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PERFORMANCE EVALUATION OF THE MQL TECHNIQUE IN GRINDING OF A MOULD VP ATLAS STEEL

Environmentally Friendly Fluids

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Abstract. In order to avoid thermal damages on the machined components, grinding is performed in the presence of flood coolant applied in high volume. This technique can cause many environmental and health hazard because of improper maintenance and disposal of coolants, thus the need to seek for alternative techniques to flood coolant. In this study, Minimum Quantity Lubrication (MQL) technique which uses low quantity of oil has exhibited technical and economic viability relative to conventional technique. This paper evaluates the performance of the MQL technique in grinding of the mould VP Atlas steel under several machining conditions. Three values of depths of cut (0.02, 0.04 and 0.06 mm) were tested. Ra parameters and grinding power were used to assess grinding performance using MQL technique. The results showed that the MQL technique outperformed the conventional technique in all parameters tested. This is attributed to the enhanced lubrication function which reduces friction during grinding.

Keywords: Grinding, MQL technique, VP ATLAS steel, Roughness, Grinding Power.

INTRODUCTION

Grinding is an abrasion machine process usually employed in the finishing of high hardness materials. In this process, the grinding wheel, composed of several hardness abrasive grains, act as a cutting tool, rotating at high speeds (generally upper to 30 m/s) and promoting the removal of material from the workpiece surface in chip form [1].

During the grinding process, a high amount of heat is generated in the cutting zone. Factors like low thermal conductivity of the abrasive conventional wheels and small section of chips contributes to increase amount of heat being transferred to the workpiece during machining which can compromise the surface integrity [2]. Therefore, the grinding processes requires the presence of a large amount of cutting fluid in order to promote cooling and lubrication in the cutting zone to avoid thermal damages, such as burning, cracks and residual stresses. The cutting fluid, beyond the functions of cooling and lubrication, also promotes cleaning of the grinding wheel, removing the chips from the grinding zone [3].

The growing demand for high precision parts and components has informed research to improve the manufacturing processes. In the automotive industry, moulds with complex geometry and low dimensional tolerances are used for injection of non-ferrous materials, as ceramics and plastics [4]. These moulds are generally of hardened steels, such as VP ATLAS steel, which combines high hardness, toughness and good wear resistance. Thus, to ensure the low dimensional tolerances and low roughness values, grinding process is the most recommended industrial process, because it can be used in the finishing of hardened steels, ensuring low roughness values ranging from 0.2 µm to 1.6 µm [5].

The high amount of fluid applied by the conventional cooling-lubrication technique in the cutting zone has been questioned because of its impacts in the human health and environment. This prompted the search for alternative techniques of cooling-lubrication, among them, the Minimum Quantity Lubrication (MQL) technique. This technique has attracted great attention because of the lower quantity of lubricant used during the process ([6]; [7]; [8]), while in the conventional technique is usually employed at a fluid rate of 9 L/min per 1 mm wheel width. In the MQL technique, the fluid is generally applied at a flow rate ranging from 30 ml/h to 240 ml/h [9].

According to [6] the MQL is one of the most efficient methods available for the reduction of the amount of cutting fluid because it consists of a small amount of cutting fluid directed into the grinding zone in aerosol form. Some researchers evaluated the effectiveness of the MQL technique in surface grinding with aluminum oxide grinding wheel and presented a comparative study among the conventional technique, dry grinding and MQL technique. They reported that MQL technique outperformed the others techniques in terms of surface roughness, temperature and grinding power. Superior performance of MQL technique compared to conventional coolant technique in grinding process were also reported by [9], [10] and [11]. In general, they agreed that MQL technique was able to significantly reduce the shear forces.

Experimental trials in cylindrical grinding of plastic mould VP 50 steel with Al_2O_3 abrasive wheel reported by [12] showed improved performance of the MQL technique in comparison to the conventional technique, especially in terms surface roughness. [13] also reported that that the roughness values increased with depth of cut, as expected after grinding a mould VP 80 steel grinding with Al_2O_3 abrasive wheel.

According to [14] and [15] the efficiency of the MQL relative to the conventional technique during grinding process is due to the ability of the compressed air jet to break the air barrier formed around the rotating wheel thus ensuring a more efficient delivery of the lubricant into the cutting zone. This action tends to minimize friction and consequently the heat generation on the workpiece surface during grinding.

This paper aims to evaluate the performance of the MQL technique in peripheral surface grinding of a mould VP ATLAS steel in terms of surface roughness and grinding power, relative to the conventional flood cooling technique.

METHODOLOGY

The workpiece material is VP ATLAS steel that were prepared in the form of rectangular bars, with dimensions: 48.8 mm (length) X 18.0 mm (height) X 20.0 mm (width). Chemical composition and hardness of VP ATLAS steel are shown in Table 1.

Table 1. Chemical Composition (% mass) of the VP ATLAS steel [16].

C	Si	Mn	P	S	Cr	Mo	Ni	V	Hardness
0.26	0.27	1.53	0.026	0.006	1.78	0.68	0.55	0.08	41 HRC

The grinding tests were conducted in a tangential grinding machine supplied by MELLO, model P36, with z-axis resolution of 5 µm Fig. 1 shows the setup used to perform the grinding tests. An aluminum oxide grinding wheel, with designation AA60K6V with a vitrified bonder and dimensions of 303 mm X 25 mm X 76 mm was employed.

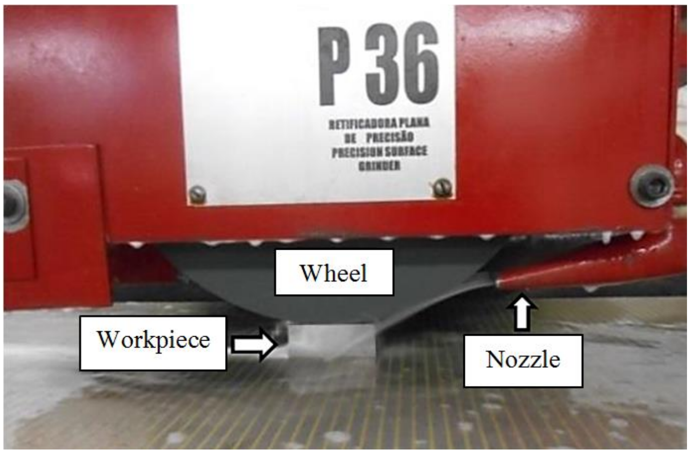

Figure 1. Experimental set-up of the grinding tests.

The input parameters used during the grinding process are summarized in Table 2. The cutting speed (33 m/s) and worktable speed (10 m/min) were kept constant during all the tests, and three values of depth of cut were used (0.02 mm, 0.04 mm and 0.06 mm).

Table 2. Input parameters of the grinding tests.

Cutting speed (V_s)	33 m/s
Worktable speed (V_w)	10 m/min
Depth of cut (a_e)	0.02 mm, 0.04 mm and 0.06 mm
Equivalent cutting thickness (h_{eq})	0.09 µm, 0.18 µm and 0.27 µm
Depth of dressing (a_d)	10 µm
Coolant flow (Conventional technique)	545, 000 ml/h
Oil Flow (MQL technique)	60 ml/h

The equipment used to deliver the oil through the MQL technique was a specially designed syringe pump as shown in Fig. 2. One of the ends of the syringe is attached to system having a threaded rod with known pitch that is driven by a stepper motor rotation. An Arduino controller and a precision potentiometer for variation of rotation are used to control the rotational speed.

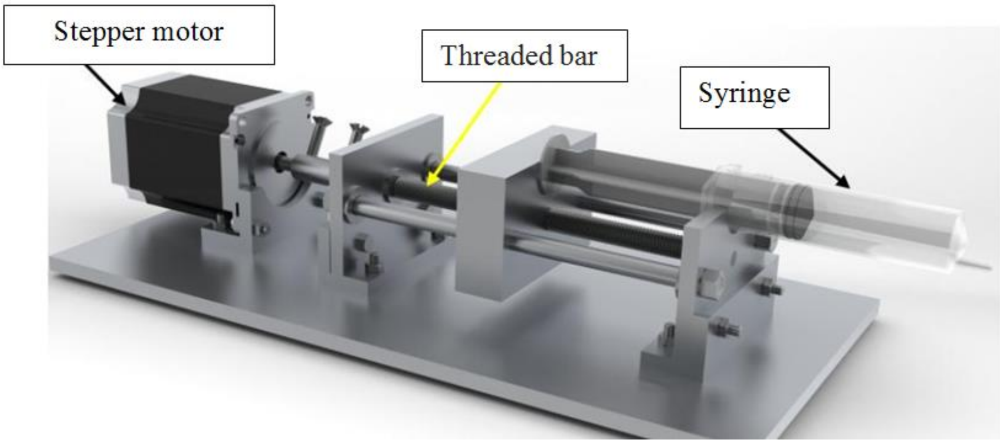

Figure 2. Illustration of the equipment used in the MQL technique

The cutting fluid used in the conventional technique was a vegetable based synthetic cutting fluid, ME-3 diluted in water at a concentration of 5%. For the MQL technique, a vegetable based neat oil with additives was used.

The surface roughness values, Ra parameter, were recorded with a portable surface roughness tester with resolution of 0.01 µm, using a cut-off of 0.8 mm. The measurements were performed in four different regions of the ground surface, distance 15 mm from each other and perpendicular to the grinding direction.

The grinding power values were obtained through current and voltage signals. For the measurement of electric current, a HAS - 50 – 600S sensor was used, while for the voltage measurements a LV – 20p sensor was employed. The results were processed through LABVIEW Software, supplied by National Instruments. The results represent the average values recorded during a grinding pass of the abrasive wheel on the work material surface.

RESULTS AND DISCUSSIONS

The surface roughness, Ra, values obtained after grinding with MQL and conventional techniques under the three different cutting conditions are shown in the Fig. 3. From this figure, it can be observed that the roughness values increased with the depth of cut (a_e) irrespective of the cooling-lubrication technique employed. This is expected since the equivalent chip thickness (h_{eq}) increased with increasing depth of cut (a_{e}). According to [17], increase of h_{eq} results in an increase of surface roughness and the grinding forces.

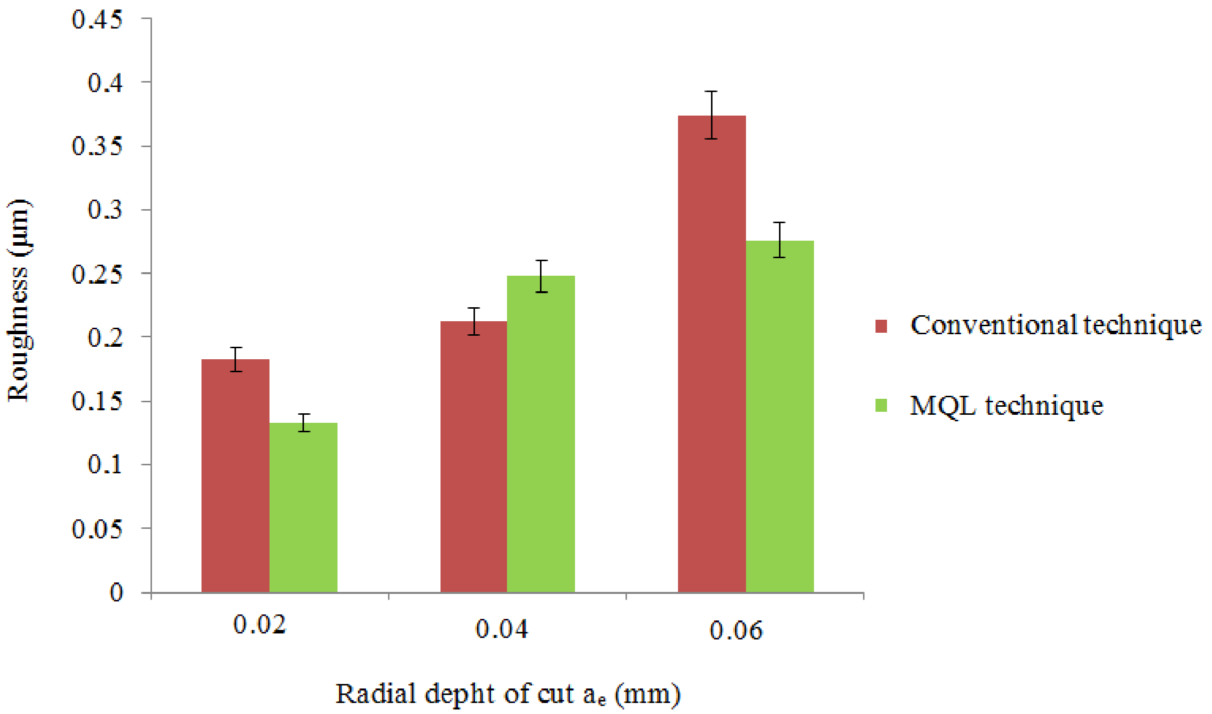

Figure 3. Surface roughness versus radial depth of cut

Fig. 3 also shows that for the same depth of cut, machining with the MQL technique presented equal or lower values of Ra than the conventional technique. This could be due to the improved lubrication in the contact zone between the grinding wheel and the workpiece caused by the ability of the compressed air jet to break the air barrier created by the grinding wheel and promote a more efficient delivery of the lubricant that reduces the friction. [18] performed grinding tests on ABNT 4340 (60 HRC) under various cutting conditions and reported similar findings where the roughness obtained with the MQL technique were lower than those obtained with the conventional technique.

An experimental study on grinding of plastic mould VP 80 steel with an abrasive Al_2O_3 showed that the roughness surface increased with depth of cut, as expected due to the increase of active grains per unit area [13]. Results obtained by [12] also showed improved performance in terms of surface integrity under MQL technique when grinding the plastic mould VP 50 steel with Al_2O_3 abrasive wheel.

Figures 4 and 5 are show SEM images of the VP ATLAS steel workpieces surface after grinding with the conventional technique and MQL technique, respectively. It can be observed from Figure 4 that the feed marks left by the abrasive grains are generally well defined for all conditions for the three depths of cut tested. In addition, the flow of material pushed to the side between the grooves increased with increasing depth of cut.

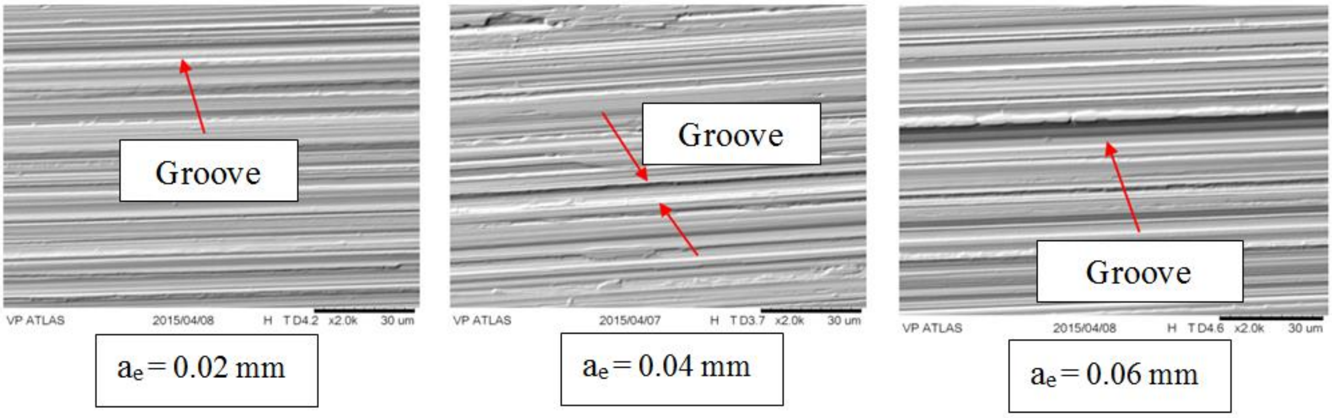

Figure 4. Images of VP ATLAS steel surface under convention technique grinding for three different depth of cut

Figure 5 shows that the feed marks left by the abrasive grains in the workpiece are well defined and there was practically no evidence of debris or adhesion of material to the workpiece and no cracking of the machined surfaces.

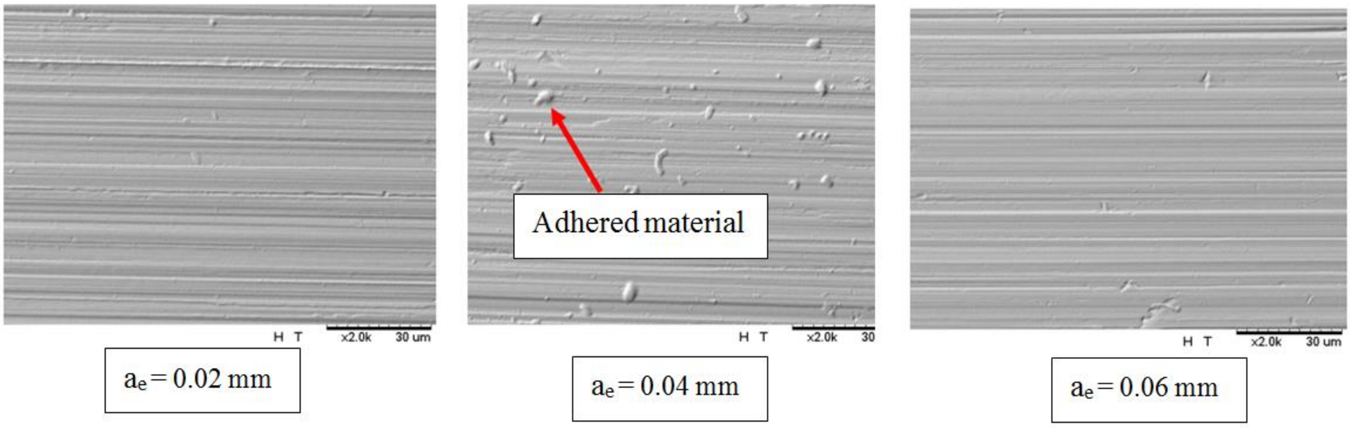

Figure 5. Surface roughness versus depth of cut.

The grinding power generated is presented in the Fig. 6. As expected, the grinding power increased with increasing depth of cut and that they did not reach the nominal maximum motor power of the grinder machine, which is 2400 W. It can also be seen that the MQL technique requires lower cutting forces relative to the conventional coolant technique, thus reducing the grinding power. This may be attributed to the better lubrication promoted by the oil supplied by the MGL technique that efficiently accessed the grinding zone, thereby reducing friction between abrasive grits and workpiece material. According to [14], two advantages of the MQL techniques rely on the reduction of the grinding forces and preserving the characteristics of the grinding wheel after dressing.

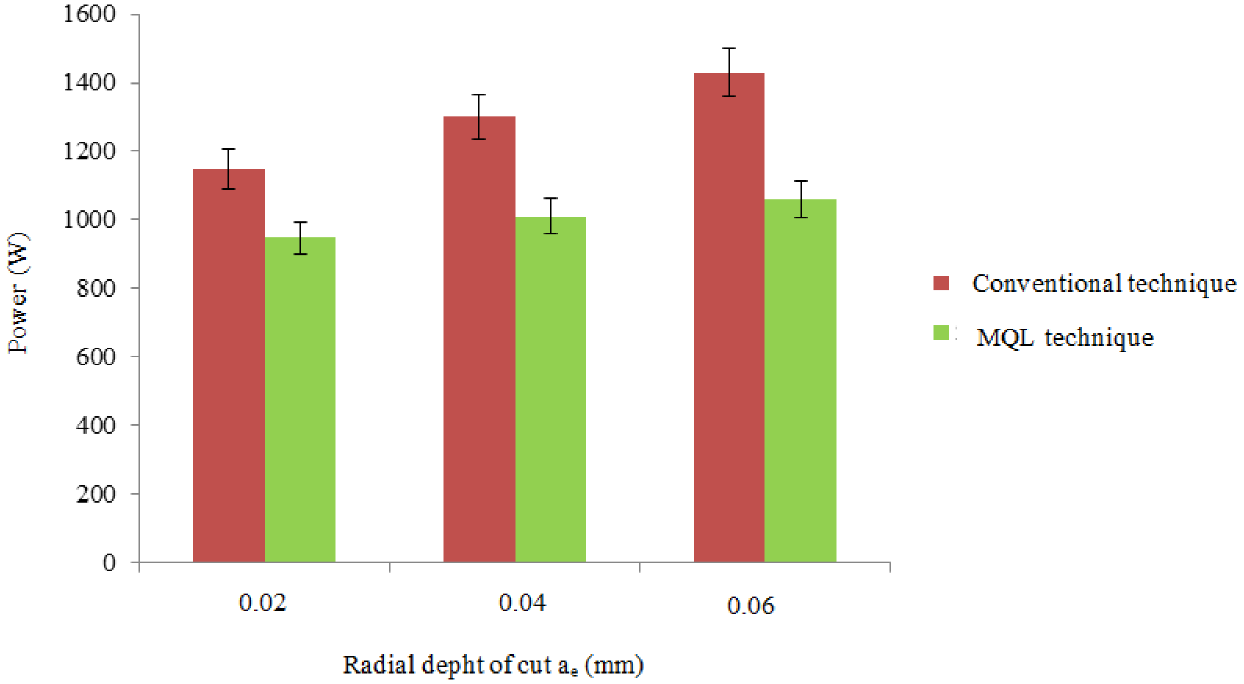

Figure 6. Power versus radial depth of cut.

CONCLUSIONS

The following conclusions could be drawn from this study:

- The surface roughness, Ra, values, increased with increasing depth of cut, irrespective of the cooling-lubrications technique. The values obtained after grinding with the MQL technique, even after the most sever condition (a_e = 0.06 mm), were lower than those obtained after grinding with the conventional technique;
- SEM images of the ground surfaces shown that, in terms of texture, the MQL technique outperformed the conventional flood cooling technique due to the improved surface quality provided and the absence of apparent crack;
- The grinding increased with increasing depth of cut, irrespective the cooling-lubrication technique employed, and that MQL technique provided the lowest values;
- The MQL technique outperformed the conventional one and is therefore a viable alternative to the conventional technique when grinding at certain conditions.

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