STUDIES ON THE COOLING MINIMUM QUANTITY AND ON CONVENTIONAL COOLING AT HARDENED STEELS GRINDING PROCESSES

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Abstract. *The purpose of this work is to explain the concept of cutting fluids reasonable usage through the fluid minimum quantity at grinding processes. In that purpose, the development of a new nozzle and an own and adequate methodology should be required, in order to obtain good results and to compare them to the conventional methods. The analysis of the grinding wheel fluid performance was accomplished from intake steady parameters: outflow variation by nozzle diameter changes (three diameters values: 3mm, 4mm and 5mm), besides the conventional round nozzle already within the machine. As cutting fluids were used an integral oil and an emulsion. The tools or the grinding wheels used were a conventional and a superabrasive grinding wheel with vitrified bond and the workpiece were made of steel VC 131, tempered and quenched with 60HRc. Thus, as the outflow and the nozzle diameter changes, keeping steady fluid stream velocity (equal to cutting velocity), we attempted to find the best machining conditions, with the purpose to obtain a decrease on the cutting fluid volume, taking into consideration the analysis of the process output variables such as cutting strength, cutting specific energy, G ratio and roughness. A comparative analysis between the conventional and the optimized cooling will also be presented.*

Key-words: *Grinding, Cutting fluid, Grinding wheel, Optimization process.*

1. INTRODUCTION

One of the finish process of machining most employed in the precision workpieces manufacturing is the grinding. Its performance depends upon the operator's ability and sensibility and the grinding wheel machining conditions. The decisions during grinding are usually taken by the machine's operator, which, despite his many years of experience, not always has theoretical knowledge of the process (Machado and Wallbank, 1996).

This fact is specially serious in Brazil because conventional grinding wheel are yet widely employed. Those conventional grinding wheel have lower material remotion capacity and superficial quality, when compared to superabrasive grinding wheels, especially for high hardness materials grindings (above 50HRc).

The foreign competition has led the national industries to reach international standards, with even more sophisticated workpieces manufacturing, with high geometrical tolerance degree and superficial finishing, at low cost with no environment pollution. For that reason, the cutting fluids (essential for grinding processes), once discharged straight to the environment, must mow suffer preceding treatment, according to federal laws, and to a new production concept, which brings the "green stamp". The stamp informs that the processes employed in some workpiece production, do not pollute the environment.

Many researches concerning the cooling quantity decrease have been performed, once the tendency is to decrease the cutting fluid usage at machining processes for many reasons. According to Howes et al. (1991), the environmental impacts brought by the industries were not taken as crucial technical factors for some project accomplishment, however, such fact has been meaningfully changed. According to the public opinion and the government rules, the industries have started to behave in such a different way concerning their industrial garbage.

Following Quinn (1992) apud Machado and Wallbank (1996), the cutting fluids may also bring serious problems, such as health and security problems (the last one the most serious). People exposed to cutting fluids may have contact through their skin, to inhale vapors or even to swallow particles. Such things might cause dermatitis, digestive and respiratory systems problems, and in some cases even cancer, due to its high toxicity. Before the environmental matter, recycling and discharge problems as well as the fluids handling have played their role on the environmental maintenance.

Through their experiences, Bennett and Gadian (1983) apud Howes et al. (1991) came to the conclusion that the cutting fluids employed at industries are risky factors for laborers, and also that for the greatest majority of cases, the main effects from the contact with such substances are respiratory and dermatological damages.

According to Gadian (1983) apud Howes et al. (1991), the dermatological damages caused by the cutting fluid contact may occur, basically in two ways: skin irritation, through contact, ranging 50% to 80% from all cases; and the allergic effect due to contact, responsible for 20% up to 80% of all cases. The skin irritation is caused by the constant contact with the fluid; however, such effects may be avoided, decreasing the exposure time. The allergy comes from the human skin intolerance before the chemical compounds within the fluids, in which the allergy is not treatable, in such way to be fully healed.

Currently, the cutting fluids industry is researching with the variable pressure, not only to improve their products' performance, but also to protect the environment and to provide health and security. Heidenreich (1985) apud Machado and Wallbank (1996) discuss over these problems, and Deodhar (1995) apud Machado and Wallbank (1996), point out to procedures in order to control them. For that, a deeper analysis of the consequences of this type of change concerning the final status of the machined workpiece, should be required.

According to Ebbrell et al. (1999), the cutting fluid provides many benefits to industrial sector, however these fluids storage is inadequate. This way, high amounts of cutting fluids are wrongly employed at industries. As an example of bad employment, at many industries, great fluid dispersion at the machining time, take place, leading to great fluid loss. The lubrication and cooling depend upon the actual fluid intake at the workpiece's cutting region with the tool, with no high fluid volume requirements, even if part of this fluid would not be passing through the adequate region. The type of nozzle positioning performs great influence on the cutting process.

Following Webster (1999), some caution should be taken with the employment of water-base cutting fluids, when compared to oil-base cutting fluids, once the first ones have small density, so that great fluid dispersion at the fluid employment to conventional round nozzle, might occur. This way, great cutting fluid quantity is required in order to compensate the dispersion loss, and also the employment of high load machinery, with huge cutting fluid reservoirs, cooling units and high power pumps.

The target of this research are all industries which employ cutting fluids in grindind, with the purpose to rationalize their usage, making machining process possible with meaningful decrease on fluid discharge cost (sometimes up to 30 times the purchase cost), which could only be made by specialized enterprises. So, with the reduction on the fluid volume required in the porcess, there will be a consequent reduction on the discharge cost.

2. REMARKS CONCERNING THE GRINDING PROCESS

2.1. Grinding wheel

According to Krar and Ratterman (1990), the grinding wheels, most important products manufactured from abrasives, are composed of abrasive grains linked by an adequate bonding material. The main purposes of grinding wheels at the metallurgical industry are: the generation of plane, cylindrical an/or composed (plane and cylindrical) surfaces; the removal of tough grinding usually hard materials; the output of good finish surface with controlled and dimensional errors.

Nailor (1989), already assured, back in 1989 that machining with superabrasive grinding wheels should provide output lower cost by workpiece, of about 30% up to 50%, comparing to machining with conventional grinding wheels, once machining conditions promote the least wearness as possible of its cutting surface (grinding wheel surface responsible for metal removal from the grinded workpiece)

For Klocke and König (1995) the grinding process improvement may be only achieved with the employment of superabrasive grains such as CBN. The high performance of the abrasive material is due its extreme hardness and its wear strength, allied to its high temperature resistance and thermic conductibility (heat absorbing capacity). At CBN grinding wheel field, a fast growth of vitrified bonding employment in industries is observed. This type of bonding is fragile and extremely resistant to wearing, and also has good thermic stability. Another meaningful advantage on the employment of bonding at CBN grinding wheels comes from its good porosity and good self-sharpening properties, what usually simplifies the conditioning method.

2.2. Cutting fluid

In the grinding process, the chip originated from the material removal begins through the action of several cutting corners, aleatory spread and guided at the grinding wheel. Following Kovacevic and Mohan (1995), this material removal is followed by a high energy requirement.

According to Mayer and Fang (1993); Jahanmir and Strakna (1993), due to health and environmental agencies pressure, the cutting fluid manufacturers have industrialized "healthier" products for the tool-machine operator and less dangerous for the environment.

The conventional methods for cutting fluids employment are not much different from one another especially under severe employment conditions. In most cases, the stored energy in the fluid during its employment is not enough to overcome the grinding wheel centrifugal force or to penetrate the air barrier around the moving grinding wheel. Following Guo and Malkin (1992), the efficiency of cutting fluids is no smaller than 5% and no greater than 30%.

The cutting fluids are shown as an important part of the workpieces manufacturing, through chips removal, within a context including the operating machine, the cutting tolls, the workpieces output and the cutting fluids (Runge and Duarte, 1990).

In some cases, the cutting fluids employment at machining might reduce costs, increase output and generate profits, since the adequate type of cutting fluid is chosen. This chosen cutting fluid must also follow specific machining conditions, in which it will be exposed to, thus allowing its better performance (Motta and Machado, 1995).

Following Minke (1999), the great friction from the grinding process is such an important factor, which takes place in the machined workpiece final status. This way it's so important the development of fluids with higher friction reduction capacity in order to turn machining ecologically and economically viable.

3. METODOLOGY

For the performance of the tests and of the studies on the influence of process intake parameters (type of cutting fluid employment, type of employed cutting fluid and type of grinding wheel), were developed a set of tests, which could express the obtained results adequately. The set of tests was divided into two parts: computational and mechanical, this last one composed by CNC cylindrical grinder belonging to the Lab of Machining by Abrasion (LUA), manufactured by SulMecânica enterprise.

3.1. Computational part

For the acquirement of cutting tangential force values and the grinding specific energy in real time, the so-called LabView software program was developed, employing a data acquirement plate from National Instruments enterprise.

The software records the tension values related to the electric power required to start the motor. With the electric power values (P_e), the abrasive disc axis rotation (n) and the grinding wheel outer diameter (d_s), the cutting tangential force is obtained (F_{tc}), which is obtained by the Eq. (1):

$$F_{tc} = \frac{2 \cdot P_e}{d_s \cdot n} \qquad (1)$$

Thus, with the cutting tangential force measurement and with the grinding wheel rotation values (n), the grinding wheel peripheral velocity (v_s), the grinding width (b), the grinding wheel diving velocity (V_f) and the workpiece diameter (d_w), the specific grinding energy (u_c) is easily controlled at real time on screen for the data acquirement, through of the Eq. (2):

$$u_c = \frac{F_{tc} \cdot v_s}{b \cdot d_w \cdot v_f \cdot p} \qquad (2)$$

3.2. Mechanical part

Besides the computational part, the set of tests was composed by a cylindrical grinder, in which the workpiece to be machined was fixed. In that purpose, two types of fluids were employed (a 5% emulsion and a integral oil). Four cutting fluid employment methods were also employed on the workpiece. The first one through a conventional nozzle, and the other three with round nozzles of different diameters. Figure (1) shows the cylindrical grinding machine (model RUAP 515 H-CNC), the workpiece, the optimized nozzle of 3 mm of diameter and one of the grinding wheels to be employed during the test.

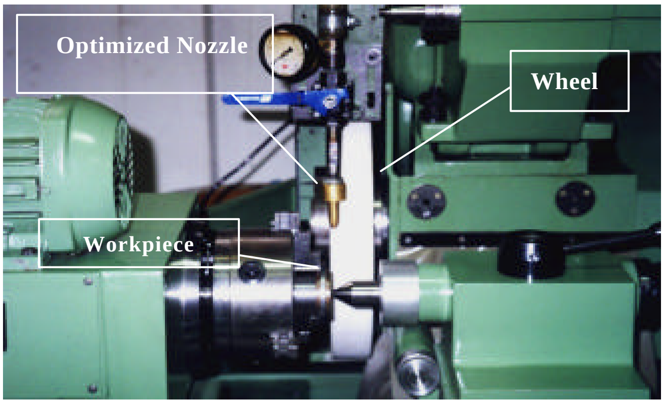

Figure 1. General disposition of employed components

The material of test specimens was the VC 131, tempered and quenched, 60HRc, in a cylindrical shape. Were performed 100 grinding cycles at workpiece (whereas each grinding cycle removed 0.1mm from the diameter of the workpiece), for all tested nozzles. Two grinding wheels were used, one aluminum oxide conventional grinding wheel specified 38A46KVS and one CBN superabrasive grinding wheel specified B151K150V17M3, manufactured with vitrified alloy.

The cutting conditions applied in the grinding tests were: cutting speed (vs)=33m/s; workpiece diameter (dw)=60mm; spark-out time of 8 seconds; plunge speed (vf)=1.5mm/min; heq=0.025µm; grinding wheel penetration (a)=100µm, grinding width (b)=3mm.

At the end of each test, the roughness measurement as well as the grinding wheel radial wear marking were performed in a 1020 steel clamp reserved for this purpose as shown in fig. (2).

Figure 2. Grinding wheel diametral wear measurement

4. RESULTS AND DISCUSSION

4.1. Cutting Tangential Force

The fig. (3) shows the tangential force behavior and the scores acquired during grinding process.

In order to get a better comparative effect, three repetition tests for the same machining condition were performed: cutting fluid, grinding wheel, advancement velocity and nozzle diameter. The cutting tangential force analysis was obtained through score filtration by a mathematical operation and the maximum values of each grinding cycle were taken. There are four grinding cycles in fig. (3). From the maximum score, a mathematical average was calculated in order for a convenient value to be reached, possible for a comparison with the other test conditions proposed by the research. Figure (4) shows the effective cutting tangential force results comparatively for the types of nozzles and fluids employed.

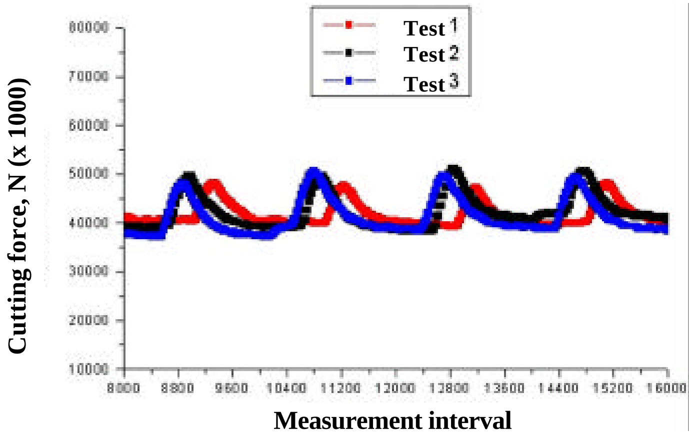

Figure 3. Example of cutting force behavior and the points acquired during grinding process

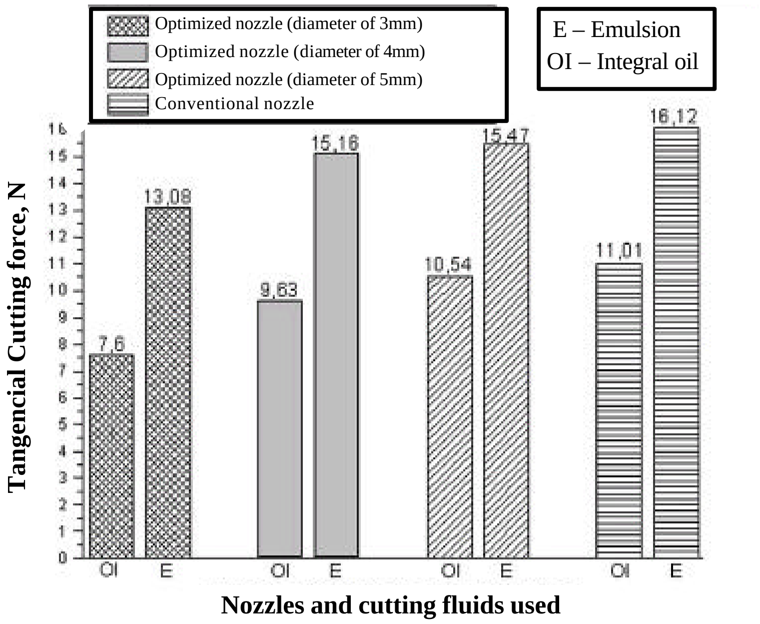

Figure 4. Cutting force and nozzles employed for both types of fluid

Analysing fig. (4), can noticed that the 3mm diameter optimized nozzle, employing integral oil as fluid, was the one with best performance, proving its efficiency, manufactured for this research. Generally analysing, can also observe that the integral oil behavior was better than the fluid 5% sinthetic emulsioin-base. This phenomenon is explained by the following factors: the oil lubricating power is greater than the emulsion's power and the integral oil is denser than the emulsion, what makes it to break the air barrier between the workpiece and the tool, both running, reaching the cutting region easier and more effective than with the emulsion employment.

Concerning the variations, for the same nozzle (concerning the greatest variation, 3mm diameter optimized nozzle), the tangential force, with emulsion employment, was 72% greater than the integral oil employment. For a wider analysis, the efficiency for the smaller nozzle with integral oil was 112%, comparing to the conventional nozzle with 5% synthetic emulsion.

Therefore, the manufacturing and employment of smaller diameter nozzle, with integral oil employment, was the most effective condition in all research, for the effective cutting tangential force. For the same nozzle diameters, the emulsion-base fluid was effective, but only when compared to the same, once it has lower performance comparing to the integral oil.

4.2. Grinding specific energy

The grinding specific energy was obtained straight from a relation between the effective cutting tangential force and the cutting velocity. In the same way for the cutting force, the scores were filtered and further each cycle maximum values were collected and an average was calculated from the three tests, in order to facilitate the performance analysis of each nozzle and each fluid employed, as shown in fig. (5).

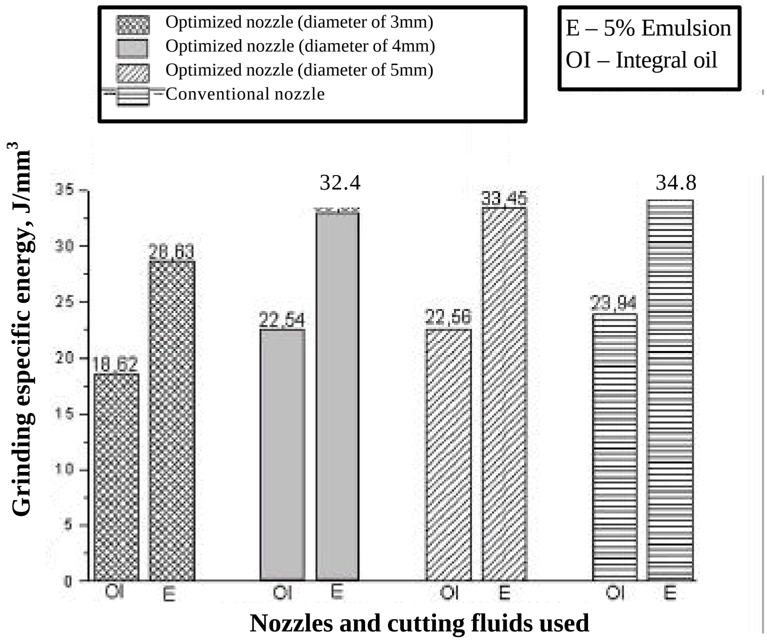

Figure 5. Grinding specific energy and employed nozzles for both types of cutting fluids

The lubricating oil had better lubricating power than the synthetic emulsion, what makes it to reduce more easily, the energy spent at the test bodies' grinding process. Analyzing the 3mm diameter optimized nozzle, the integral oil has a performance of 54% comparing to the emulsion-base fluid, once due to the phenomenon of breaking the aerodynamic barrier within the workpiece and the tool (moving), the integral oil fluid jet is even more directed towards the grinding region. For this, the tool has a lower friction force (against the movement) to overcome and, therefore, less energy is required.

The best performance on the grinding specific energy reduction was with the employment of smaller diameter nozzle together with the integral oil fluid employment, which has an improvement range of 86% comparing to the conventional nozzle.

4.3. Roughness

The aluminum oxide grinding wheel was employed in tests, where roughness was measured, and roughness values were measured at four different points of the workpiece at each machining condition. From these values, the arithmetic average was calculated as shown in fig. (6).

The roughness values, when the emulsion-base fluid was employed, were greater than when integral oil was employed, due to the oil higher density and lubricating power, what leads to a better finish piece.

A progressive increase of the superficial roughness values was observed with the increase of the employed nozzle diameter and with the change from emulsion to integral oil, once the fluid jet pressure at the grinding region decreased, then leading to a lower effectiveness of process concerning the finish result.

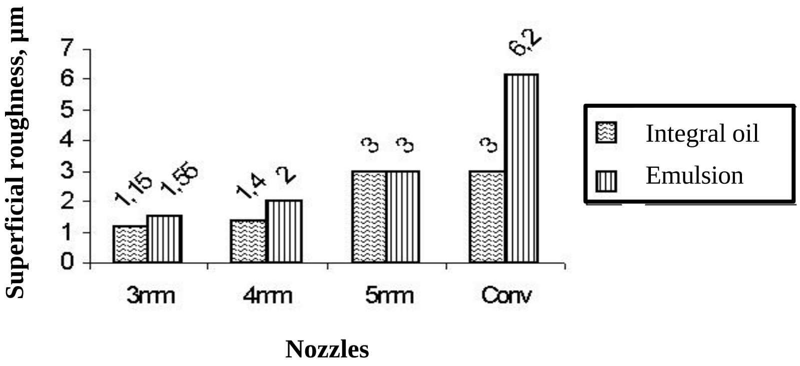

Figure 6. Superficial roughness in the workpieces after of the use of different nozzles

Concerning the equal values for both the 5mm diameter and the conventional nozzles with the employment of integral oil fluid is due to two important factors: the pump effectiveness loss, as it would not distinghish the required pressure for the respective nozzle as well as temper problems, bringing on the workpiece's final regions to have alike properties, even with the proposed variations for the tests.

For the conventional nozzle, the great difference between both fluids employed for the tests (107%), is due to the difference of density between them, bringing about, for the integral oil, the breaking of air barrier between the workpiece and the cutting tool, and therefore, making the lubricating properties to be better applied.

The 3mm diameter optimized nozzle along with the integral oil fluid was the condition that best showed the superficial result, in other words, the lowest roughness. The jet pressure at this condition is better directed toward the cutting region, together with the fluid highest density. That makes the toll to work with lower cutting force, and to improve the workpiece a better finish.

In a more general analysis, there was a great roughness variation when values from 3mm diameter nozzle with integral oil and from conventional nozzle with sinthetic emulsion-base fluid are compared, 440% approximately, showing the outstanding outcome of this nozzle for outer cylindrical grinding process.

4.4. G ratio

G ratio was acquired for all tests performed with aluminum oxide grinding wheels. For each machining condition, a value from this variable was measured, and then the fig. (7) was drawn.

The grinding wheel wear is straight related to the cutting tangential force and, consequently, to the employed fluid lubricating property. The integral oil has the required preperty better than the 5% synthetic emulsion, and since the cutting force increased as the nozzle diameter increased; the wear also followed this behavior.

The "breaking" of the wear growth by the 4 and 5 mm diameters nozzles with integral oil and synthetic emulsion fluids respectively, is due to the temper differences of each tested workpiece, leading to different variations in the toll wear. Factors such as the pump non-accuracy and the fluid density, as explained for the preceding variables, also apply to these results.

It is interesting to notice the values next to the 4 and 5 mm diameter nozzles for both cutting fluids. The phenomenon that explains such fact is the pump "inaccuracy", once for this range of power to be supplied, the pump cannot distinguish it. Figure (8) highlights the 3mm diameter conventional and optimized nozzles results for both employed fluids.

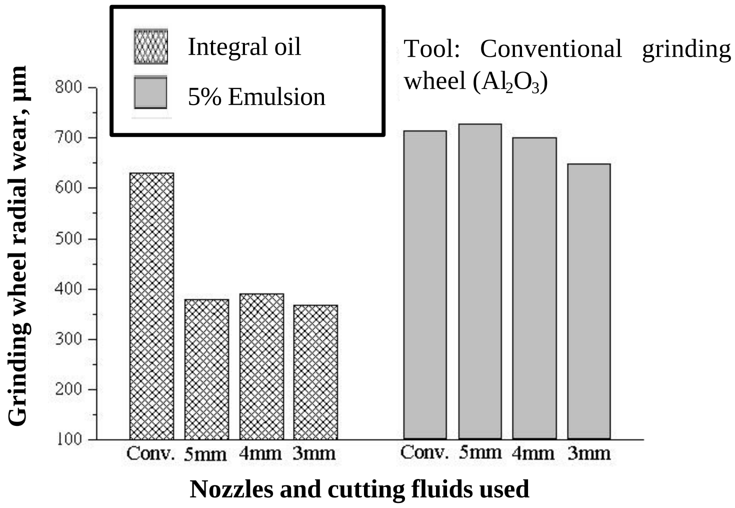

Figure 7. General results from the grinding wheel radial wear with the employed nozzles and fluids

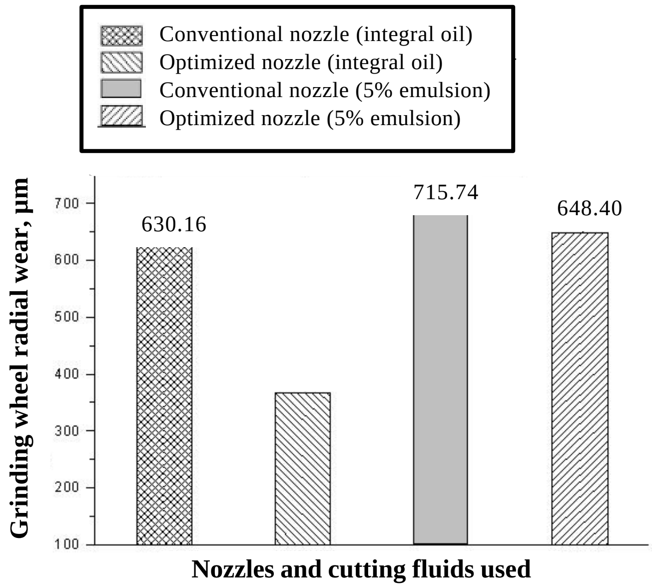

Figure 8. Optimized and conventional nozzles analysis

Figure (8) shows that were of 76% and 16% the differences between the optimized and conventional nozzles respectively, with the employment of integral oil and synthetic emulsion-base fluids, proving, once again, the great importance of the lubricating property and the oil density, and 95% was the greatest difference for the outlet variables: G ratio, because due to the low cutting force, explained by the lower toll effort, better fluid guiding and also better oil lubrication; such factors decrease the friction force, which acts against the material cutting, there was a smaller material loss from the aluminum oxide grinding wheel, leading therefore, to a smaller wear relation for the employment of 3mm diameter nozzle, along with integral oil.

5. CONCLUSIONS

The 3mm diameter optimized nozzle, manufactured for this research, along with the employment of integral oil, was the best combination among all proposed, for the great reductions of values from the outlet variables.

In order to get a better finish of pieces and a longer tool useful life, fluid must be applied effectively between tool and workpiece, and the smallest nozzle performed the task successfully. It also decreased the tool effort (and consequently its wear), due to its better guiding and higher fluid jet pressure.

The roughness was also reduced with the employment of the integral oil and the 3mm optimized nozzle, bringing advantages and better superficial results.

Concerning the worldwide reality, which employes the least amount of cutting fluid on grinding processes as possible, with no damage for the process at all, can be observed that the employment of optimized rather than conventional nozzles was extremely viable and favorable, once the conventional nozzle runs with a higher cutting fluid quantity at the grinding zone.

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