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# SURFACE FINISH EVALUATION OF AISI VP 100 STEEL AFTER GRINDING WITH MQL TECHNIQUE WITH DIFFERENT FLOW RATES

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**Abstract.** Grinding operation is a finishing process often employed when high precision and narrow geometric tolerances are required. These requirements can be achieved only if cutting conditions are properly selected, especially the cooling-lubrication technique. In general, grinding is performed in presence of cutting fluid, however, due to the environmental impacts and costs of the conventional coolant delivery technique (flow rates from 4 l/min to 300 l/min), alternative cooling-lubrication techniques have been developed on restriction of the coolants use. Among the several techniques, Minimum Quantity of Lubricant (MQL) technique has received special attention from machining users because of its advantages in terms of surface quality of workpiece and drastic reduction in use of coolant. In this context, this paper evaluated the performance of the MQL technique to the flood coolant in the AISI VP 100 steel in peripheral surface grinding with conventional aluminum oxide grinding wheel in relation the roughness ( $R_a$  and  $R_z$ ). Input parameters tested were: equivalent chip thickness (0.09  $\mu\text{m}$ , 0.18  $\mu\text{m}$  and 0.27  $\mu\text{m}$ ) and flow rate (60 ml/h, 150 ml/h and 240 ml/h). Results showed that the grinding with MQL technique provided lower surface roughness values compared to conventional technique, especially when machining under the intermediary cutting conditions. Also, with exception of  $h_{eq}$  of 0.09  $\mu\text{m}$ , the MQL technique with the all flow rates tested resulted in lower values of  $R_z$  parameter compared to the conventional coolant technique.

**Keywords:** grinding; AISI VP 100 steel; MQL technique; equivalent chip thickness; surface roughness.

## 1. INTRODUCTION

Grinding is a machining process in which the material is removed by the action of hard abrasive grits bonded in a wheel with high cutting speed, therefore, it involves a high amount of energy per volume of material removed (Malkin and Guo, 2008). During the grinding process with conventional abrasives, it is estimated that approximately 85% of the heat generated is carried to the workpiece surface, what can cause surface damages such as microstructural changes (Malkin and Guo, 2008; Diniz, Marcondes and Coppini, 2010). Thus, it is essential to use coolant during the grinding process to reduce the friction between the abrasive grits and the workpiece and the temperature in the cutting zone (Marinescu et al., 2004). Due to high costs and environmental impacts of the conventional cooling-lubrication technique (flood coolant), the technique of Minimum Quantity of Lubricant (MQL) has emerged as an environmental friendly alternative, allowing to reduce the fluid flows used (Tawakoli, Hadad and Sadeghi, 2010). The MQL technique consists in a minimal amount of fluid (frequently neat oil) pulverized in a flow of compressed air and directed toward the cutting zone (Ruzzi et al., 2017).

The AISI VP 100 steel is used in the manufacturing of molds for injection of plastics and non-chlorinated plastics. It is a low carbon steel grade developed with microalloying elements such as titanium and vanadium, which can be hardened at different cooling conditions of traditional tempering presenting homogeneous hardness from the surface to the core of the block. The low content of alloying elements in the VP100 steel, such as the low chromium content, contributes to its lower manufacturing costs, increasing its competitiveness in the market (Rodrigues et al., 2015).

The ease or difficulty of grinding is an important point because the combination of the geometric and dimensional tolerances required for some of the molds and their functional components can in general be achieved by the grinding process. According to Agostinho (1995), the roughness is defined as a microgeometric shape offset formed by protrusions and recesses present on the surface of the part, and is commonly used to verify the quality (finish) of the molds produced, since any imperfection in the mold will be reproduced on the part to be manufactured. The surface roughness ( $R_a$ ) is one of the main output variables to be measured because of the low cost of the conventional portable roughness testers and its very easily handling compared to other apparatus to evaluate machined component surfaces. In this way, the main roughness parameters employed are  $R_a$  and  $R_z$  ones, in which the  $R_a$  represents the average distance of a profile from its average line over a measured length, while the parameter  $R_z$  represents the average distance between the 5 most peaks high valleys and the 5 deepest valleys, within a measured length. Fragoso et al. (2016) performed the cylindrical grinding of the VP50 steel (38 - 42 HRC) with green silicon carbide grinding wheel, different feed rate values (0.25, 0.5 and 0.75 mm/min) and under different coolant delivery techniques. They reported that  $R_a$  parameter obtained results were between 0.5  $\mu\text{m}$  and 0.8  $\mu\text{m}$ . Anjos et al. (2016) used the same workpiece material and process as Fragoso et al. (2016), but they used the white aluminum oxide grinding wheel ( $\text{Al}_2\text{O}_3$ ). It was observed that the grinding with the conventional cooling-lubrication technique and MQL technique, varying the equivalent chip thickness (0.02  $\mu\text{m}$  to 0.1  $\mu\text{m}$ ), resulted in  $R_a$  parameter values between 0.5  $\mu\text{m}$  and 1.2  $\mu\text{m}$ . Martínez-Mateo et al. (2010) evaluated the surface damages, mainly as a function of the parameter  $R_a$ , of molds during operation. The hardness of the steel of the stationary part of the mold was 31 HRC, while the hardness of the movable part was approximately 53 HRC. It was observed that while the surface in contact with the movable mold half maintained the initial  $R_a$  value of 0.46  $\mu\text{m}$ , the surface in contact with the stationary half of the mold showed an increase as the number of injected pieces increased, until to reach 1.02  $\mu\text{m}$ . In this way, evaluating the surface roughness and texture of mold materials contributes to the sectors where they are used.

In this context, this paper evaluated the surface roughness and texture of the AISI VP100 steel after grinding with different flow rates through the MQL technique and with the conventional coolant flow delivery.

## 2. EXPERIMENTAL PROCEDURE

The tests were performed in a tangential surface grinding machine, P36 model, MELLO S.A manufacturer (Figure 1). The workpiece material was the AISI VP 100 steel (40 HRC) with the dimensions: 48.8 mm length x 20 mm width x 18 mm height. A conventional aluminum oxide grinding wheel (AA60K6V) with the dimensions of 303 mm external diameter x 25 mm width x 76 mm internal diameter, from Norton Abrasives manufacturer, was employed. The grinding wheel was dressed before each test with a dressing overlap ratio ( $U_d$ ) of 3.

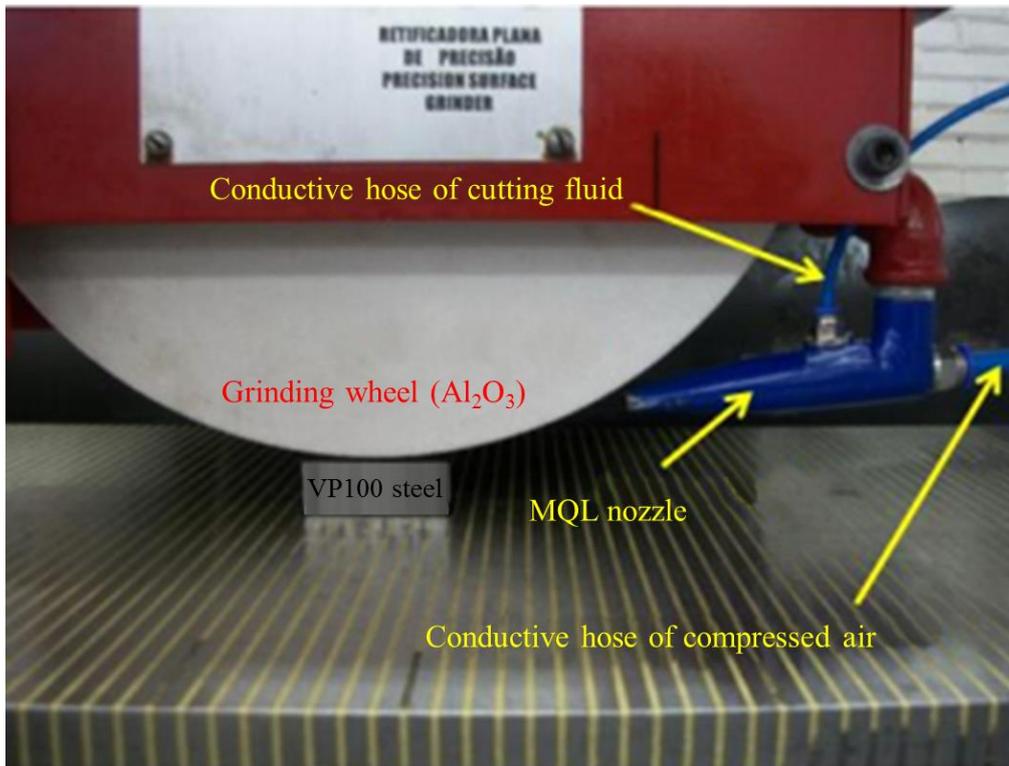


Figure 1. Experimental set-up for grinding with MQL technique.

Two different cooling-lubrication techniques, the MQL and the conventional, were tested. To the MQL cooling-lubrication technique, a vegetable based straight oil, IORGABIO MQL SPECIAL specification, from IORGA OLEOS E PROTETIVOS INDUSTRIAIS LTDA, whereas an emulsion of the vegetable-based synthetic at concentration of 5%, manufactured by TAPMATIC of BRASIL Ind. e Com. Ltda (ME-3 designation) was tested in conventional coolant technique. This fluid has a pH of 8.9 (basic characteristic). Summary of the machining parameters is shown in Tab. 1.

Table 1. Grinding parameters

Cutting speed ( $V_s$ ) [m/s]	38
Equivalent chip thickness ( $h_{eq}$ ) [ $\mu\text{m}$ ]	0.09, 0.18 and 0.27
Worktable speed ( $V_w$ ) [m/min]	10
MQL flow rates [ml/h]	60, 150 and 240
Flood coolant flow rate [ml/h]	545,000

The surface roughness parameters  $R_a$  and  $R_z$  were measured after each test with aid of a portable surface roughness tester, SJ201 P/M model, manufactured by Mitutoyo (Figure 2a). A cut-off of 0.8 mm and sampling length of 5 mm were selected for the measurements. Measurements were performed in four different equidistant locations from each ground surface, as shown in Fig. 2b, and average of the readings was calculated. Examination of the machined surfaces was performed in a Scanning Electron Microscope (SEM) to help in the analysis of the grinding mechanisms.

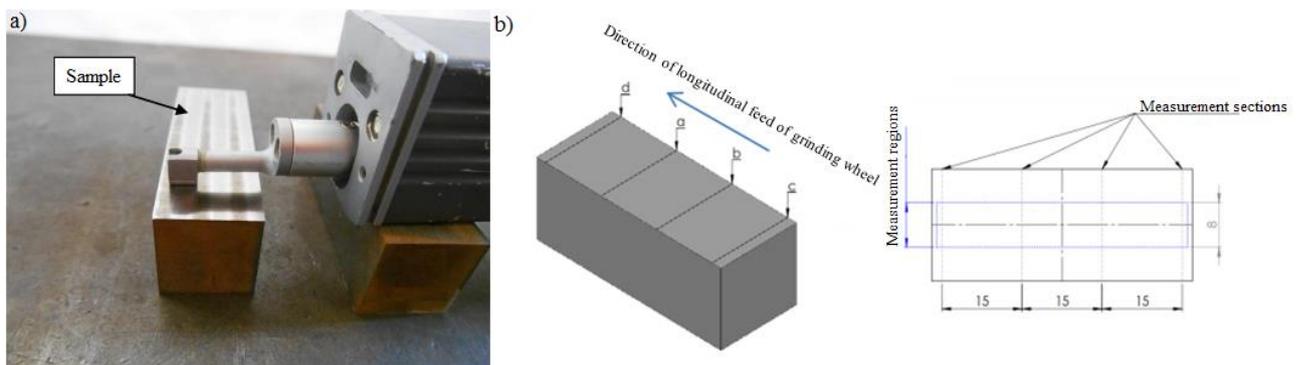


Figure 2. a) Surface finish measurement set up. b) Regions of the workpiece for measurements of surface roughness.

### 3. RESULTS AND DISCUSSION

In Figure 3 are shown the surface roughness (Ra) values after grinding the AISI VP 100 steel under different cutting conditions. From this figure can be noted that, in general, the roughness values increase with the equivalent chip thickness, regardless the cooling-lubrication condition. This is in agreement with the specific literature since an increase of  $h_{eq}$  also increases the material removal, cutting efforts, temperature and consequently leads to a poorer finishing (Bianchi et al., 1997). It can be also seen that machining with  $h_{eq}$  up to 0.18  $\mu\text{m}$  and MQL technique with flow rate of 60 ml/h and provided lower surface finish values, while the MQL technique with 240 ml/h outperformed the others after machining with  $h_{eq}$  in excess of 0.09  $\mu\text{m}$ . With exception of flow rate of 240 ml/h and  $h_{eq}$  up to 0.27  $\mu\text{m}$ , the results obtained with the all flow rates of MQL technique tested were similar or, in some cases, even lower than those obtained after machining with the conventional coolant technique.

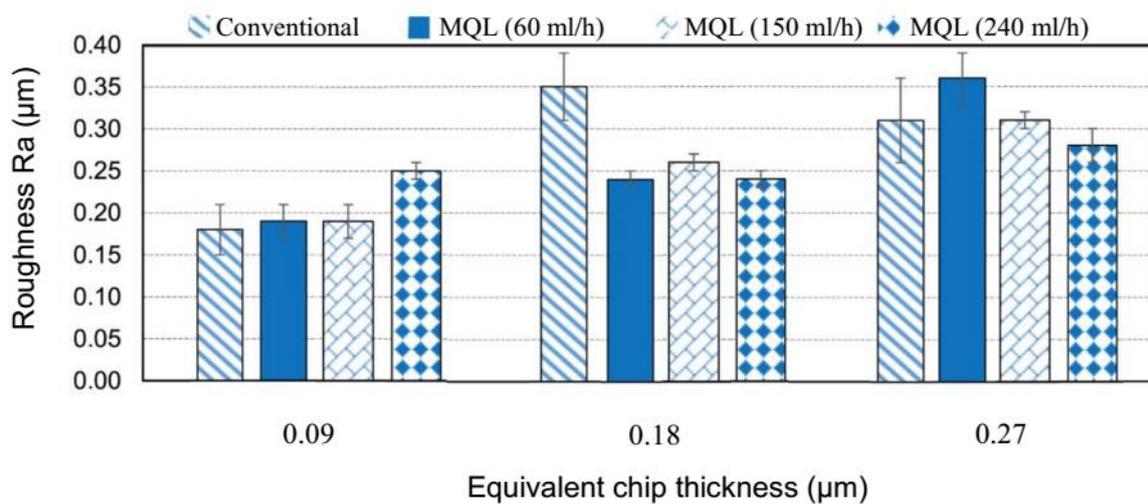


Figure 3. Roughness Ra versus the equivalent chip thickness for the different cooling-lubrication conditions.

In Fig. 4 are showed the Rz surface roughness values obtained after grinding under the different cutting conditions. It can be seen that, similar to the behavior observed for the Ra parameter, the values of the Rz values increased with the equivalent chip thickness, regardless the cooling-lubrication condition employed. In addition, it can also be seen that machining with the MQL technique at a flow rate of 240 ml/h outperformed the others in the most severe cutting conditions analyzed ( $h_{eq}$  of 0.18  $\mu\text{m}$  and 0.27  $\mu\text{m}$ ), while machining with  $h_{eq}$  of 0.09  $\mu\text{m}$  the results were similar for all conditions. With exception of  $h_{eq}$  of 0.09  $\mu\text{m}$ , the MQL technique with the all flow rates and  $h_{eq}$  tested presented lower values of Rz parameter than the conventional technique. This may be attributed to the fact that the MQL is able to break up the air barrier built around the spinning grinding wheel while this is not possible in the conventional technique because of the low pressure applied to the coolant (Ruzzi et al., 2017).

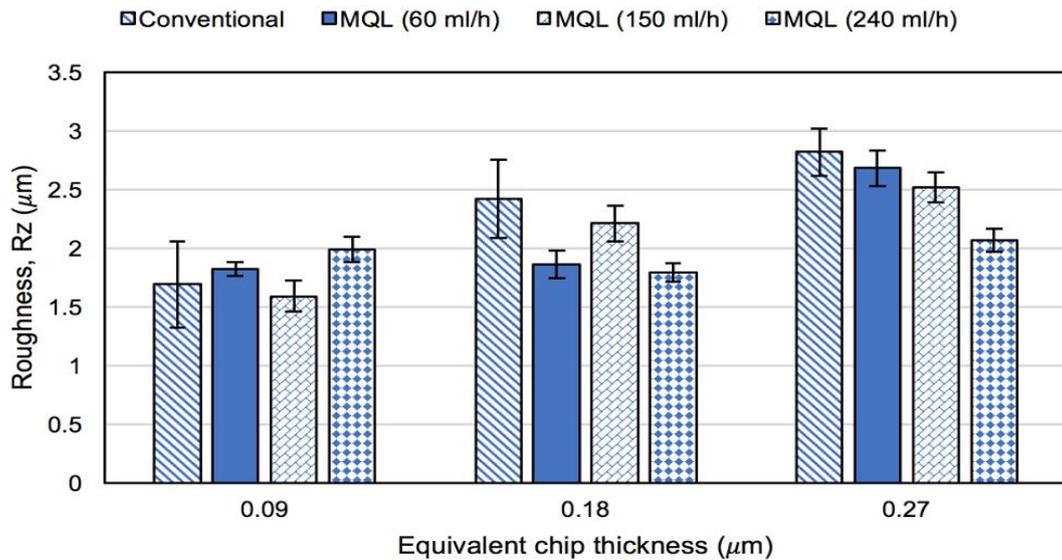
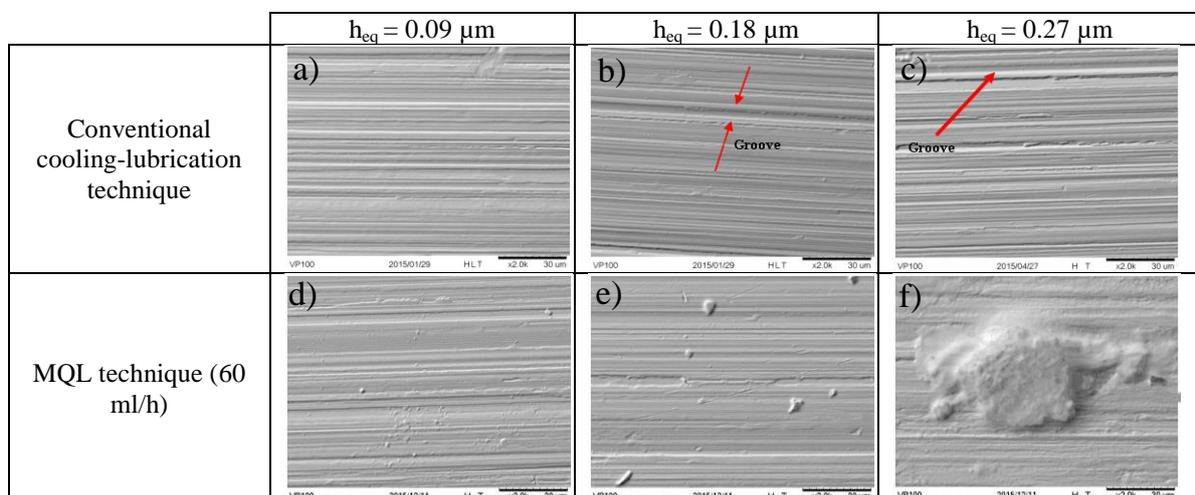


Figure 4. Roughness Rz versus the equivalent chip thickness for the different cooling-lubrication conditions.

The SEM images of surfaces ground under different cooling-lubrication and cutting conditions are shown in the Fig. 5. It can be seen from this figure that no adhered material was present on the ground surface under the conventional cooling-lubrication technique (Fig. 5a to Fig. 5c), irrespective the  $h_{eq}$  tested, thereby evidencing that the conventional technique (flood coolant) is effective on the removal of chips and maintenance of the cleaning of the workpiece as well as the grinding wheel cutting surface. Moreover, it can be also seen that the width of the grooves left by the grits of abrasive wheel on the workpiece material surface was proportional to the radial depth of cut ( $a_e$ ) employed, as expected, since higher is the  $a_e$ , higher is the area of the abrasive grits in contact with the workpiece (Marinescu et al., 2004). In the surfaces ground with the MQL technique and flow rate of 60 ml/h (Fig. 5d to Fig. 5f) can be seen some debris (material of the workpiece deposited onto the machined surface by the movement of the grinding wheel and its pressure on the surface). It can be also seen that the texture of the workpiece surface worsened with increase of the  $a_e$ , as expected, and that the feed marks presented on the surfaces after grinding with the MQL technique and flow rate of 60 ml/h. Increasing the flow rate of oil of the MQL technique from 60 to 150 ml/h (Fig. 5g to Fig. 5i) and to 240 ml/h (Fig. 5j - Fig. 5l) in general generated ground surfaces with adhered materials, probably due to the chips that were carried out by abrasive wheel and pressed against the workpiece material during the various turns of the abrasive wheel. The section of the chips increased with the  $h_{eq}$ , as expected. According to Oliveira et al. (2012), the conventional technique is more efficient than the MQL to cleaning the cutting surface of the grinding wheel their experimental work with CBN abrasive wheel, thus, grinding with the MQL technique is more susceptible to clogging the pores of the abrasive wheel, what may explains the inferior performance of the MQL technique tested in this work.



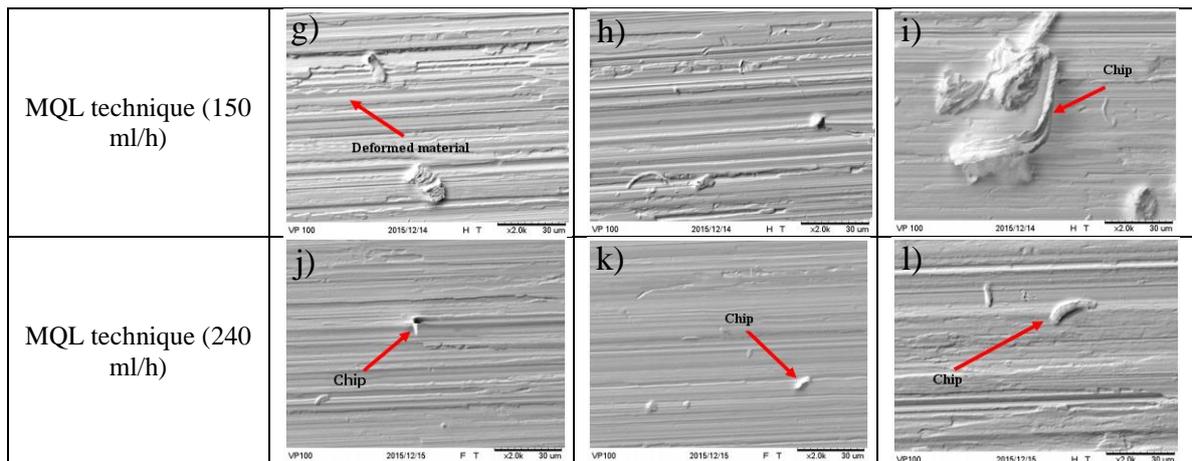


Figure 5. SEM Images of ground surfaces after machining with different cooling-lubrication techniques and cutting conditions.

#### 4. CONCLUSIONS

After the grinding tests, the following conclusions can be drawn from this work:

- Surface roughness, both Ra and Rz values, increased with the equivalent chip thickness for all the cooling-lubrication conditions tested and the results obtained after machining with all flow rates of MQL technique were in general similar or, in some cases, even lower than those obtained for conventional coolant technique;
- The surfaces obtained after the grinding with the conventional cooling-lubrication technique were more uniform than those obtained with the MQL technique;
- The flow rate of MQL technique plays influence on the surface finish and its inferior performance compared to conventional coolant technique was probably due to the its inefficient cleaning of the chips from the grinding zone, what makes abrasive wheel more susceptible to clogging phenomenon during grinding.

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