STUDY ON THE MINIMAL QUANTITY OF COOLING AND CONVENTIONAL COOLING IN GRINDING PROCESS FOR THE VF 800 STEEL

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Abstract. *The employment of grinding processes has increased in the last few years, and for that reason, industries have employed much higher volumes of cutting fluids. Such statement could be extremely advantageous if treatment and waste disposal processes were not so expensive and illegal as well. So, this work is based upon the concept of the cutting fluid's rational use through the minimal quantity of cooling in grinding processes. The purpose, however, consists in the experimental analysis of the cutting tangential force behavior, superficial roughness, acoustic emission and G ratio through the employment of the minimum quantity of cooling, when compared to the conventional process of cutting fluids employment. The parameters to be analyzed in this work are the variation of the fluid outflow (three values), one conventional grinding wheel, one feed rate, two types of cutting fluids and some different nozzles (conventional and optimized nozzles) . The results showed that the best combination was a nozzle of 3mm of diameter with the integral oil as cutting fluid.*

Key-words: *Grinding, Optimized process, Minimal quantity of cooling, Cutting fluid.*

1. INTRODUCTION

Currently, when new technologies are available, the development of even more sophisticated workpieces, with high geometric and dimensional tolerance level, at low cost and mainly with minimal environmental contamination becomes necessary. Several conventional machining processes employ cutting fluids as lubricating and cooling means of the produced workpiece. So, cutting fluids usually employed for the grinding process are discharged to the environment. Currently, due to new laws for the protection of the environment, such excessive cutting fluid waste is no longer accepted.

Once the "green label" was created, the achievement of researches highlighting the importance of decreasing the use of cutting fluids, once such label states that processes employed on the output of certain workpiece would not do any harm to the environment, and this way, the mass employment of cutting fluids is indeed decreasing, researches in order to decrease the interference of such substances on the environment and therefore, on the productive sector, become necessary. In that purpose, a deeper analysis of the outcome of such alteration concerning the final status of the machined workpiece is required.

Industries, which employ the grinding process, many times discharge great amounts of cutting fluids at the environment. Such behavior has brought problems of great relevance. So, this work has as its main purpose the achievement of researches with the purpose of rationalizing the use of cutting fluids in grinding processes.

Besides the environmental regard, the comparison of the results obtained for the minimal quantity cooling to results obtained for the conventional cooling employed in most industries, was made. Such results will allow us to analyze what types of cutting fluids the grinding process with minimum cooling quantity would best match as well as to analyze in which grinding conditions the process would statistically obtain the best results.

2. BIBLIOGRAPHICAL REVIEW

According to Ebbrell et al. (1999), many are the benefits provided by the cutting fluids to the industrial sector; however, the storage of such substances has been made in an improper way. So, high amounts of cutting fluids have been improperly employed at industries as well. As an example of such harmful employment, fluid scattering occur in many industries bringing great losses of fluid. The lubrication and cooling depend upon the actual intake of fluid at the cutting region of the workpiece with the tool, this way, the required volume of fluid is not so great, even though part of it does not actually penetrate the cutting region. However, the nozzle type and position meaningfully influences the cutting process.

According to Webster et al. (1995), a fluid jet happening right on the cutting region is able to meaningfully reduce the temperature at the cutting region, however, high jet velocities are required in order to actually penetrate the cutting region. Through the use of a round shaped nozzle, a meaningful reduction on the temperature at the cutting region was observed, when compared to the conventional jet. One also observed that the angle of incidence of the jet at the cutting region does not meaningfully change the cooling of the workpiece, however the tool's peripheral velocity related to the jet is so meaningful to the cooling process of the workpiece.

Still according to Webster et al. (1999), great volumes of cutting fluid are no longer required, due to the increase of productivity at industries and the improvement of the process employment. Certain attention should be taken with the use of water-base cutting fluids, when compared to oil-base fluids, due to the low density of the first one, bringing great fluid scattering at the moment of its use, when conventional nozzles are employed. This way, as great volumes of cutting fluid is required in order to compensate the losses brought by the fluid scattering, the adoption of large machinery with huge fluid reservoirs, cooling units and high power pumps, has become necessary. Another problem to be analyzed is the air barrier placed between the nozzle and the workpiece, which should be overcome by the cutting fluid, bringing fluid scattering during its penetration at the cutting region, and the use of an effective nozzle in order to avoid such situation should be again necessary.

According to the article "*environmental correct technology for the internal cylindrical grinding*", a research was performed in order to evaluate the minimal quantity lubrication (MLQ) for the internal cylindrical grinding, as an environmental correct alternative to the conventional soluble oil (or ester oil of non-carcinogenic inoffensive characteristics). As final result, concerning all parameters involving the minimal quantity of lubrication employment process for the internal cylindrical grinding, we could observe that the ester oil brought better results as lubricant, when compared to the conventional soluble oil.

3. METHODOLOGY

The experimental setup was basically composed by a cylindrical grinder, in which the devices were installed in order to allow the performance of the tests with the designed nozzle with the same characteristics as the nozzle employed in the work preformed by Webster (1995), as shown in fig. (1), a acoustic emission measurement device model BM 12, label Sensis, attached next to the tailstock as well as a rugosimeter further employed in order to obtain the roughness arithmetic average values of the ground workpiece.

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. Were used a conventional grinding wheel of Al_2O_3 and an integral (whole) oil and a emulsion as cutting fluids. Figure (2) shows in details the illustrative outline of the arrangement of devices installed at the grinder for the performance of the tests.

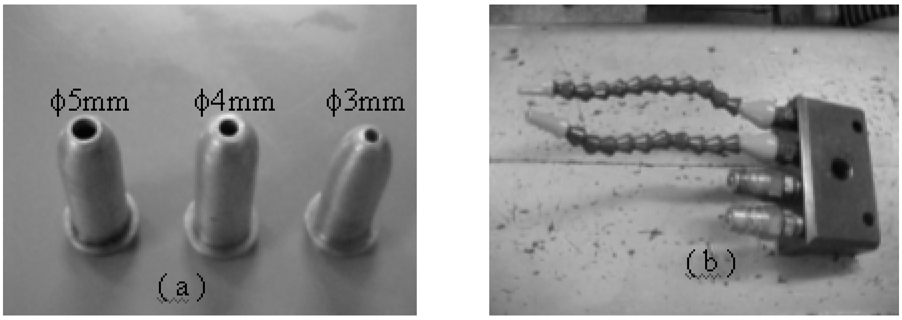

Figure 1. Nozzles. (a) Optimized nozzle; (b) Conventional nozzles (6mm of diameter);

The tests were performed until they reached a certain pre-established limit on the volume of removed material from the workpiece, fixed through preceding tests. This way, we intended to highlight the workpiece's behavior, besides making possible the achievement of recurrence of the tests in order to obtain statistically more trustable database.

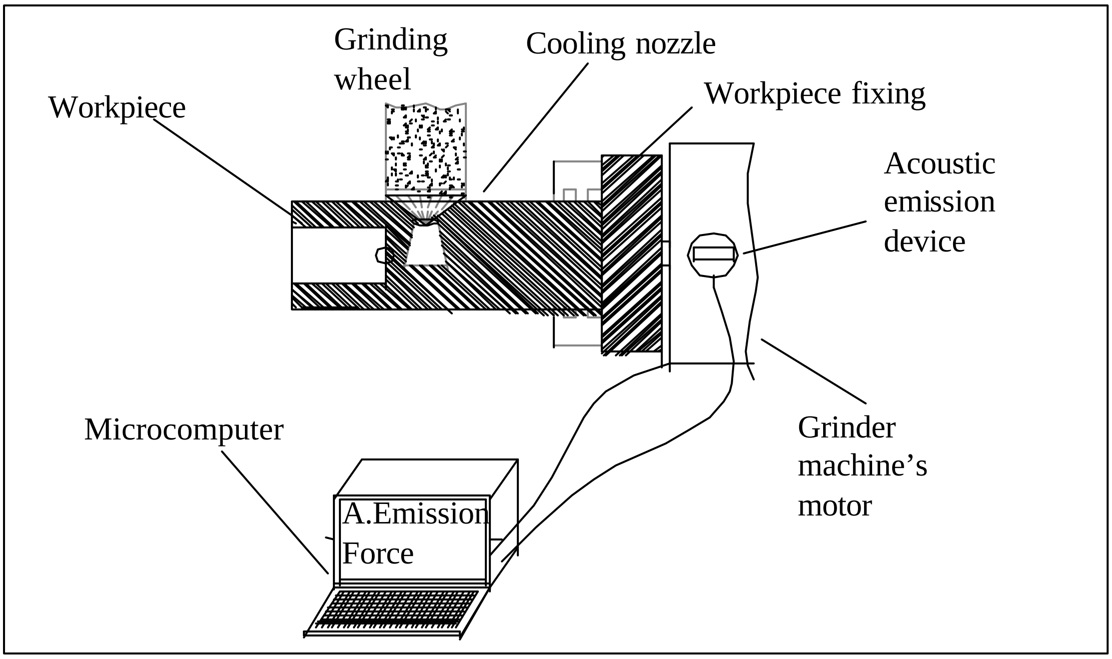

Figure 2. Illustrative outline of the tests

4. RESULTS AND DISCUSSION

4.1. Results of Cutting tangential force

The first output variable to be analyzed is the cutting tangential force. The LabVIEW software was employed for the attainment of such variable, through which all points of force during the process were obtained.

Figure (3) shows the graphic values, in a certain measurement space, relating to the moment of the material cutting, as well as the spark-out interval, employing the conventional grinding wheel and the emulsion oil as cutting fluid. The following figure enlightens it all.

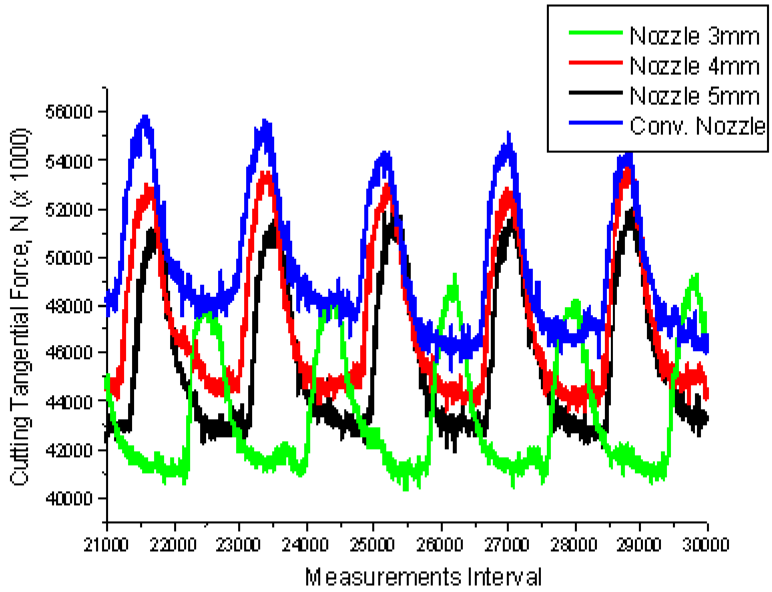

Figure 3. Tangential force *versus* measurement intervals (Emulsion oil)

From this graphic, one may conclude that all processes employing the minimum quantity lubrication, during the grinding process, produced values lower than the conventional cooling.

Such graphic features only one measurement interval, showing some points from the grinding process; however, the integral process has the same behavior concerning this interval. Indeed, concerning the tangential force, the optimized fluid employment is quite fair.

Yet, the nozzles with the minimal quantity cooling, the nozzles with 3mm and 5mm are the ones showing the lowest values for the tangential force. The nozzle with 4mm shows a worse behavior if compared to the last two nozzles, but still showing better results comparing to the conventional cooling.

Figure (4) shows graphs of the cutting tangential force of the grinding process employing the conventional grinding wheel and integral oil as fluid for the four employed nozzles. Such graphic is based upon the general identification of an interval from the integral grinding cycle, verifying the cutting process itself as well as the spark-out moments.

As we analyze this graphic, we observe that the integral process show lower values for the tangential force when it is applied to the minimum quantity of cutting fluid. However, among the employed optimized nozzles, the nozzle with 3mm was the one showing the best results, followed by the nozzles with 5mm and 4mm respectively.

After analyzing both graphics, it was observed that the use of the minimal quantity cooling related to the cutting tangential force output variable, for the grinding wheel conventional type, is higher than the conventional cooling employed by the majority of industries, which employ the external cylindrical grinding process.

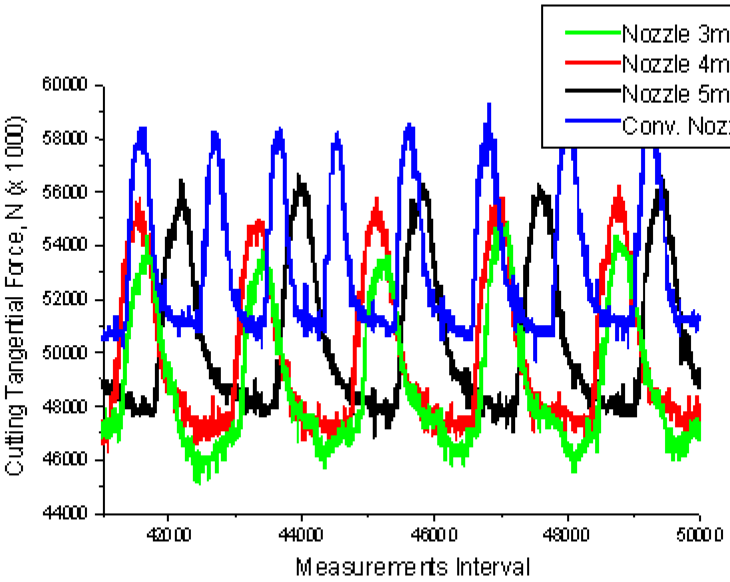

Figure 4. Tangential force *versus* measurement intervals (integral oil)

4.2. Results of acoustic emission

Another variable to be analyzed is the acoustic emission, through which we will be able to measure the sound activity at the moment of cutting of the workpiece. The acoustic emission device was fixed to all the tests near of the grinding zone.

It is noticed that, at the moment of the tests, the graphic corresponding in the LabVIEW (software employed for the database acquisition) has a waving behavior, in other words, the curve trends to increase when metal is being cut, and to decrease when spark-out takes place, where there is no cut at all.

Therefore, through this variable, it is possible to verify what the highest acoustic emission level is obtained in the cutting process. This way, one would be able to tell which process is under the highest and the lowest grinding strength.

Two graphics are drawn, whereas the first one shown in fig. (5) is related to the use of the emulsion as cutting fluid, while the second one, integral oil as cutting fluid.

The first graphic (fig. (5)) shows the acoustic emission peaks for the employed nozzles, when emulsion oil is employed. Through this graphic, we observe that the nozzle with the best behavior is the one with 3mm diameter. We also observed that for the integral cutting cycle, such nozzle seemed to show the lowest acoustic emission level if compared to the others employed.

Indeed, the 4mm nozzle as well as the 5mm one have low outflows, however, it is observed that both have similar behavior comparing to the conventional nozzle, where no meaningful differences in the acoustic emission level are observed. Therefore, with the employment of quantity of fluids lower than the conventional cooling, lower or at least equal acoustic emission levels are obtained.

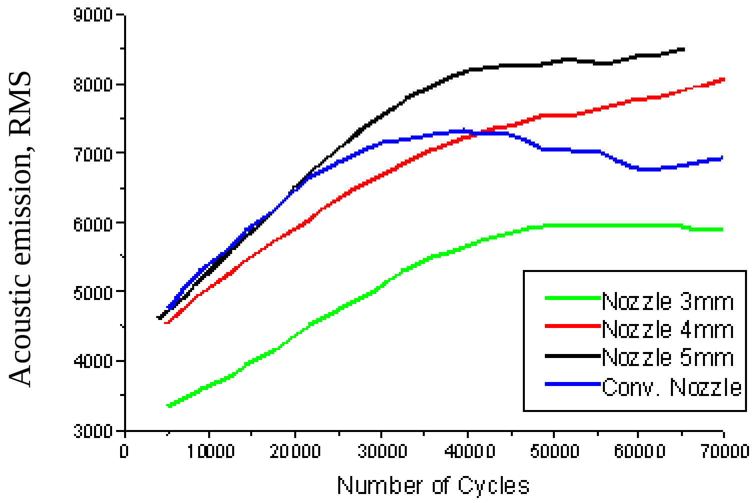

Figure 5. Acoustic emission *versus* Number of cycles (Emulsion oil)

Therefore, with the analysis of such variable, we can say that the applied minimum quantity of cutting fluid is greater or equal to the conventional cooling with the use of the conventional nozzle, whereas the best result was achieved with the nozzle of 3mm diameter.

The second graphic shown in fig. (6) relates the acoustic emission level for the four employed nozzles during the number of cycles, employing integral oil as cutting fluid. For the drawing of it, all points found during the cutting process were set in order to further find the highest emission values (peaks), and consequently to plot them with the aid of a software.

As we analyze the graphic from fig. (6), we notice that the curves corresponding to each application nozzle have certain physical similarity. There are no meaningful differences from one curve to another, once the values are approximately near to one another.

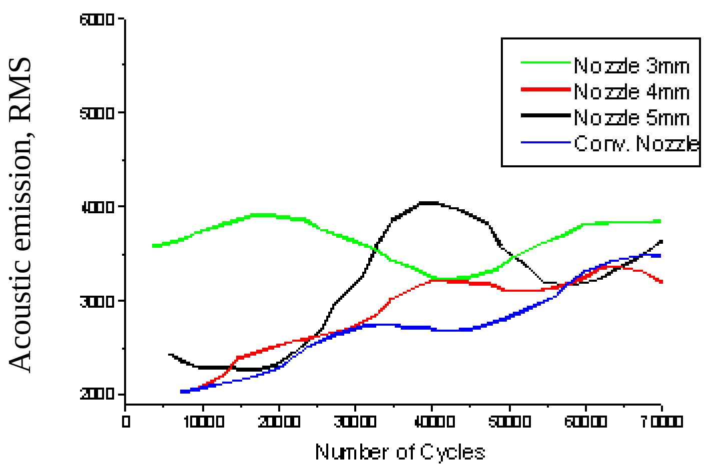

Figure 6. Acoustic emission *versus* Number of cycles (integral oil)

However, we may conclude that the minimum quantity cooling, when integral oil is employed, is just as effective as the conventional cooling, concerning the acoustic emission. So, we can say that the results are also good, since the acoustic emission level of a conventional or optimized cooling had no alteration at all, even though the quantity of the employed cutting fluid had been reduced.

From the detailed analysis of the nozzle of 3mm diameter, we notice that the behavior of its curve disagrees a lot from the others. We also notice that the values of the peaks shown in the graphic have the same steady behavior during the integral grinding cycle. Therefore, we can say that the acoustic emission behavior, when nozzle of 3mm diameter is employed, is quite regular, showing no meaningful changes during the integral process.

It is worth to highlight that acoustic emission acquirement has been considered quite complicated, since it depends on a few elements, which may influence such results. For instance, depending on the fixing force of the acoustic emission sensor in the tailstock, the results might be several. Therefore, such variation is quite acceptable.

4.3. Results of surface roughness

Another variable to be analyzed is the superficial roughness. As the name suggests, this variable shows how "well finished" is the workpiece after the grinding process.

In order to perform the measurements, a rugosimeter was employed, where several measurements on the tangent region at many points of the round workpiece were performed in order to confirm the validity of the results, and from those measurements, an average was found and plotted into a graphic.

Such graphic, shown in fig. (7), is made up by the four types of the employed nozzles, as well as by all types of cutting fluids for grinding with conventional grinding wheel.

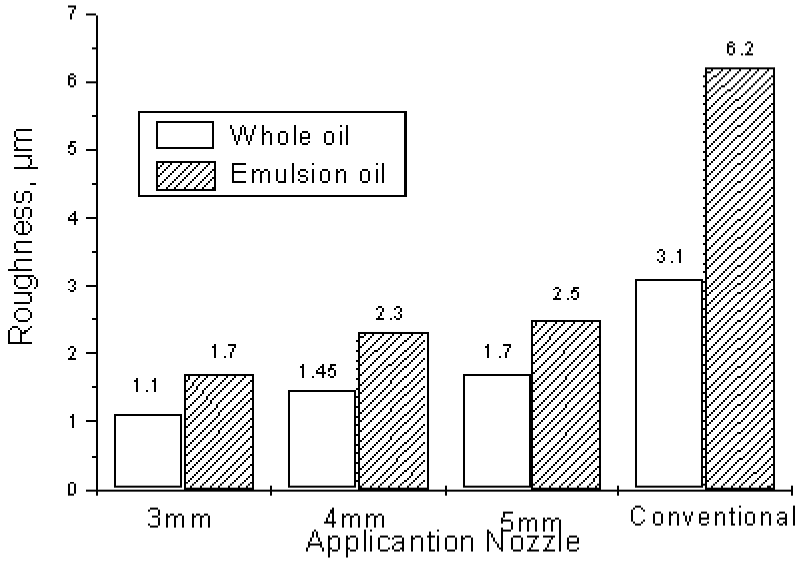

Figure 7. Superficial roughness *versus* application nozzle

The roughness values, when emulsion-base cutting fluid was employed, were higher than values when integral oil as fluid was employed. Such fact is explained by the oil higher density and lubricant power, bringing a better superficial finishing.

The superficial roughness results progressively increased as the diameter of the employed nozzle also increased and as the use of the emulsion was exchanged to integral oil as cutting fluid, since the jet pressure of the fluid at the grinding region decreased, so the process was not quite effective concerning the finishing.

There is a great difference of roughness between the employed fluids for the conventional nozzle. However, it becomes simple to explain that such difference is due to the barrier breakage performed by the integral oil into the workpiece due to its high density, applied to high outflows, allowing a good lubrication of the machined workpiece, which outcome is a better superficial finishing of the workpiece, comparing to the use of emulsion oil.

The emulsion oil, in turn, showing lower density, is not able to outstrip the barrier well enough, bringing a worse quality of finishing to the workpiece.

The best result showed so far, concerning the superficial roughness, was the result showed by the 3mm optimized nozzle, employing integral oil as fluid. It is worth to highlight that all optimized nozzle showed better results comparing to the conventional nozzle. However, we can say that the 3mm nozzle was the best one also due to a better jet position of the fluid on the workpiece.

In a general analysis, there was a great roughness variation when the values of 3mm, 4mm, 5mm and the conventional nozzles are compared to one another for both employed fluids. Such fact allows us to say that the optimized employment of the cutting fluid brings good results for the superficial roughness output variable.

4.4. Results of G Ratio

The variable G ratio is finally analyzed, which was measured and analyzed for all employed workpieces. For each grinding condition, concerning the variation of both the cutting fluid and the application nozzle, the following results, which are analyzed through the graphics, were obtained.

The next graphic (fig. (8)) is related to the grinding wheel diametric wear with the employed fluids and nozzles.

The grinding wheel wear is straightly related to the cutting tangential force and, consequently, to the employed fluid lubricant properties. Through the analysis of this graphic, one notices that the use of the minimal quantity cooling showed better results than when the conventional nozzle was employed.

Concerning the grinding processes with the minimal quantity of lubrication, we should highlight that the 3mm diameter nozzle showed the lowest values for the G ratio variable. However, it is worth mentioning that the 5mm and 4mm nozzles, for the both employed cutting fluids, also showed better results comparing to the conventional nozzle, this way showing the optimization validity, when such variable is concerned. Factors such as the non-accuracy of the pump and the fluid density might have influenced, but not invalidated such results.

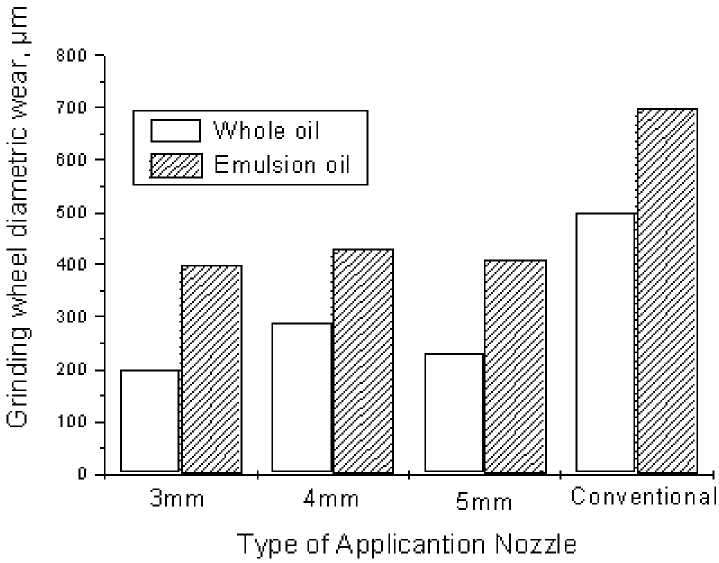

Figure 8. Grinding wheel diametric wear

As mentioned before, the G ratio has characteristics straightly proportional to the tangential force, since due to the low cutting tangential force, explained by the lower tool's strength, the better is the position of the fluid jet and the better is the oil lubrication. Due to factors that decrease the friction force, which works against the cutting of the material, the loss of material from the aluminum oxide grinding wheel was smaller, this way bringing a smaller wear relation for the use of the 3mm diameter nozzle and integral oil as cutting fluid.

5. CONCLUSIONS

The 3mm diameter optimized nozzle with the use of integral oil as cutting fluid, was the best match for great reductions of values from the proposed output variables.

In order to obtain a better finishing and a longer tool life, the fluid should be placed just where such advantages actually occur – at the cutting edge between tool and workpiece, where the smallest nozzle successfully performed such task.

The nozzle also decreased the tool's strength (and consequently its wear) for the material removal, due to its better positioning and the higher fluid jet pressure. It is worth highlighting that the viscosity from the strength of cutting oil provides a "hydraulic muffling", reducing shock and the abrasive wear.

The acoustic emission as well as the roughness also decreased with the use of the match mentioned at the first paragraph, bringing advantages such as the noise reduction and the better superficial finishing.

We attempt to evaluate the minimal possible use of cutting fluids in the process, and therefore, database allowing an advantageous work conclusion concerning the mentioned output variables were obtained. Through such database and results, many industries, which employ the cylindrical grinding process, will be able to have advantages through the identification of cases in which tools can save cutting fluids with no harm for the final quality of their products, reducing costs with the minimal environmental contamination. Besides, such behavior sums up credits for the acquisition of the worldwide-recognized "green label".

It is also worth mentioning that the 5mm and 4mm application nozzles showed good results as well. Both showed better results when compared to the conventional nozzle. However, the 3mm optimized nozzle, as already mentioned, showed the best results of all, even better than the two other ones. Maybe some factors might have contributed for the better performance of the 3mm optimized nozzle, rather than the 4mm and the 5mm nozzles.

One of these factors maybe related to the better positioning of the cutting fluid jet between the grinding wheel and the machined workpiece, since a lower fluid quantity was employed, an accurate positioning of the fluid jet on the correct region should be obtained.

Another important factor is the inaccuracy of the employed pump, as also already mentioned. Such pump might not have fixed the correct fluid quantity for each employed nozzle.

However, can be said that this experiment was successfully accomplished concerning the results. We could prove that an optimized nozzle, applied to low outflows and high pressures, may show improvements to the grinding process if compared to a nozzle applied to high outflows and low pressures, such as the nozzles currently employed by the majority of industries.

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