EXTERNAL PLUNGE GRINDING OF THE N2711 STEEL FOR PLASTIC INJECTION MOLD WITH TWO DIFFERENT TECHNIQUES OF LUBRICATION AND COOLING

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Abstract. *Grinding is an abrasive process mostly used in finishing operations to provide low roughness and closer form and dimensional limits to the workpiece. However, this process presents a peculiar characteristic when employing conventional abrasive wheels, the great amount of heat generated in the cutting zone that can go into the workpiece. So, cutting fluids are indispensable during grinding. Also, their appropriated delivery technique helps to minimize the possible thermal damages to the workpiece. Into this context, this work presents a contribution to machining field in which a N2711 steel grade that is used for plastic injection mold was machined with GC silicon carbide wheel under two different cooling-lubrication techniques: MQL and conventional. Three values of feed rate of 0.25, 0.50 and 0.75 mm/min were investigated. The reason is because no relevant grinding information has been available in the scientific community so far. The output parameters investigated were the diametrical wear of the grinding wheel and signals of the acoustic emission and the grinding power. Results showed that machining with the MQL technique outperformed the conventional technique in terms of lower diametrical wheel wear, whereas conventional technique resulted in the lowest signal of acoustic emission and grinding power.*

Keywords: *External Plunge Grinding, N2711 Steel, Green silicon carbide wheel, MQL technique, wheel wear, acoustic emission, power consumed.*

1. INTRODUCTION

Abrasive machining processes belongs to a large field of manufacturing processes that include grinding, polishing, lapping, honing, among others, that employ hard grains as cutting elements to remove metal material from a workpiece, modifying its geometry and the texture (Marinescu, *et al.,* 2013). According to Rowe (2009), the grinding process is a term used in the modern machining practice to describe a manufacturing process with grinding wheels with high cutting speed. Bianchi *et al.* (2011) have defined the grinding as an operation for finishing purposes, seeking an improvement of the superficial quality of the machined part, as well as for reducing the dimensional and form errors especially for materials presenting medium to high hardness, like steels employed for mold and dies applications. Contact lenses and electronics components are some examples of products that the grinding process is applied during their manufacturing (Rowe, 2009 and Marinescu *et al.,* 2013).

The grinding process is carried out with a huge number of abrasive grains with several cutting edges having an irregular and no defined geometry and that act simultaneously when wheel passes over the workpiece surface. Correct selection of the machining conditions, including grinding wheel, for instance, can significantly optimize the tool life and the machining process, providing higher capability of material removal rate (Bianchi *et al.,* 2011).

One of the main limiting factors when performing grinding process is the workpiece thermal damage. This damage can be minimized or even avoidable by properly applying coolant in the grinding zone (Irani *et al.,* 2005). According to Irani *et al.* (2005), Rowe (2009) and Marinescu *et al.* (2013), cutting fluid is a term that describes the fluids implemented to cool and lubricate the cutting zone during the machining process, so that use of cutting fluids during the grinding becomes essential to remove heat from cutting zone because great generation of heat is typical from grinding with conventional abrasive wheels due to poor thermal properties of abrasive grains as well as the constant friction of the uncountable cutting edges. In addition, Rowe (2009) reported that the absence of cutting fluids in grinding can lead to serious damages to the product, deterioration of its finishing, reduction in quality and the grinding process.

Despite of the uncountable benefits obtained when using of cutting fluids grinding, they can cause serious hazard when not handled properly because some of them are potentially dangerous to the nature. They can also cause diseases to the operator with long exposition to the fluid (Marinescu *et al.,* 2013). Regarding the cost, cutting fluids aggregate cost to the whole system necessary to implement it that includes their own cost, discard, disposal, cleaning, filtering, maintenance, environment laws and the operator health. All these factors together have led the researchers to test new possibilities of applying cutting fluids in machining process in order to reduce their percentage in machining overall cost or even to decrease the processes waste. Walker (2013) affirms that there are many advantages in the using of fewer quantities of fluids, including to an economic perspective, since the operation costs of the cutting fluids system are estimated between 8 and 16% of the total cost of the process, illustrated on Fig. (1).

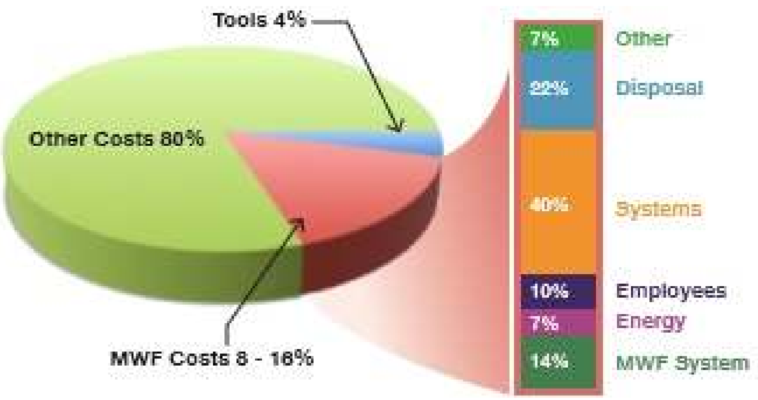

Figure 1. Machining cost breakdown (Walker, 2013).

Into this context, this paper aims to investigate the influence of the MQL technique in diametrical wheel wear and in signals of acoustic emission and grinding power generated during the external plunge grinding of the N2711 steel for plastic injection mold in order to provide grinding data for such steel that can be useful for metal working industry

1.1 Considerations about Minimum Quantity of Lubricant Technique

In order to reduce the waste from the machining processes, MQL is an innovative lubrication technique that has been investigated in machining in the last years as an alternative to the conventional cooling method. Tawakoli *et al.* (2010) affirms that the MQL technique is a promising alternative to the application of the conventional methods due to it both lubrication and cooling actions. Oliveira *et al.* (2012) have defined the MQL technique as small oil droplets in a spray jet of compressed air. Usually, the lubricant is sprayed directly to the cutting zone, what is an advantage in terms of reducing quantity of fluid compared to higher high flow rate employed in conventional cooling method.

According to Lee et al. (2002), the compressed air jet that assists the MQl technique is a tool that can be used to reduce clogging because the air impacts the wheel surface and also removes a large number of the impurities that adhere to it. These authors attributed the reduction of the wheel wear rate and form accuracy improvement to the pressure air jet. Oliveira et al. (2012) affirm that with the implementation of a compressed air cleaning system along with the traditional MQL cooling-lubrication equipment brings a good perspective to improve the quality of the process.

The quantity of fluid is dependent on the manufacturing system characteristics. From Walker (2013) the amount of fluid is something subjective and it will depend primarily on the workpiece material followed by the process and the tool. MQL flow rate for usually ranges from 20 ml/h to 200 ml/h.

Silva, *et al,* (2013) investigated the efficiency of two cooling methods in the external plunge grinding of the AISI 4340 steel and observed that in some cases, the diametrical wear of the grinding wheel was lower after machining with the MQL system. MQL superior efficiency was attributed to its excellent lubrication property of oil that improves tribological conditions in the grinding zone.

Hadad and Sadegui (2012) carried out a study to calculate the grinding temperature and the energy partition to the workpiece during grinding of a 100Cr6 (SAE 52100) steel grade with various coolant technique (MQL, conventional and dry). They found that measured average convection heat transfer coefficient in the grinding contact zone for MQL technique was up to 96% lower than for conventional coolant technique. Despite the good lubrication property generally encountered when using the MQL technique, cooling action is still the most required property of fluids in grinding.

In a recent study, Rabiei et al. (2015) investigated the effect of mechanical properties of four steel grades (CK45, S305, HSS and 100Cr6) with aluminum oxide wheels in grinding forces, friction coefficient and surface integrity under various coolant techniques (MQL, dry and conventional). They found that grinding with MQL technique not only significantly reduced the quantity of fluid delivered during the process, but also resulted in lower friction coefficient compared to the conventional cooling method. Also, they observed reduction in tangential grinding force due to the reduced cutting power and improved the surface finish especially of the hard steels.

It is widely known the grinding forces and the machining quality depend on the tool performance. Therefore, it is very important to study the wheel wear behavior, in order to control the quality and the effectiveness of the grinding process (Ding *et al*., 2014). According to Iceri *et al.* (2012), the wheel wear is directly related to the cooling-lubrication system employed in a grinding process, enabling the abrasive grains to remain longer connected to the bond.

2. MATERIALS AND METHODS

The grinding trials were conducted on a cylindrical CNC grinding machine, manufactured by SULMECÂNICA company, RUAP 515H model (Fig.2).

Three feed rate values of 0.25, 0.50 and 0.75 mm/min were varied in this work. The other cutting parameters were kept constant during all the experiments. They are described below.

- Cutting Speed (Vs): 30 m/s ;
- Work Speed (Vw): 0.8 m/s ;
- Material removed in each grinding cycle: 0,1mm ;
- Dressing Depth: 0.04mm;
- Dresser translation speed: 100mm/min (performed manually).

Figure 2. Cyllindrical CNC grinding machine.

The workpiece material was the N2711 steel grade with a hardness varying from 38 to 42 HRc, manufactured by Villares Metals. Ring-shaped samples were prepared with outer diameter of 75±0,1mm, internal diameter of 30±0,1mm and thickness of 4±0,1mm, as illustrated in Fig 3. The chemical composition of N2711 steel is showed on Tab.1.

Figure 3. N2711 steel geometry.

Tabel 1. Chemical Composition of N2711 steel.

C	Mn	Cr	Mo	Ni	V
0.56	0.70	0.70	0.30	1.56	0.075

Two different cutting fluids were employed in this work. An straight synthetic oil, Accu-Lube LB 1000 provided by ITW Chemical Products Ltd, for the MQL technique, at a flow rate of 100ml/h. This technique was assisted by compressed air delivered by a pressure and flow rate of 0.6 MPa and 2,7 x 10^{-3} m^3/s, respectively. A semi-synthetic soluble fluid was used to the conventional method, with ULTRACUT 370 specification manufactured by ROCOL, with a proportion of 1:39 which was recommended for grinding process. It was delivered at a pressure and flow rate of 4 MPa and 17 L/min, respectively.

For MQL technique it was employed also a cleaner auxiliary system. The wheel cleaning system is comprised of a compressor, compressed air flow and pressure meters, flow distributor, and application nozzle. The air flow rate was 480 L/min and the pressure for each nozzle was 7 MPa. The air flow meter was Siemens Sitrans-P. The nozzle was attached at a distance of 1 mm from the wheel surface.

A vitreous bond green silicon carbide abrasive wheel with 60 mesh and L hardness with dimensions: diameter of 300 mm, thickness of 30 mm and internal diameter of 127 mm was employed in all the trials. It was provided by ABRASIPA Company and has the following properties: higher hardness and better thermal conductivity compared to other conventional abrasives. Because the workpiece material behavior during grinding is still unknown, the choice of such grinding wheel was based on these two properties of abrasive wheels.

The dressing process was performed with a multigrain dresser. To control the translation speed of the dresser in 100mm/min, it was used a millimeter ruler linked to the grinding machine. It was determined a total distance of 50mm, being 30 mm about the grinding wheel thickness and 10 mm to the output and input of the dresser in the grinding wheel topography. Therefore, this total distance should be coursed during 30 seconds. Reason of the operation was manually performed is due to the non-automatic control of the table's translation speed in the grinding machine.

The output parameters investigated in this work was the wheel diametrical wear, acoustic emission and grinding power signals

The measurement of diametrical wheel wear was conducted by using an AISI 1020 steel cylinder. Because the wheel thickness is not totally used during grinding, after each trial, the cylinder is machined with the worn grinding wheel, so that the wheel profile is left in the cylinder. Finally, the marks on the cylinder are detected by Surtronic3+ profile meter.

The acoustic emission data generated by the process was gathered by a sensor placed on the machine tailstock, transmitted to an A/D board and then read in a computer, using the National Instruments LabVIEW.

The power signals required by the machine was recorded with aid of a system having potentiometer that acquired grinder signals and then transfer them to a dedicated software (LabView® 7.1, National Instruments®) in a PC. The file generated by the software was processed in MATLAB® 2012.

3. RESULTS AND DISCUSSION

In this section are presented the experimental results of the output variables for each grinding condition. The conventional cooling-lubrication system (flooding) was used as a reference because it is the most widely used in industry..

3.1 Wheel Diametrical Wear

Diametrical wear of wheel values versus feed rated values for both cooling techniques are showed in Figure (4). The diametrical wear tends to increase with the radial feed rate as expected. With increase in feed rate, more grains are required to perform cutting and they wear faster during the process. By comparing different cooling-lubricating methods for a same radial feed rate, it is possible to note that converge to the Rabiei *et al.* (2015) proposal. These authors reported that the MQL technique can provide better lubrication action to the cutting zone, reducing friction coefficient and consequently reduction in cutting forces when compared to the conventional method. If the tribological conditions existing in the grinding zone are improved, less wheel wear is generated.

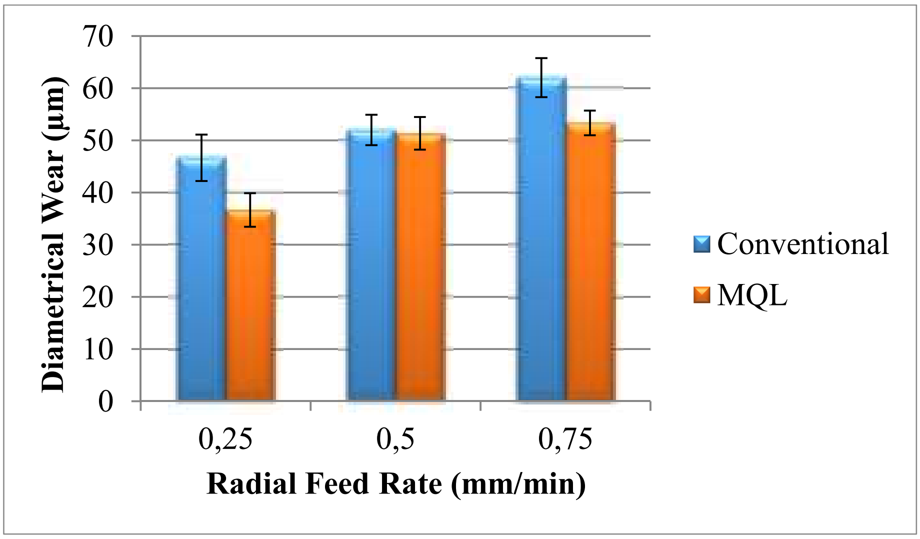

Figure 4. Diametrical Wear versus radial feed rate after grinding N2711 steel with two cooling-lubrication techniques

3.2 Acoustic Emission

In the Figure (5) are shown the acoustic emission (AE) signals recorded after grinding with three radial feed rate values and two cooling-lubricating techniques. It can be noted that the acoustic emission values increase with radial feed rate values, similarly to that observed with diametrical wheel wear (Figure 4). However, it can be seen that AE signals obtained after MQL technique were higher than that for conventional technique. These results may be attributed to the lower heat dissipation of MQL oil that affects chip formation and is detected by AE signals.

The acoustic emission technique employed on monitoring of the grinding process helps to better understanding of grinding phenomenon, to study the chip formation and friction, to detect bond/grain braking and thermomechanical phase transition (Babel et al., 2013). Dornfeld and Cai (1984) employed AE emission from surface grinding to measure wear-related loading of the grinding wheel and sparkout between the wheel and the work surface.

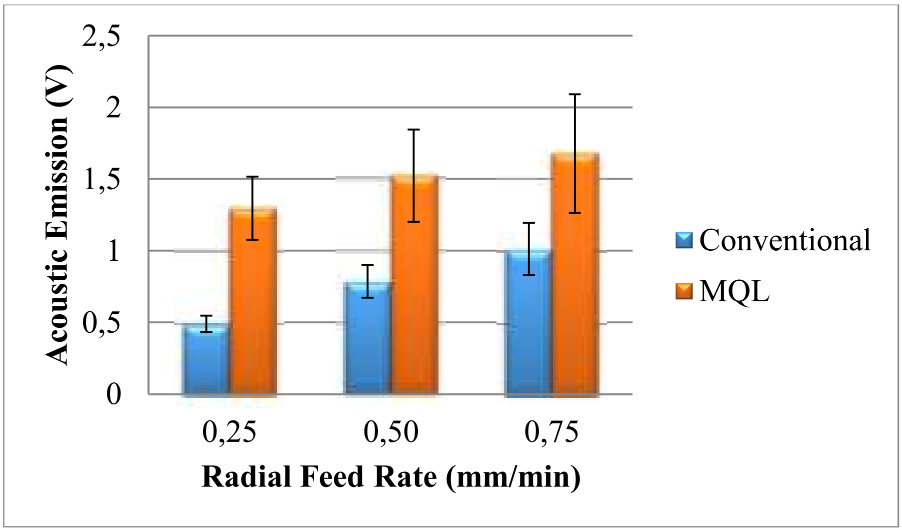

Figure 5. Acoustic Emission signals versus radial feed rate values for both cooling-lubrication techniques.

3.3 Grinding Power

Grinding power signals recorded in this work are presented in the Figure (6).

According to the Eq.(1), developed by Malkin (2008), the power (P) is directly related to the tangential cutting force (F_t) and also to the cutting speed (V_s) and Work Speed (V_w).

$$P = F_{t\,.}(V_s \pm V_w) \qquad (1)$$

By analyzing the Eq.(1) and relating it to the machining conditions, the only variable which has varied during the experiments was the tangential cutting force, since the cutting speed and the work speed were kept constant.

From Figure 6 it can be seen that grinding power increased with radial feed rate values for all the cooling-lubrication conditions investigated. Higher values were obtained after machining with MQL technique compared to conventional one, thereby suggesting that MQL technique requires more cutting forces to perform cutting, with exception of radial feed rate value of 0.50 mm/min.

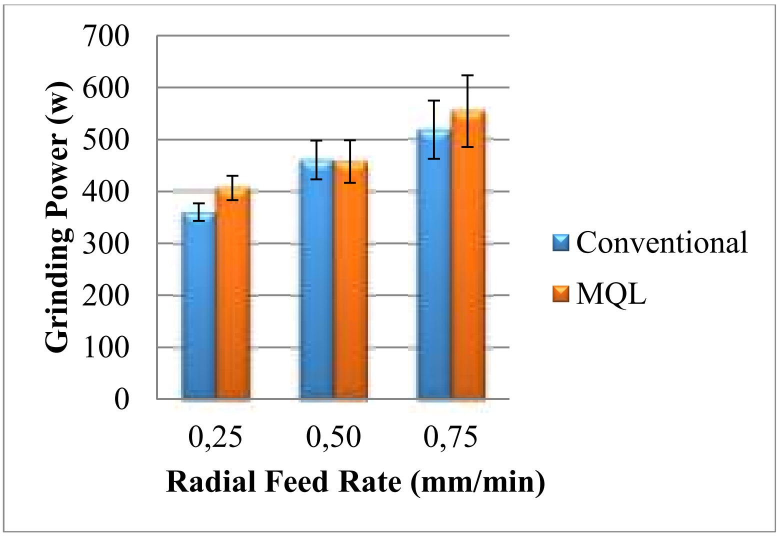

Figure 6. Grinding Power recorded after grinding N2711 steel under different cutting conditions.

Oliveira *et al.* (2012) reported that relationship among wheel wear, acoustic emission and grinding power should be of proportionality. However, the results obtained in this work are contraries to expected. Acoustic emission and the grinding power results when associated to the wheel wear results reveal how complex the grinding process is. It was expected that both AE and grinding power signals increased with wheel wear progresses due to changes in grain geometries (tendency of grain to flat wear mode) and consequently increase in forces to keep machining.

4. CONCLUSIONS

The following conclusions can be draw after grinding the N2711 steel for plastic injection mold with a green silicon carbide wheel under different cutting conditions:

- In terms of diametrical wear, the MQL technique outperformed the conventional one because of its better lubricating action that lead to less friction and reduction of cutting forces in the cutting zone under the conditions investigated.
- Despite of the better lubricating property of the MQL oil compared to the conventional fluid, the MQL technique provided values of grinding power and acoustic emission higher than the conventional coolant technique;
- By using the MQL technique, the decreasing of waste comes to 99.9% (MQL flow is 100 ml/h while conventional flow is 17 l/min) in the conditions investigated;
- The lowest flow rate from MQL technique combined with the reduced wear rate recorded after machining with this technique represented economic and environmental gains, especially because frequency of wheel replacement is reduced.

5. ACKNOWLEDGEMENTS

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