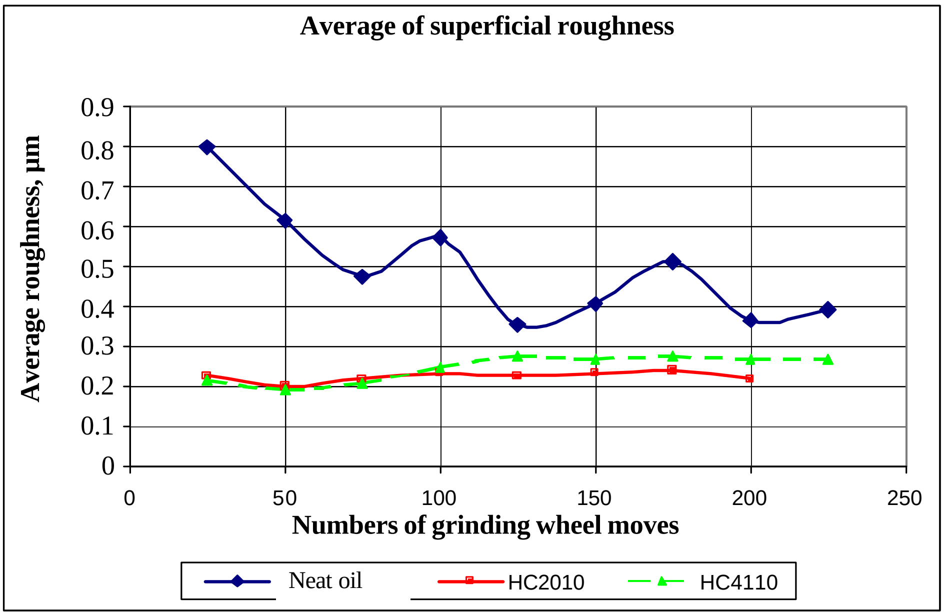

Figure 4. Comparative results for the average roughness.

Analyzing the soluble fluids HC 2010 (vegetal emulsion), HC 4110 (synthetic solution), one observes that both have similar behavior with relation to the roughness (Ra). All that, in function of the non-employment of the unitary relation (where the fluid employment velocity is equal to the grinding wheel peripheral velocity) due to the technical limitations, the pressure and flow rate requirements. For these cases, it was not possible to overcome effectively the air barrier brought by the grinding wheel rotation, which could be replaced by adopting the unitary relation between the velocities, as observed by Webster (1995, 1999).

For the cutting oil, a higher roughness ($R_a$) was obtained by along the grinding process, due to the fact that its highest viscosity requires an employment minimum flow rate, in order to guarantee an adequate lubrication. According to Webster (1999), there is a critical flow rate, which can be defined as a determinate jet output velocity, where above this value, the final properties of the ground workpieces might be improved.

Therefore, the fluids that showed the lowest roughness were the water soluble ones: vegetal emulsion and synthetic solution.

### 4.2. Results for the acoustic emission

According to Soares & Oliveira (2002), the acoustic emission (EA) is characterized by tension waves produced by the sudden movement of the tensioned materials, and the classical emissions come from deformation processes, such as the growth of a cracking and plastic deformations. Those sudden movements generate tensions, which diffuse by the material by physical environments, until it reaches the EA sensor, and the most employed nozzle for the sensors fixing are the counterpoint, the cube or the grinding wheel axis, or even the cutting fluid tube. It is a value acquirement method very sensible, where the sensor receives electric signals of high frequency and free from noises from sources out of the process.

Analyzing Fig. (5), which shows the comparison of the acoustic emission values for the tested fluids, one observes that the neat cutting oil was the fluid showing the lowest values for acoustic emission due to its high lubricating power, followed by the vegetal emulsion an by the synthetic solution.

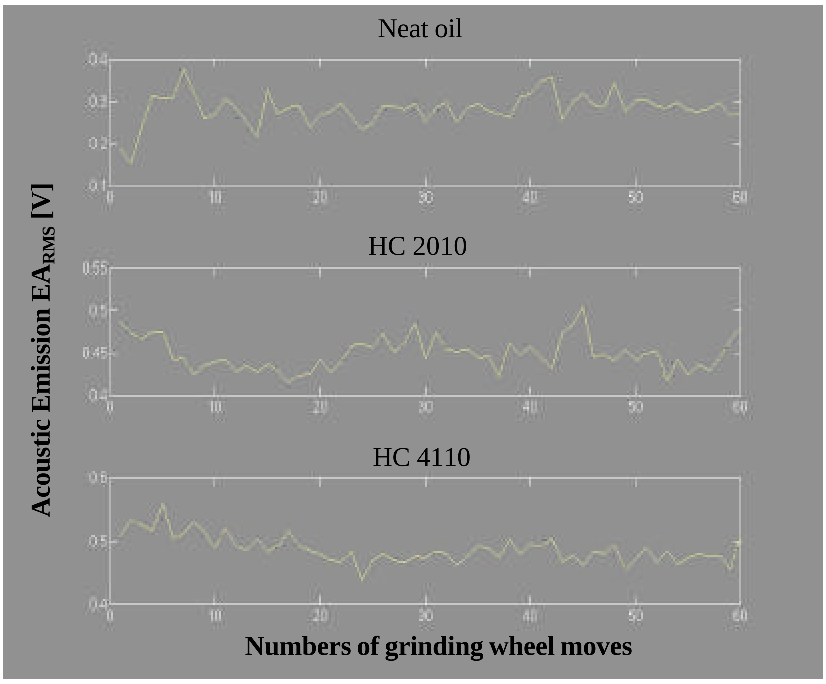

Figure 5. EA comparative results for the fluids.

### 4.3. Results for the cutting tangential force

The Fig. (6) shows the comparison of the obtained values for the cutting tangential force.

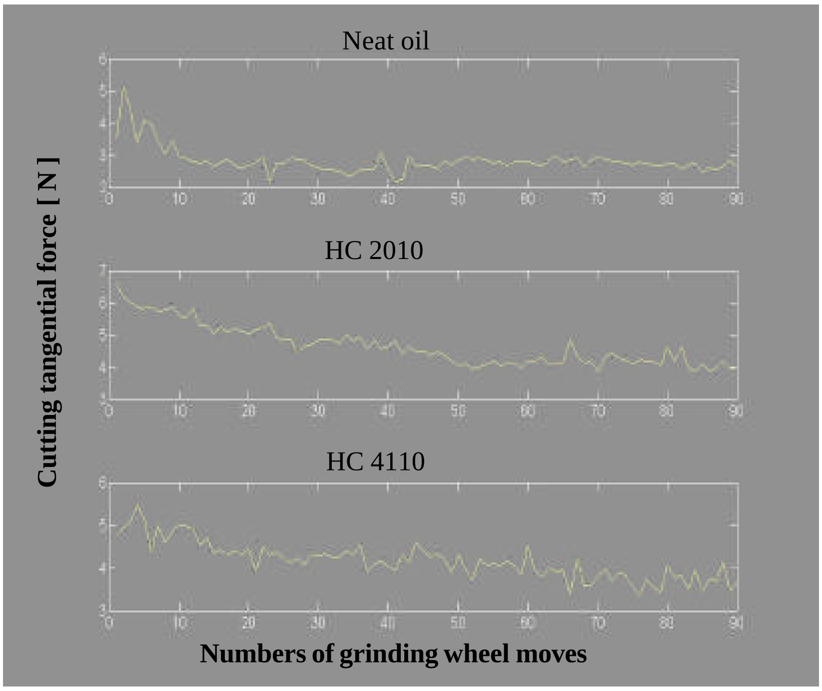

Figure 6. Tangential force comparative results.

The soluble fluids showed behavior of cutting force values more unstable than for the neat cutting oil. The vegetal emulsion started process with greater cutting force, however, it behaved more likely to stability than the synthetic solution by along the process. The synthetic solution showed more unstable behavior during the process.

The cutting oil showed more stable behavior for the cutting force, as the number of moves increased, when compared to the other tested fluids. It also showed a lower cutting value by along the whole process. Such fact is explained by the higher lubricating capacity of this fluid, when compared to the other tested. The neat cutting oil turns the grinding wheel sharper, inhibiting the soon wear of abrasive grains, through the decrease of the grain-workpiece friction coefficient. This way, it allows a smoother cut, reducing the dissipated energy, once the cut is facilitated (Hitchiner, 1990).

### 4.4. Temperature results

Figures 07, 08, 09 show the temperatures for the three employed thermocouples.

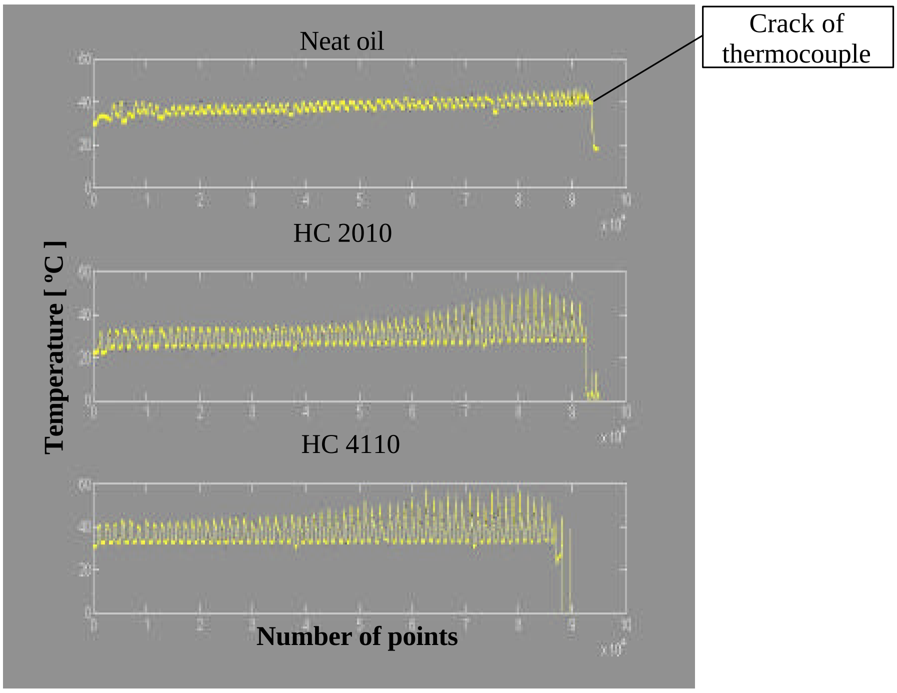

Figure 7. Comparative results of temperatures for the 1st thermocouple.

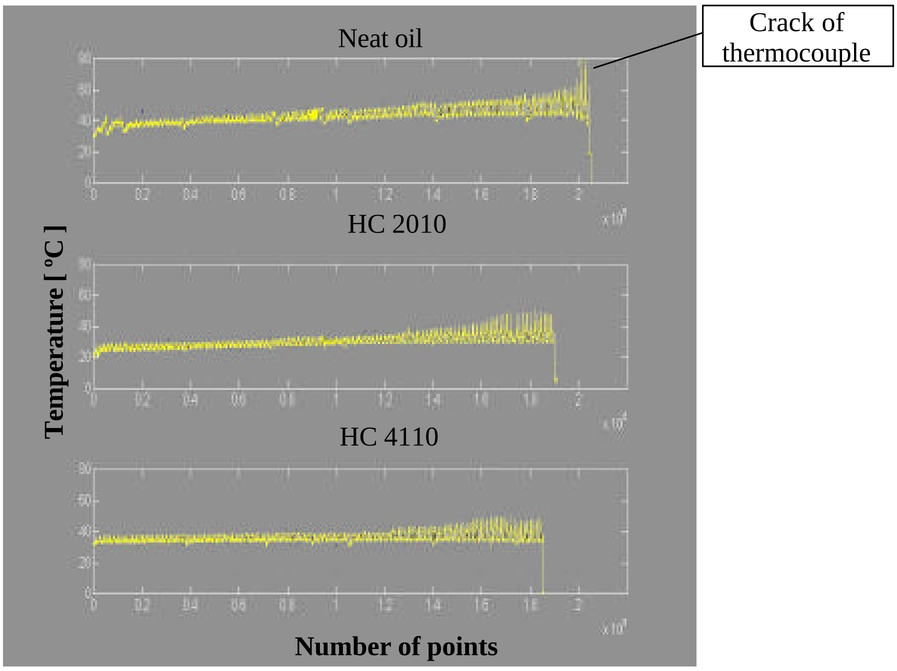

Figure 8. Comparative results of temperatures for the 2nd thermocouple.

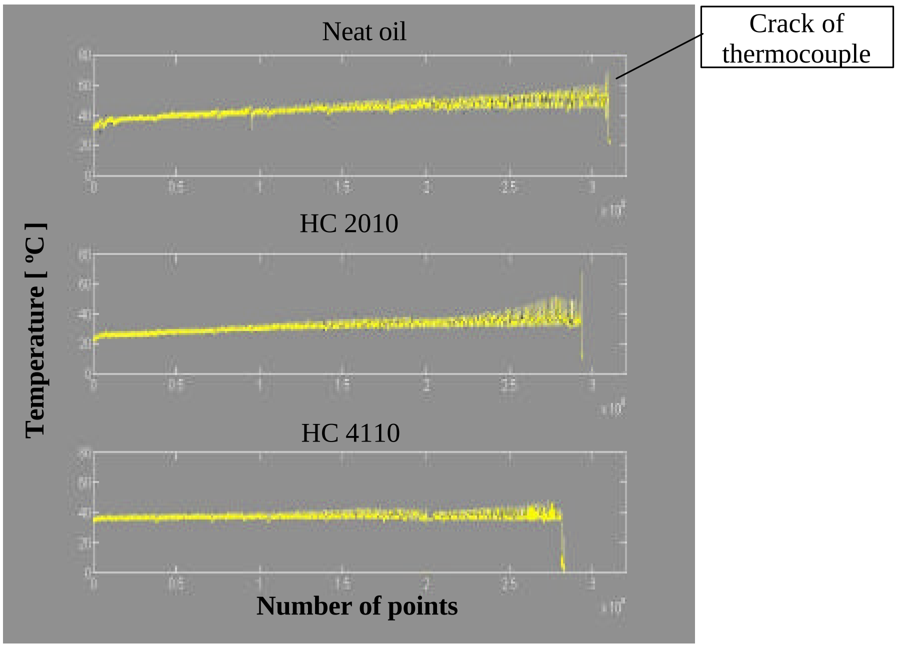

Figure 9. Comparative results of temperatures for the 3rd thermocouple.

The breaching of the first thermocouple happened approximately at the 70th move after the grinding of 5 mm from the material. The 2nd thermocouple breached at the 140th grinding wheel move and the 3rd at the 210th move, both after the grinding of 5 mm from the workpiece.

This breaching may be seen at all thermocouples every time there is a sudden temperature drop.

Similar breaching behavior when cutting fluids are changed is also observed, once as it gets next to the thermocouple breaching (after 5 mm of removed material), the temperature starts to increase and just when the thermocouple breaches, there is a sudden temperature drop.

The neat cutting oil was the fluid that showed the greatest temperature variation at all thermocouples, proving its better efficiency in the heat dissipation. The synthetic solution showed greater temperature variation comparing to the vegetal emulsion for all thermocouples. Thus, the vegetal emulsion was the fluid that showed the best performance in the heat dissipation.

## 4.5. Results for the G ratio

The Fig. (10) shows the comparison of G ratio values for the tested cutting fluids.

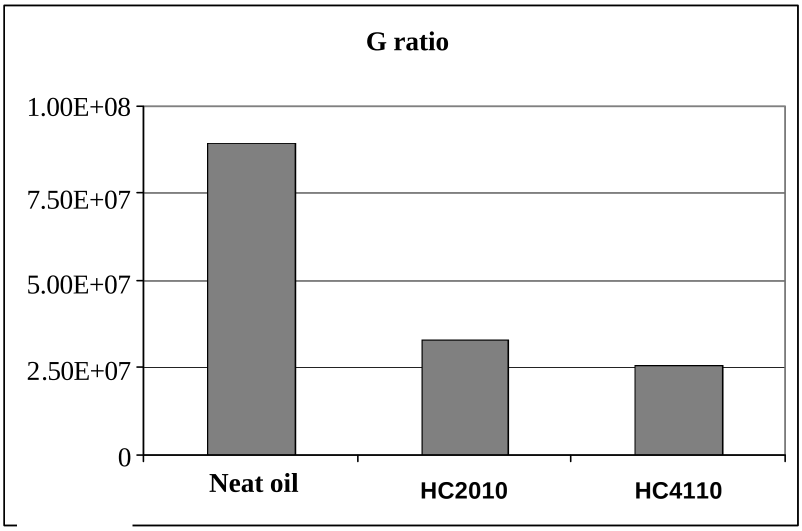

Figure 10. Comparative results for G ratio.

The highest values for G ratio were obtained employing cutting oil. That may be explained by the higher lubricating capacity of this fluid, when compared to the other tested fluids. Those results were also observed by Carius (1989) apud Webster (1995), where, at most cases, the grinding wheel radial wear is reduced by the cutting oil employment.

The vegetal emulsion and the synthetic solution showed similar behavior with relation to the grinding wheel radial wear and, consequently to the G ratio, however, a little difference between the fluids may be verified. The vegetal emulsion showed higher G ratio than the synthetic solution, in other words, a smaller value of the grinding wheel radial wear.

## 5. Conclusions

Analyzing the results obtained for the plane grinding process with high cutting depth, “a”, by machining cycle (grinding wheel move cutting on the workpiece), we have come to some important conclusions:

Among the tested cutting fluids, the neat cutting oil showed the best performance with relation to the following output variables: acoustic emission, cutting tangential force and G ratio, mainly due to its great lubricating power.

The vegetal emulsion was the cutting fluid that best dissipated heat from the cutting region, proving its great cooling power.

Concerning the superficial roughness, the vegetal emulsion and the synthetic solution showed similar behavior and both better than the neat cutting oil. However, according to Webster (1995), the roughness could be reduced for the neat cutting oil, increasing the velocity and the fluid pressure at the cutting region, however, due to technical limitations, it was not possible.

It is important to highlight that the G ratio in the tested fluids was high, due to the small wear of the CBN grinding wheel with relation to the volume of the removed material.

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