THE MINIMUM QUANTITY OF LUBRIFICATION (MQL) TECHNIQUE FOR THE USE REDUCTION OF THE CUTTING FLUID

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Abstract. *The success of structural ceramics in most applications depends not only on the materials properties and component design, but also on the quality of machined products. One factor usually mentioned as a barrier to the wide use of ceramics is the lack of reliability of ceramic components, due to the variability on the mechanical strength caused by defects generated during the grinding process. Ceramics grinding, as well as in steel grinding, is generally performed with excessive cutting fluids, which can result in serious ecological, physiological and economic issues. Seeking process improvement, different forms of fluid application were studied. The conventional method of cooling and lubrication was compared to the Minimal Quantity Lubrication (MQL) technique, which uses an air jet containing a minimum quantity of lubrificant fluid. The MQL technique kept a better integrity of the grinding wheel, but produced a bigger superficial roughness.*

Keywords*: Grinding, Ceramics, MQL.*

1. INTRODUCTION

According Zhang *et al.* (2003), grinding is used as the most efficient and effective technique to finish ceramic workpieces. As quality of advanced ceramic has dramatically improved with the modern manufacturing techniques, the bulk defects are significantly reduced in terms of their size and numbers.

Zhang *et al.* (2000) says that more and more ceramic parts are used to substitute for metal counterparts due to their excellent physical, chemical and mechanical properties. However, ceramics, especially structural ceramics, are extremely difficult to machine because of their high hardness and brittleness. According Lee *et al.* (2000), the ceramic high hardness causes fast wear in cutting tools, which makes that a difficult material to machine. Beyond that, ceramics can generate cracks which decrease the resistance of the material. Therefore, finding a technique for effective machining of ceramics is currently a very important topic of research.

Ceramics grinding process is the process which predominates in post-sintering machining during the manufacture of ceramics products. Excellent superficial quality and optimal geometric tolerance are obtained in that process. Excessive cut fluid is used in those products grinding.

In this study, different forms of fluid application were studied. For this, the conventional method of lubrication-cooling was compared to the Minimal Quantity Lubrication (MQL) method, which uses an air jet containing a minimal quantity of lubrificant fluid. Seeking to perform this comparison, data were collected, for instance, roughness and diametral wear rate of the grinding wheel. As a result, the roughness obtained on the tool using the method of MQL was bigger, however, analyzing the G ratio, whose result seems to indicate that the main wear mechanism was the abrasion micro-wear and the acting forces in grinding were not enough to promote micro-fracture and removal of abrasive grains. It was possible to notice that with the conventional method there was a much bigger wear of the grinding wheel, compared to the MQL technique. Also, the depth of cut showed a great influence on the results of the machining. Based on the data, we can conclude that the MQL technique is a viable alternative for certain depths of cut.

2. MATERIALS AND METHODS

The methodology used consisted of grinding wheel preparation, process parameters checking, experiments performing and materials characterization. Due to the relevance of the grinding wheels conditioning on the results (Tönshoff *et al.* 1996), each new experiment was preceded by the correction of the grinding wheel profile and exposition of the abrasives, following a standard procedure to keep the condition constant.

Experiments performing consisted of collecting data during 5 grinding cycles on the specimen, to quantify the initial condition of grinding. After that, another specimen was grinded, having 17 mm (16000 mm^3) of its height removed, aiming to promote enough wear on the grinding wheel to measure G ratio.

2.1. Equipment Used

The experiments were performed on a tangent grinding machine model 1055E Sulmecânica. Roughness was measured by a roughness meter Surtronic $^{3+}$ Taylor Hobson, adjusted for a 0.8 mm sampling length (cut-off) and calibrated to measure Ra parameter.

The piece of equipment used to apply the MLQ technique was the Accu-Lube by ITW Chemical Products Ltda. That system works based on a pulsing method of providing oil through a stream of compressed air. Besides, it allows the flow adjustment of compressed air and lubricant oil to be made individually.

Workpiece with 99,8% of alumina were manufactured by uniaxial pressing at 600 MPa followed by sintering at 1600 ^oC - 2h, Charred Alumina A1000-SG (Almatis, Inc.) with particle equivalent average diameter of 0.4 µm, surface area of 7.7 m^2/g and ρ_{real}: 3,99 g/cm^3 was used.

The diamond grinding wheel – Nikon - used is specified by D 107 N 115 C 50, with the letter D indicating the type of grain used (diamond), 107 the size of the grain used (107 µm), the letter N the grinding wheel hardness (average hardness), the value 115 indicating the type of the diamond and the designation C50 the grains concentration. The grinding wheel dimensions are given by a 35 0mm diameter and a 15 mm thickness.

2.2. Cutting Fluids

Cutting fluids can have one or more functions, which can comprehend tool cooling, piece cooling and generated splinters elimination, lubrication of the contact area piece-tool by reducing friction and heat in the cut area, causing minimization of the tool wear and consequently, increasing its life cycle (Sales *et al.* 2001). Nevertheless, using cooling fluids can result in ecological, physiological and economic issues (Pereira *et al.* 2005).

The fluid used in the conventional condition was a synthetic soluble oil by Mobil. The manufacturer recommends working with a concentration between 4% and 6% and pH between 8.5 – 9.5. Accu-Lube LB-1000 by ITW Chemical Products Ltda. was tested in the minimal lubrication condition, without dilution.

Two different methods of lubrication-cooling were used in this study, with a distinct nozzle for each one. The conventional lubrication-cooling method (Figure 1) was characterized by the application of cut fluid at high flow and low pressure. The nozzle worked with a 27.5 l/min flow, pressure lower than 0.2 Kgf/cm^2 and cut fluid speed of 3m/s.

Figure 1. Picture of grinding through lubrication-cooling with conventional nozzle.

To perform the MQL technique we used a specific nozzle which offered better efficiency in de cut area (Silva *et al.* 2007). Air flow was determined considering a pressure of 8Kgf/cm^2; the compressed air speed was the same as the grinding wheel peripheral speed (Webster *et al.* 1995). The air flow used was 26.6 m^3/h (450 l/min). Oil flow determined during preliminary experiment was 80 ml/h (0.0013 l/min). The nozzle used is represented in Fig. 2 and showed in Fig. 3.

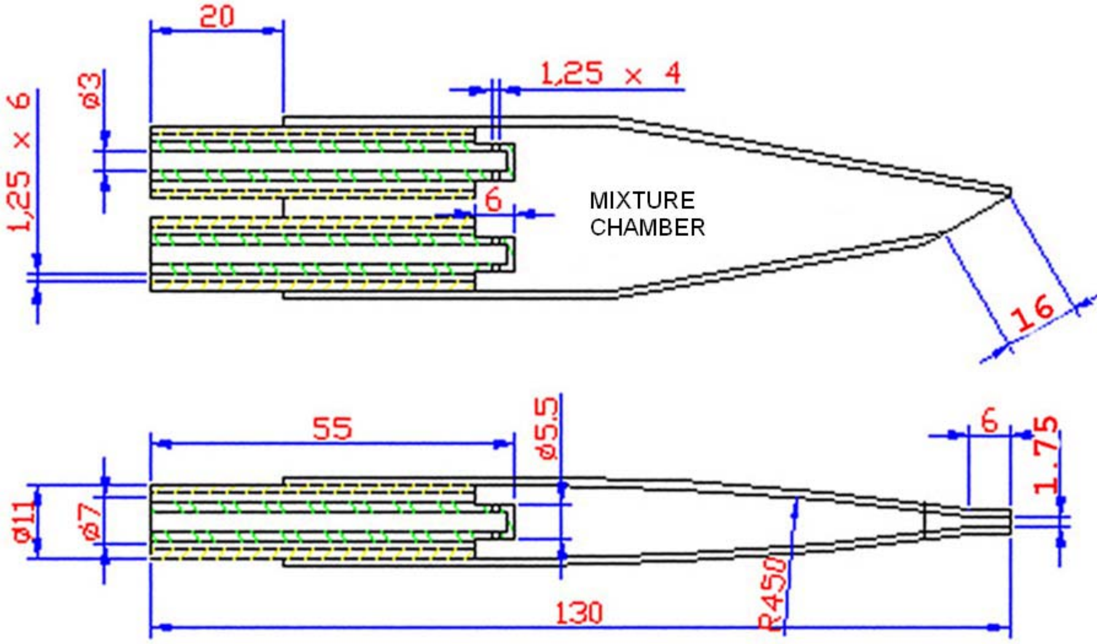

Figure 2. Drawing of the nozzle used for MQL.

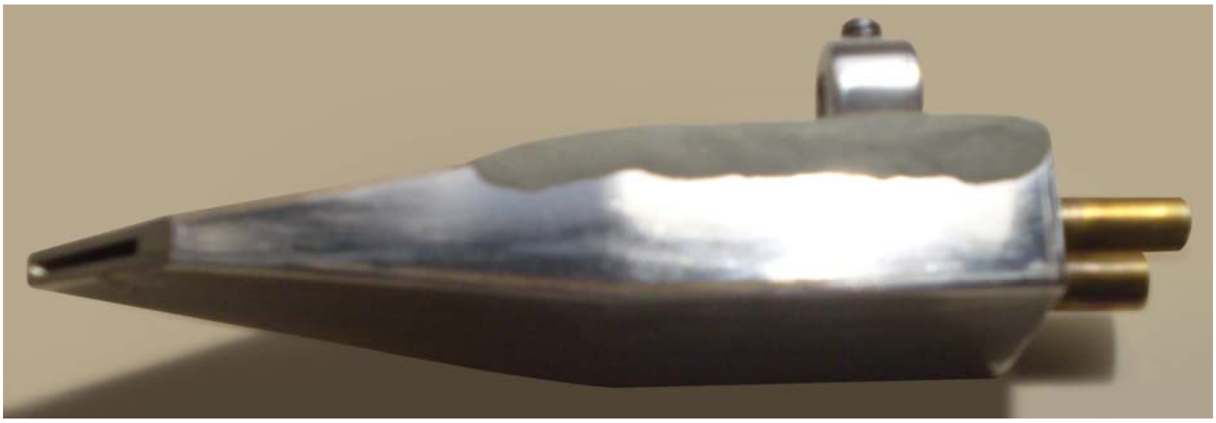

Figure 3. Picture of the nozzle used for MQL.

2.3. Before Tests

Workpiece were produced through pressing and sinterization. This way, two specimen geometries were defined, one specimen to measure G ratio and the other, 8 mm thick, 60 mm high and 120 mm long, to evaluate the damages, as well as to measure the tangent force of grinding, normal force, specific energy, acoustic emission, roughness and other output variables. Fig. 4 shows a picture of the two specimen geometries used.

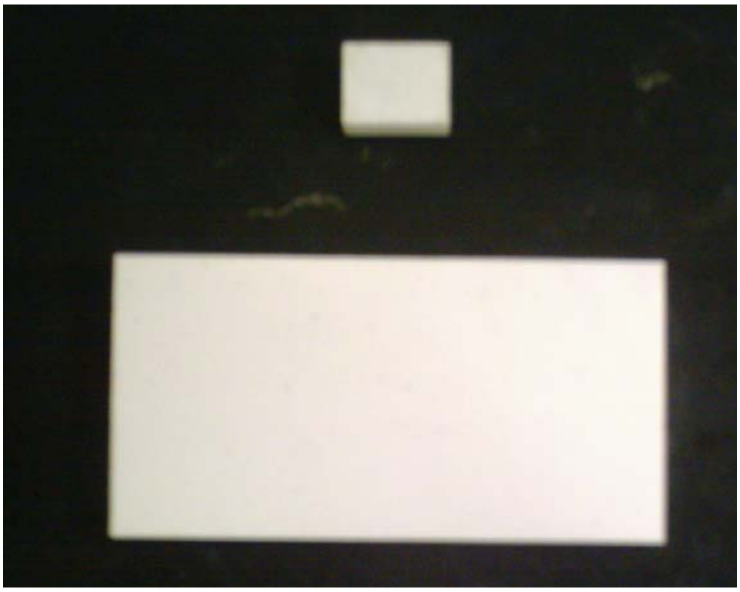

Figure 4. Picture of the specimen used to observe superficial damages and collecting data and to determine G ratio.

To minimize interferences from the grinding wheel preparation procedures, the grinding wheel profiling and truing operations were standardized. The grinding wheel was profiled through a multiple diamond dresser and trued by a white alumina rod of 320 mesh. The profiling operation is seen in the Figure 5.

Figure 5. Grinding wheel profiling operation.

Each experiment was preceded by grinding wheel dressing, producing a new cut face for the grinding wheel in each process.

3. RESULTS AND DISCUSSIONS

Roughness, diametral wear and G ratio data will be presented here.

3.1. Roughness

Roughness data obtained through the method of lubrication-cooling with minimal quantity lubrication were bigger than the ones obtained through the conventional method (Fig. 6). Due to the fragile removal mode and ceramics materials intrinsic porosity, roughness measurements present a considerable standard deviation. Moreover, although the grinding wheel was dynamically balanced, some vibration and its own rigidity could have contributed to roughness variation.

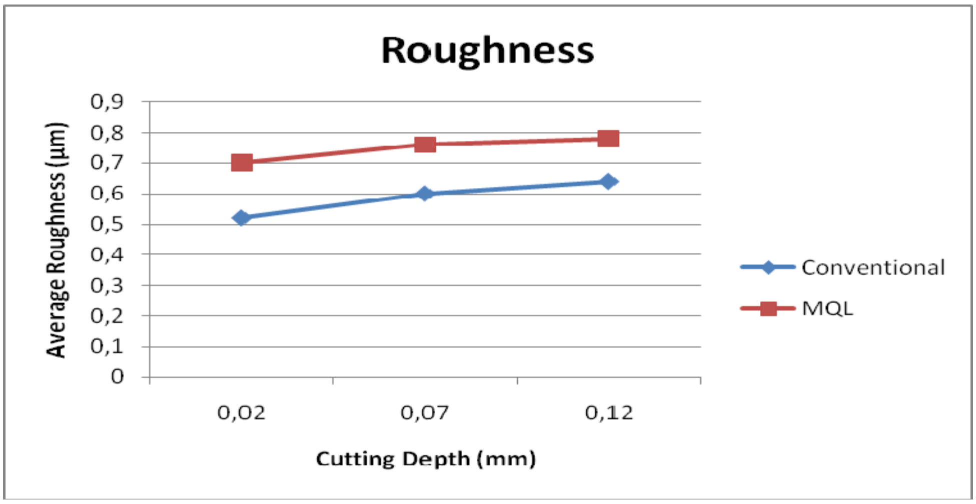

Figure 6. Graph of the pieces average roughness at different depths of cut through different lubrication-cooling methods.

The tendency for better finishing in the experiments through conventional lubrication-cooling can be explained by a more efficient lubrication in the cut area. That lubrication, however, did not reflect a reduction of cut forces, because the excessive lubrication action was situated in the central region of the specimen. It is important to emphasize that all roughness measurements were made along the whole specimen, perpendicular to the direction of the cut made by de grinding wheel.

3.2. Diametral Wear on the Grinding Wheel

Grinding wheel wear data showed that the MQL produces a smaller diametral wear, compared to the conventional lubrication method. The diametral wear is represented in Fig. 7.

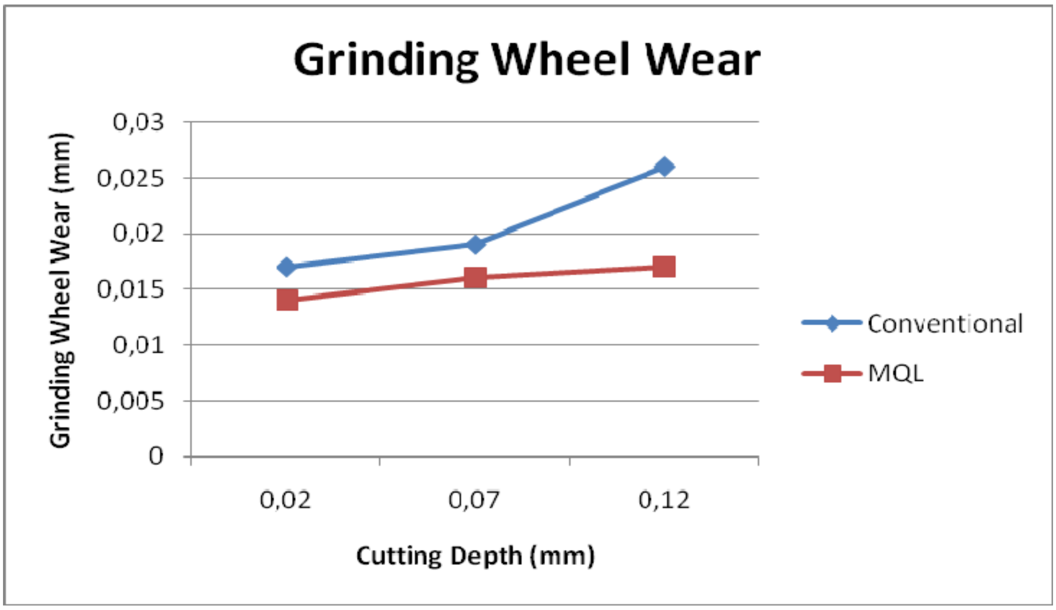

Figure 7. Data of diametral wear on the grinding wheel.

3.3. G Ratio

According to Ramesh *et al.* (2001), a grinding wheel performance can be assessed by G Ratio, defined as the ratio between the volume of removed material Z_w and the volume of worn grinding wheel Z_s:

$$G = \frac{Z_W}{Z_S} \tag{1}$$

The experiments carried out using the conventional method presented a smaller G ratio than the ones using the MQL method. The influence of the depth of cut was also observed. The graph showing the G ratio is represented in Fig. 8.

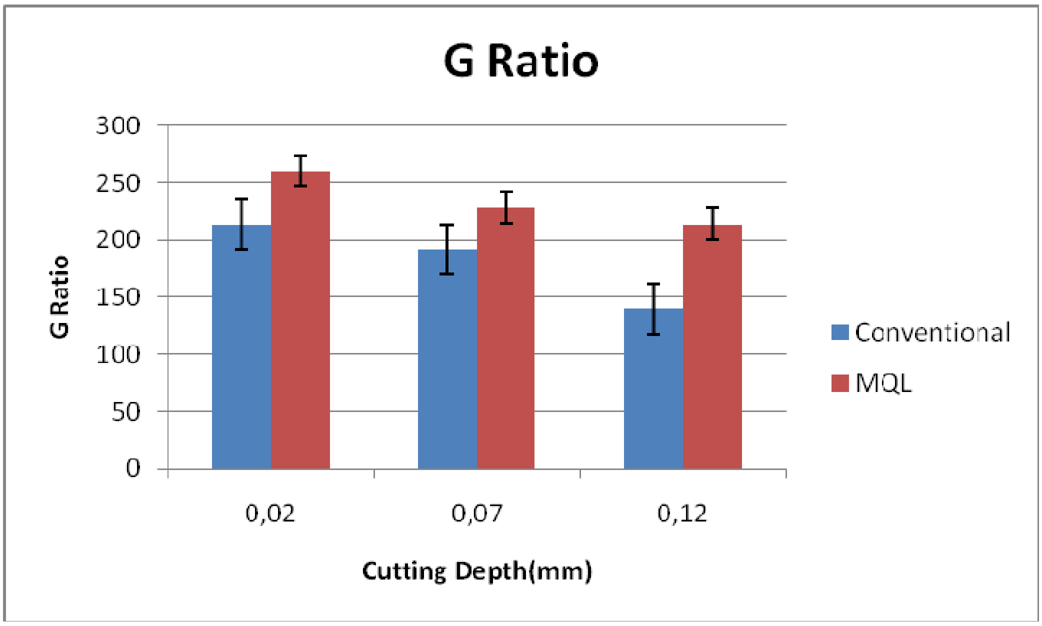

Figure 8. Graph showing G ratio.

The bigger the depths of cut, the smaller the G ratio. As previously mentioned, This result seems to indicate that the main wear mechanism was the abrasion micro-wear and the acting forces in grinding were not enough to promote micro-fracture and removal of abrasive grains.

4. CONCLUSIONS

According to the results obtained, we can conclude that:

- Grinding by the method of lubrication-cooling with the MQL presented a high roughness and, on the other hand, a low wear on the grinding wheel, which provided a high G ratio. In processes aiming better superficial quality, an analysis should be made before using this process.

- The conventional lubrication method produces a low roughness and a higher diametral wear than the MQL method, but even so, it is a good alternative to be used in grinding. Nevertheless, this method takes a big quantity of cut fluid, which is difficult to dispose after use.

- The depth of cut had relevant influence on the output variables. Roughness presented a positive correlation with the depth of cut, while the G ratio presented a negative correlation.

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