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EVALUATION OF PLUNGE CYLINDRICAL GRINDING OF AISI 4340 STEEL UNDER THE APPLICATION OF THE MINIMUM QUANTITY LUBRICATION COOLANT TECHNIQUE ASSISTED WITH WHEEL CLEANING SYSTEM

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Abstract. *The MQL coolant delivery method promotes the substantial reduce of amount of cutting fluid employed in machining tests, mitigating of risks to people's health. This technique is also related to environmental sustainability and economic benefits. Nevertheless, one of common problems related to the MQL usage is wheel clogging phenomenon. The final quality and finishing is impaired by the accumulation of a lubricant mist on the wheel surface intrinsic to an inefficient chip removal. On this way, this study evaluated the plunge grinding of AISI 4340 steel with aluminium oxide wheel under application of the Minimum Quantity Lubrication coolant technique assisted with wheel cleaning jet with the main purpose of reducing risks to health and environment. This method carried out with the following flow rates: 30, 60 and 120 ml/h. The results recorded were compared with the ones obtained in tests under application of MQL without wheel cleaning and the conventional coolant method; all tests occurred at the same grinding conditions. The output variables analyzed were: roughness, roundness, diametrical wheel wear, acoustic emission and microhardness. The MQL technique assisted with wheel cleaning jet outperformed the MQL technique without cleaning system showed performance similar to the conventional method with flow rates of 60 and 120 ml/h in terms of the results obtained for all output parameters investigated. Through the optical microscopy, it could be attested the non-occurrence of thermal damages and cracks on the machined surface and sub-surfaces after grinding AISI 4340 steel irrespective of the technique.*

Keywords: *Cutting fluid, MQL technique, Flow rate, Cylindrical grinding, Alumina Oxide wheel.*

1. INTRODUCTION

Cutting fluids play important roles in grinding processes; they are related to cooling and lubricating the contact zone between workpiece and grinding wheel. They also remove and clean chips in the cutting zone, increasing the service life of wheel grinding and the quality of workpiece. When the cutting fluid isn't efficiently employed, the intense interaction between tool abrasives and workpiece generates large amount of heat which is directed to the workpiece due to the low thermal conductivity of conventional abrasives at high grinding temperatures. By the way, it

can bring about thermal damages by friction and plastic deformation, resulting in: cracks, grinding burns, microstructure alterations and residual tensile stress (MARINESCU et al, 2013).

According to Dhar et al. (2006), in despite of the technological advantages of the cutting fluid application in the grinding process, some negative effects have been reported in the literature. In accordance with Brinksmeier et al. (2010), the application of cutting fluids into the cutting zone under high pressure causes the occurrence of dangerous aerosols which are hurtful to human skin and can be inhaled. Moreover, the total cost with cutting fluids related to storing, filtering and disposal is more expensive than with tooling costs (WALKER, 2013).

Minimum Quantity Lubrication (MQL) technique was proposed in the past with the goal of substantial reducing of consumption of cutting fluids, risks to human health, environmental impacts in comparison to the conventional machining process. This technique supplies a substantial reduction in flow rate employed, about 600,000 ml / h to 240 ml / h, representing a drop of 99.96 % and, consequently, reduction in hazards to employee's health and environment integrity (ZHANG et al., 2017).

Nevertheless, hot chips are generated in the cutting with the application of MQL technique, trending to the occurrence of lodging in the wheel pores (OLIVEIRA et al., 2012). According to Cameron et al. (2010), the wheel clogging phenomenon can be expressed as a grout formation which appears when chips aren't completely removed from the cutting zone by the action of the cutting fluid. Inasmuch as the heat generation in the cutting zone increases, not only the total specific energy enhances by the increase of the sideflow plowing contribution, but also the heat flux to the workpiece increases. Thus, the efficiency and quality are diminished by the fact that steady contribution of elastic and plastic deformation in total grinding energy is the increased because of the great heat generated in cutting zone.

In order to improve the MQL technique for a cleaner and more productive machining process, this work evaluated the performance of with the MQL assisted with the wheel cleaning system in the plunge cylindrical grinding of AISI 4340 steel with an aluminium oxide wheel under different flow rates: 30, 60 and 120 ml/h. The output variables analyzed in the tests were: roughness, roundness, diametrical wheel wear and acoustic emission.

2. EXPERIMENTAL PROCEDURE

Tests were carried out on a CNC cylindrical plunge grinding machine (RUAP 515H model). The abrasive tool used was a white aluminum oxide wheel with vitrified bond. The abrasive tool used was a white aluminum oxide wheel with vitrified bond with the following dimensions: 355.6 mm outer diameter, 127 mm internal diameter, 25.6 mm width. The grinding wheel was manufactured by NORTON Co.

The workpiece material is an AISI 4340 steel, quenched and tempered (697 HV). The ring-shaped samples were prepared with the following dimensions: 54±0.1mm outer diameter, 30±0.1mm internal diameter and 4±0.1mm thickness. Table 1 shows the test conditions.

Table 1: Tests conditions.

Grinding process	External cylindrical plunge grinding
Grinding wheel	38 A 150 L 6 V (white aluminum oxide grinding wheel with vitrified bond)
Cutting speed (v_s)	30 m/s
Radial feed rate (v_f) (specific material removal rate)	0.50 mm/min (1.41 mm ³ /s)
Work speed (v_w)	$v_w = 0.58$ m/s
Effective depth of cut (a_e)	$a_e = 1.2; 2.5; 3.7$ µm/ver
Workpiece material	AISI 4340 steel, quenched and annealed (60 HRc – 697 HV)
Dresser	Diamond cluster – volume of 15 mm × 8 mm × 10 mm
Dressing depth (a_d)	$a_d = 0.200$ mm (50 cycles – 0.004mm for each cycle)
Sparkout time (t_s)	$t_s = 8$ s
Dressing speed (v_d)	740 mm/min

Four inbuilt devices compounded the MQL system employed, they are: air compressor, pressure controller, flow measuring device and mixer nozzle. The wheel cleaning system was composed of: compressor, compressed air flow, pressure meter, flow distributor, and nozzle. Figure 1 shows the MQL system and the compressed air jet in wheel cleaning.

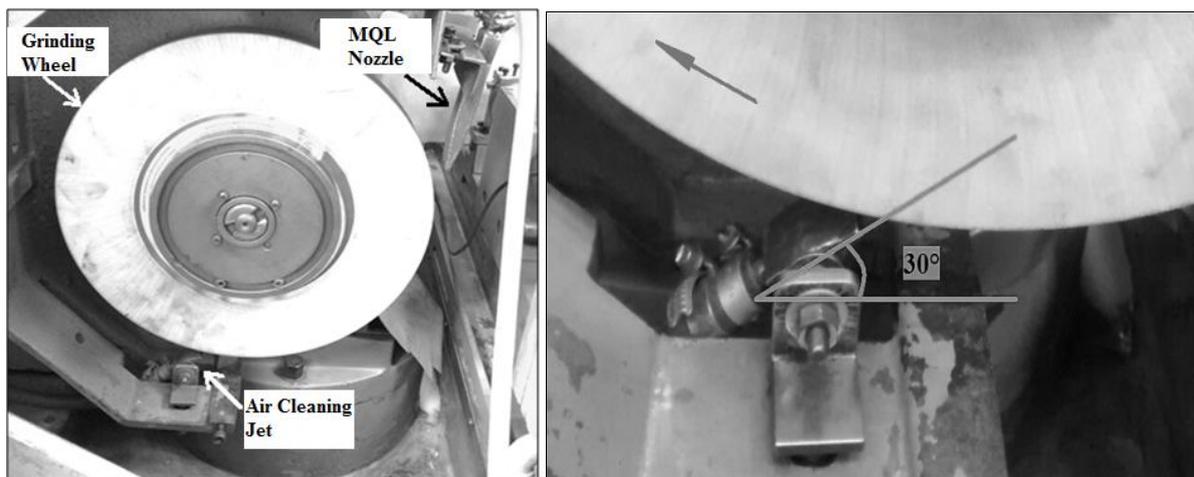


Figure 1. a) The MQL system and the compressed air jet in wheel cleaning; b) Details of compressed air jet.

The cutting fluid employed in conventional technique was semi-synthetic vegetable oil based emulsion (concentration of 2.5%) - ME-2 supplied by Quimatic/Tapmatic Brazil – flow rate: 450,000 mL/h. The MQL technique employed straight oil Accu-Lube LB 1000 - 100% vegetable-based, biodegradable with viscosity of 70 centistokes (25°C) from ITW Chemical – flow rates: MQL: 30 ml/h, 60 ml/h; 120 ml / h.

The surface roughness Ra parameter was measured using Taylor Hobson Surtronic3+ portable stylus instrument. The measurements were taken using a cut-off of 0.25 mm and 1.25 mm sampling length. The measurement results correspond to the average of readings in three different positions (120° spacing) for each workpiece under the same cooling-lubrication condition. Similarly to the methodology for measuring roughness, roundness error measurements were obtained in all experiments with aid of a Taylor Hobson Talyrond 31C device. This equipment has a mobile arm supplied by a ruby ball which touches the workpiece in order to obtain the roundness error value.

The measurements of the workpiece were taken in a microhardness tester from Mitutoyo, HM-211 model. A load of 300g during 40 s was used for a better view of indentation. With the purpose of examining the occurrence of possible alteration in the microstructure, the specimens which presented the lowest standard deviation for roughness and roundness were assessed by optical microscopy (Olympus BX-51) with 500x magnification.

In terms of wheel wear measurements, a cylindrical AISI 1020 steel workpiece was used for printing the wheel profile. This technique is widely employed because the profile produced in the wheel surface during the grinding experiment can be printed on the soft steel cylinder. The diametrical wheel wear was measured via profile projection and measurement with the aid of surface roughness meter software (Taylor Hobson TalyMap).

The monitoring of acoustic emission (RMS) generated by the grinding process under different cooling-lubrication techniques was carried out as follows: a sensor was placed on the machine tailstock and the data was transmitted to an A/D board and then read in a computer with the National Instruments LabVIEW. The RMS signals were acquired using a time constant of 1 ms and the A/D board was set to sample the signal using a sampling rate of 4 KHz.

3. RESULTS AND DISCUSSION

The conventional cooling-lubrication method was more efficient in comparison to the MQL technique in cleaning the wheel surface during grinding. Therefore, when great amount of cutting fluid applied was applied with flood technique, the wheel cleaning was more effective; consequently, roughness and roundness errors were diminished. Irrespective to the result analyzed the application of MQL assisted with wheel cleaning jet outperformed the conventional MQL (without wheel cleaning jet), reducing the grout formation and bringing closer the technique evaluated to the conventional technique. In special, the closest results obtained near the conventional technique were recorded after machining with the flow rate values of 60 and 120 ml/h.

3.1 Surface Roughness

Figure 2 shows the results obtained for the Ra parameter (μm) in terms of each cooling-lubrication condition.

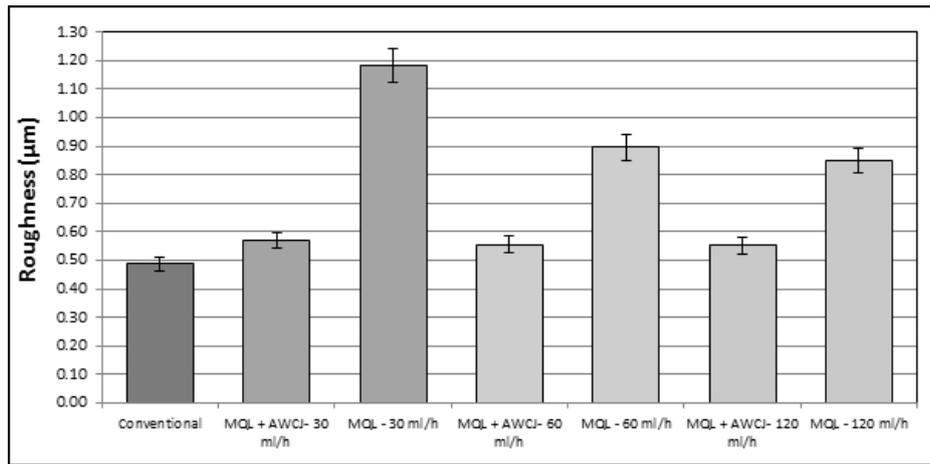


Figure 2. Surface roughness values under different cooling-lubrication techniques and flow rates.

Roundness error is directly related to grinding conditions, also thermal damages, mechanical loads, cutting fluid flow and pressure. Roundness error indicates variation of workpiece geometry. A machining process with high generation of heat can promote dimensional and geometrical variation on the workpiece (Hadad et al., 2012).

From this figure can be seen that the lowest surface roughness values were recorded after machining with the conventional coolant technique. The highest ones were obtained for the traditional MQL technique, while for the MQL assisted with wheel cleaning jet the surface roughness values were intermediate. By comparing the values and standard deviation recorded after machining with the MQL Assisted with Wheel Cleaning Jet with flow rate values of 30, 60 and 120 ml/h, it can be inferred that there is no difference among them and also that they are as close as those obtained for conventional coolant flow. Oliveira et al. explain this fact by non-occurrence of the wheel clogging phenomenon in relation to MQL assisted with wheel cleaning jet, promoting the closest Ra parameter values in comparison to the conventional coolant technique.

3.2 Roundness

Figure 2 shows the results obtained for the roundness errors (µm) in terms of each cooling-lubrication condition.

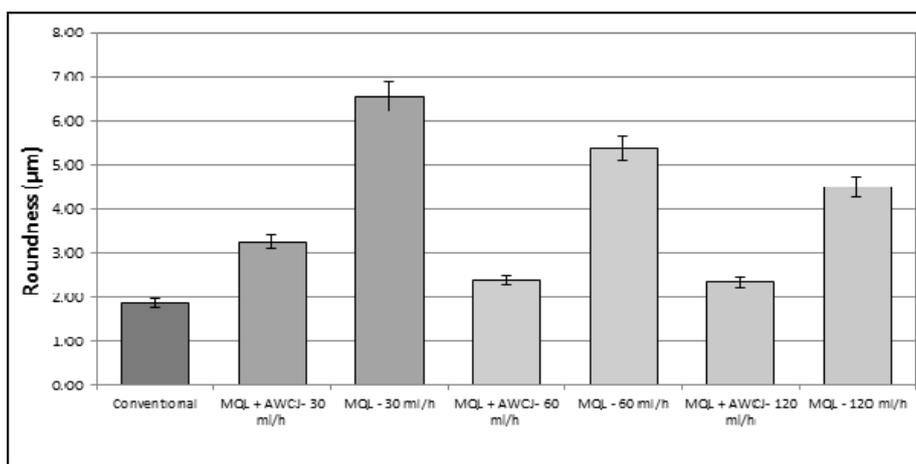


Figure 3. Roundness errors under various cooling-lubrication conditions.

From Figure 3, it can be seen that the lowest roundness error was recorded after machining under the conventional coolant technique (1.90 µm) and the highest ones were related to machining with the traditional MQL technique at a flow rate of 30 mL/h. During the grinding process, lower dissipation of heat occurs in the cutting zone due to the reduction of the amount of cutting fluid, and consequently, thermal expansion of workpiece results in higher roundness errors (Fusse et al., 2004). Therefore, based on the results obtained for roundness errors, it can be concluded that machining with the MQL Assisted with Wheel Cleaning Jet outperformed the conventional MQL. Lower roundness errors were also recorded after machining with the MQL assisted with wheel cleaning jet. Considering the standard

deviations, it can be presented that there is no difference in roundness errors obtained MQL Assisted with Wheel Cleaning Jet in comparison to the conventional coolant technique.

3.3 Diametrical Wheel Wear

Figure 4 shows the results obtained for the diametric wheel wear (μm) in terms of each cooling-lubrication condition.

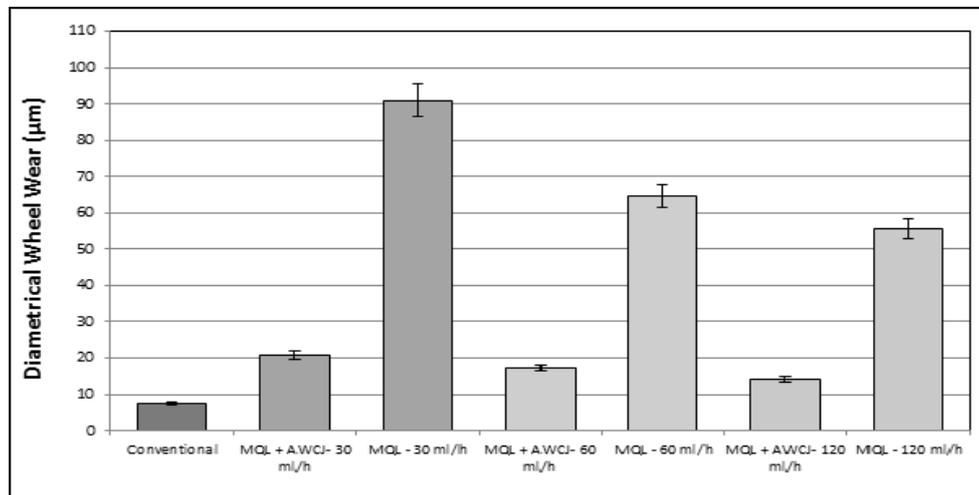


Figure 4. Diametrical wheel wear values under various cooling-lubrication conditions.

According to Silva et al. (2007), diametric wheel wear is reduced when the cooling-lubrication is increased by the cutting fluid action. Therefore, the decrease of friction among abrasive grains, workpiece and chips allows the abrasive grains to stay longer attached to the bond, minimizing wheel wear. From Fig. 4, it can be seen that machining with the MQL Assisted with Wheel Cleaning Jet reduced substantially the wheel wear because of the attenuation of the wheel clogging phenomenon. Moreover, the wheel wear values recorded after grinding with application of the MQL Assisted with Wheel Cleaning Jet, in special for flow rates of 60 and 120 ml/h, were close to those measured for conventional coolant technique.

Figure 5 shows the results obtained for the acoustic emission (V) in terms of each cooling-lubrication condition.

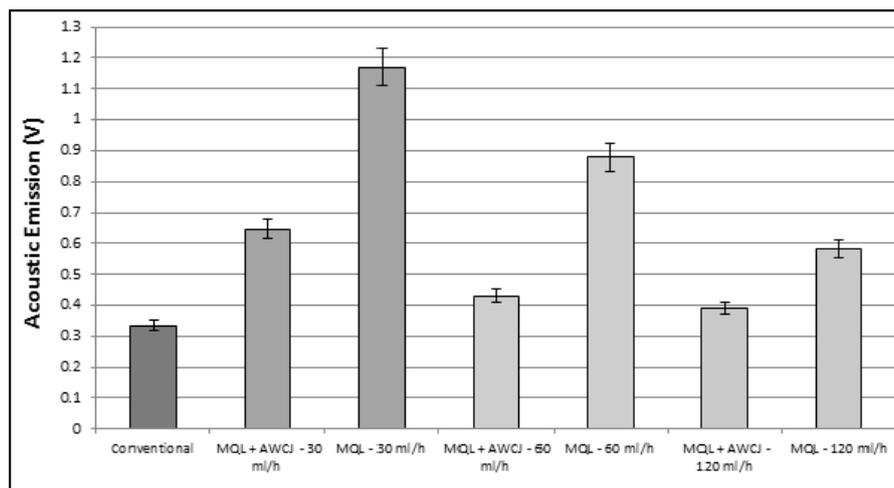


Figure 5. Acoustic emission values under various cooling-lubrication conditions.

From Figure 5, it can be noticed that acoustic emission signals followed the same behavior observed for other output parameters investigated in this work (surface roughness, roundness and wheel wear). In fact, the acoustic emission generated is related to the occurrence of the physical phenomena, such as: friction, plastic and elastic deformation, and chip removal.

4. CONCLUSIONS

The following conclusions can be inferred from this research:

- In terms of the quality parameters roughness and roundness, the MQL technique without cleaning system showed inferior performance than conventional coolant method. The results obtained with flow rates of 60 and 120 ml/h under application of MQL Assisted with Wheel Cleaning Jet were very close to those recorded by the conventional coolant method;

- The output variables for diametrical wheel wear and acoustic emission presented a performance similar to the trending obtained to roughness and roundness. Not only tests under employment of MQL technique without cleaning system exhibited inferior performance in comparison to conventional coolant method, but also machining with the MQL Assisted with Wheel Cleaning Jet technique resulted in efficiency very close to conventional technique.

Therefore, the MQL assisted with wheel cleaning jet showed to be technically viable alternative to conventional coolant mean in cylindrical grinding of AISI 4340 steel with an aluminum oxide wheel; the flow rates 60 and 120 ml/h were close to those obtained in terms of conventional technique. In addition this technique symbolizes a cleaner environment and lower consumption of fluid.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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