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THE EFFECT OF NOZZLE TYPE AND ITS POSITIONING ON SURFACE INTEGRITY OF VP100 STEEL AFTER GRINDING

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Abstract. *Grinding is a final machining process employed when smooth surfaces and closer geometric tolerances are required. Among the various parameters that can affect grinding performance, cutting fluid and its delivery to the cutting zone play an important role because, depending on the wheel-workpiece system combination, it can represent up to 16% of the total cost of the process. Thus, in order to achieve the best benefit-cost relation for any specific case, it is important to investigate, in addition to the cooling delivery technique, the influence of nozzle geometry and its positioning in grinding efficiency. Into this context, this paper presents a study on grinding of ABNT VP100 mould steel employing two types of nozzle system (the conventional type and the plastic flexible one) under two different positioning (tangential and intermediate). Experimental trials were carried out in a tangential surface grinder. Three depth of cut values (20, 40 and 60µm) were tested. The surface integrity was analysed in terms of surface roughness (Ra parameter), microhardness below machined surface and also SEM images of grinding surfaces. Results showed that the lowest Ra values were obtained after grinding with the plastic flexible nozzles at the tangential position. No significant difference on microhardness was noticed after varying nozzle type and its positioning.*

Keywords: *grinding, cutting fluid, nozzle type, nozzle positioning, surface roughness*

1. INTRODUCTION

Grinding is a finishing operation widely used on manufacturing on order to improve dimensional quality of hard/brittle materials (Marinescu, 2004). It is also employed when conventional processes that use geometrically defined cutting tools such as turning and milling cannot fulfil minimum requirement. The grinding process uses hard non-metallic abrasive particles with no defined cutting edges as cutting tools. These particles remove material from the workpiece according to three different stages: friction, ploughing and chip formation. Such tribological condition is responsible for generating a large amount of heat at cutting zone.

In the grinding process, a great quantity of energy is used to remove a small quantity of material. The most part of this mechanical energy is transformed in heat due friction and scratching promoted by the grains action when they penetrate the workpiece (Marinescu, 2004). The heat generated in the process is dissipated through the workpiece, chip, cutting fluid and environment. However, due the characteristics of the process, most part of this heat generated goes to the workpiece, thereby leading to dimensional and/or microstructural damages.

The properties of the machined surface generated by the grinding process can affect the product liability in terms of fatigue and corrosion resistance. High temperatures can generate residual tractive stresses on the workpiece surface which is undesirable (Fergani et al., 2014). The microhardness below the machined surface is other parameter that can be used to verify the quality of a machined surface, then it can be evaluated whenever possible (Malkin & Guo, 2008).

In this context, the use of cutting fluid is crucial to minimize the thermal effects on the workpiece and consequently guarantee the efficiency of a grinding process. Furthermore, not only the type of cutting fluid, but also its delivery way to the cutting zone needs to be investigated, since the cutting fluid represents a great parcel of the total manufacturing cost, including purchase and disposal.

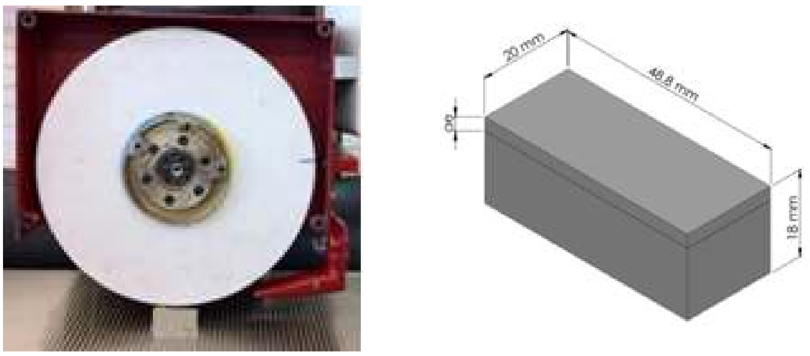
Grinding without a cutting fluid is practically inviable and most cutting fluids in grinding must have high cooling properties. The position in which the cutting fluid is delivered (nozzle positioning) is an important factor in the grinding process. The correct selection of an application method of cutting fluid in the grinding zone can increase both lubrication and cooling capability, thereby generating lower cutting forces and smoother surfaces.

Ebbrell et al. (2000) studied three different nozzle positions: angular, tangential and normal. Comparing all the three positions, the lower values of roughness were obtained after grinding with the angular position. According to the authors, high forces were recorded after machining with nozzle adjusted on the angular position due to the insufficient lubrication and cooling actions of cutting fluid because of the position. Because of the poor lubrication action, the grain's wear intensifies due the high friction, increasing the contact area between the abrasive grain and the workpiece, which increases the "flatting effect" of the workpiece, and adversely affecting its surface roughness.

In this context, this work presents the effect of nozzle type and its positioning on the surface integrity of ABNT VP100 steel after tangential surface grinding process. The surface integrity was analysed in terms of surface roughness (Ra parameter), microhardness below machined surface and SEM analysis of the ground surfaces.

2. METHODOLOGY

Experimental trials were carried out on a Mello peripheral surface grinding machine, P36 model, with 3 HP of power and maximum rotation speed of 2400 rpm. A conventional straight white aluminium oxide (Al_2O_3) abrasive wheel, designation AA60K6V with dimensions 300 mm x 25 mm x 76 mm (Fig. 1(a)) was employed in the all trials. The workpiece was the ABNT VP100 steel grade (40 HRc) with dimensions 48 mm x 20 mm x 17 mm, as shown in Fig. 1(b).



(a) (b)

Figure 1 – (a) Abrasive wheel – AA46K6V; (b) Dimensions of VP100 steel grade workpiece.

The following cutting parameters were used: wheel speed (Vs) of 37 m/s; longitudinal speed of the workpiece of 10 m/min, constant. Three different values of depth of cut (20, 40 and 60 µm) were used to remove the same quantity of material of 120 µm of the workpiece height. The cutting fluid used was the vegetable based synthetic soluble oil ME-3 from TAPMATIC, at 5% concentration, which was applied to the cutting zone by the conventional technique with at two different flow rates: 420 and 545 L/h.

Three different types of nozzle were used: the conventional one that is available in the tool-machine and two plastic flexible nozzles (flat and round shapes). The former was applied with the highest flow rate, while the latter was adjusted be used at the lowest flow rate of 420L/h. The conventional nozzle was tested at two different positions: tangential (Fig. 2(a), N1-P1) and intermediate (Fig. 2(b) N1-P2). The two plastic flexible nozzles were mounted to reach at the same time the abrasive wheel by the radial and side position (Fig. 2(c) and (d)). The flat nozzle geometry was tested as the conventional nozzle (at tangential (N2-P1) and intermediate position (Fig 2(c) N2-P2), while the round shape was kept always at the grinding wheel side. The Figure 2 shows the types of nozzles as well as their positioning used in this work.

(a) N1-P1 (b) N1-P2

(c) N2-P1

(d) N2-P2

Figure 2 - Type and nozzle positioning: (a) conventional nozzle at tangential position (N1-P1); (b) conventional nozzle at intermediate position (N1-P2); (c) plastic flexible nozzles at tangential position (N2-P1); (d) plastic flexible nozzles at intermediate position (N2-P2).

The parameters used to evaluate the effect of the nozzle type and its positioning in the surface integrity were: surface roughness (Ra parameter), microhardness below the machined surface and SEM analysis of the machined surfaces. The surface roughness was measured using a portable surface roughness tester (Mitutoyo SJ-201P) with a cut-off of 0.8 mm at the end of each experimental trial at four different regions on the machined surface; the measurements were performed perpendicularly to the grinding direction, The microhardness was measured with a HMV Micro Hardness tester, SHIMADZU, after standard metallographic preparation of the workpiece; ten measurements were performed from a distance below the machined surface of 20 to 200 μm; they were replicated twice; the parameters were: Vickers indenter, load of 490.3 mN (HV 0.05), time of 15 s. The SEM analysis was made on a TM3000 SEM, HITACHI. Images of the machined surfaces for each condition were obtained.

3. RESULTS AND DISCUSSION

The Figure 3 shows the surface roughness (Ra parameter) of VP 100 steel grade as a function of nozzle type and its positioning for all the values of depth of cut (a_e) employed in grinding trials.

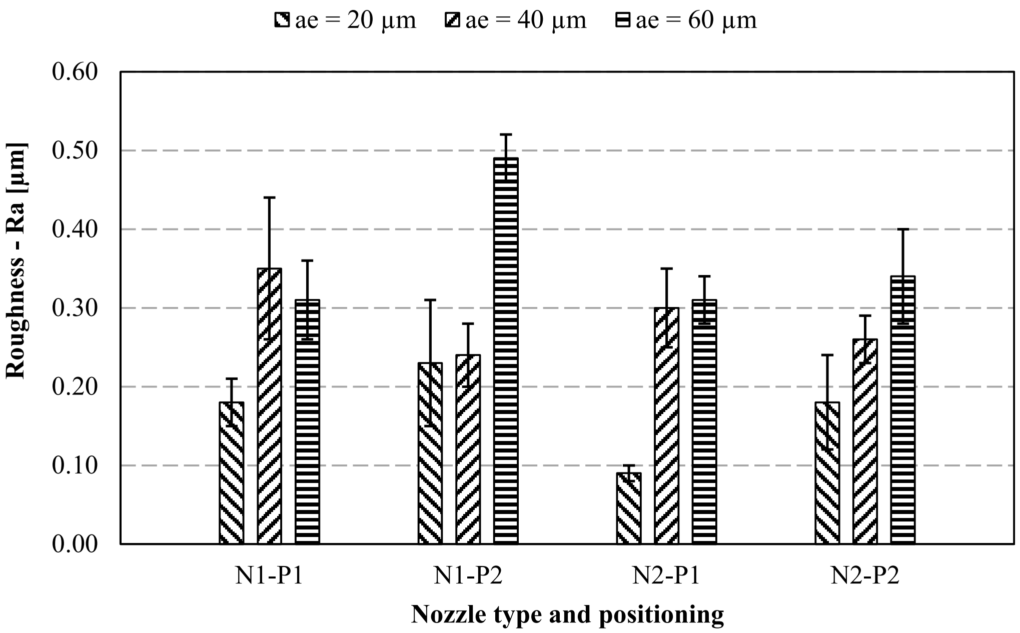


Figure 3 - Surface roughness (Ra parameter) as a function of the nozzle type and its positioning for all the depth of cut values employed.

As can be seen From Fig. 3, all the results of surface roughness are in agreement to grinding processes, i.e., Ra is below 1.6 µm. In addition, the lowest value of roughness was recorded when grinding with the two plastic flexible nozzles at the tangential position (N2-P1) and with a_e = 20 µm. In this condition reduction the Ra was over 50% when compared to the other conditions using the same depth of cut. Probably, the use of two nozzles directing the cutting fluid to the workpiece surface increased the useful flow rate, that means, the quantity of fluid that reaches the contact zone, improving both cooling and lubrication. According to Malkin & Guo (2008), the surface roughness is directly proportional to the workpiece properties as well as grinding conditions, including lubrication and cooling.

By considering the average Ra values, the surface roughness increased with depth of cut as expected, except for the conventional nozzle at tangential position (N1-P1) for a_e of 40 and 60 µm. The higher the depth of cut, the higher the number of abrasive grains in contact with the workpiece, and consequently more intense will be the plastic deformation. This phenomenon increases the workpiece surface irregularity, resulting in poorer surface finishing.

Also, it can be observed from Fig. 3 that the use of the two plastic flexible nozzles (N2) was, in general, outperformed the conventional nozzle (N1), irrespective of nozzle positioning. Not only the surface roughness was lower using the N2 system, but also the cutting fluid flow rate, which represents gain in productivity, since the estimated costs of cutting fluid are approximately 16% of the total costs of a product (Debnath et al., 2014). Furthermore, according to Irani et al. (2005), by delivering cutting fluid from the abrasive wheel side can improve the workpiece finishing.

The Figure 4 shows the microhardness measurements for all experiments as function of the depth below machined surface, where the line R stands for the microhardness average of the workpiece prior the grinding process. As can be seen, there was not a significant difference on the microhardness results after machining with different nozzle types and its positioning. However, variation in the depth of cut affected the results. It was observed some softening up to 40 µm below the machined surface when machining with a_e = 40 and 60 µm as shown in Figure 4(b) and (c). On the other hand, it was noticed a dropping in hardness up to 20 µm below the machined surface after grinding with a_e = 20 µm (Fig. 4(a). Such softening is probably due to tempering closer the machined surface, a common phenomenon on the grinding of hardened steels, which is directly proportional to depth of cut (Malkin & Guo, 2008). It is important to note that the results for the condition N1-P1 and a_e = 40 µm can be considered unusual, since they presented a hardness lower than the average (line R) for all measured points.

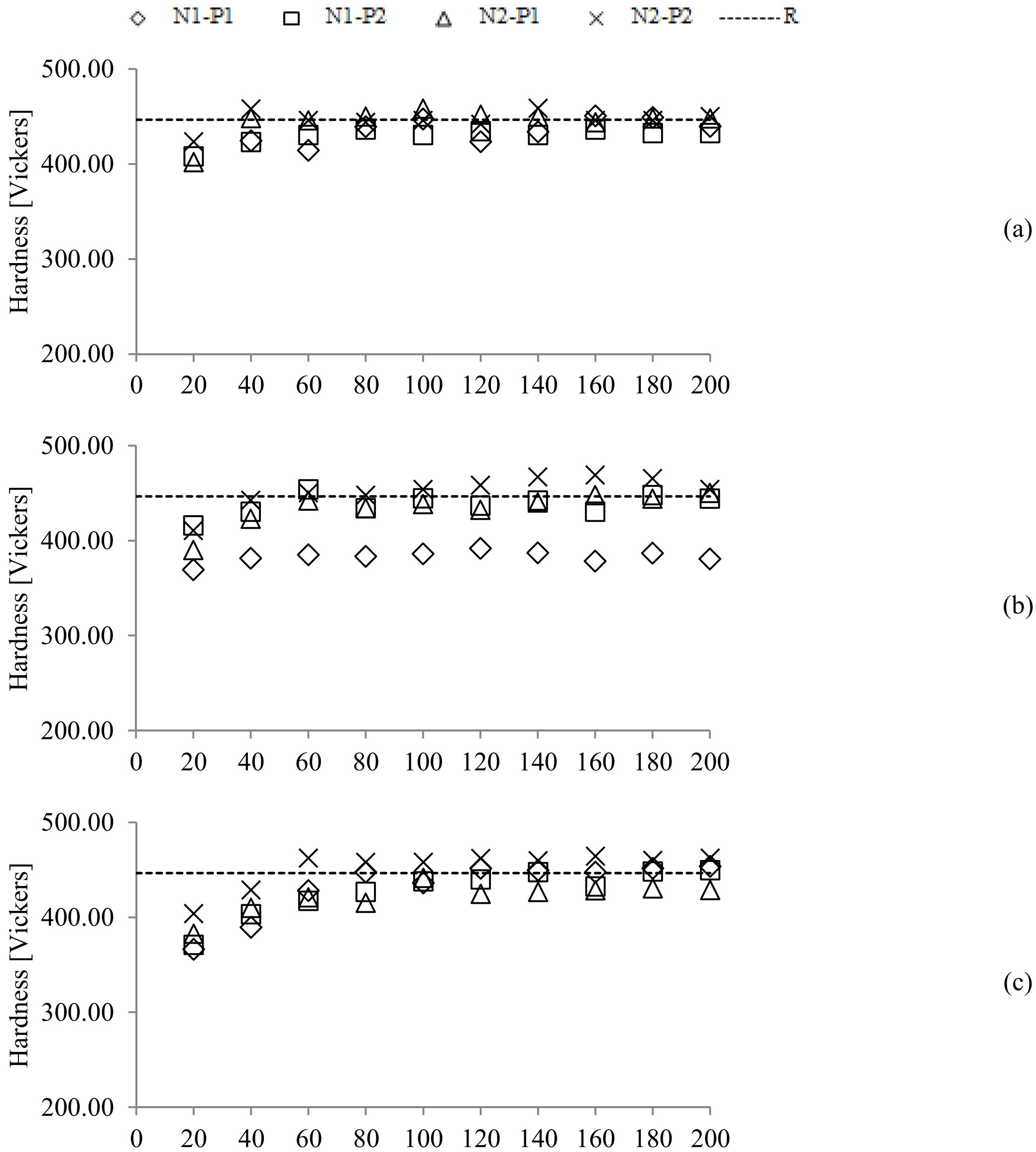
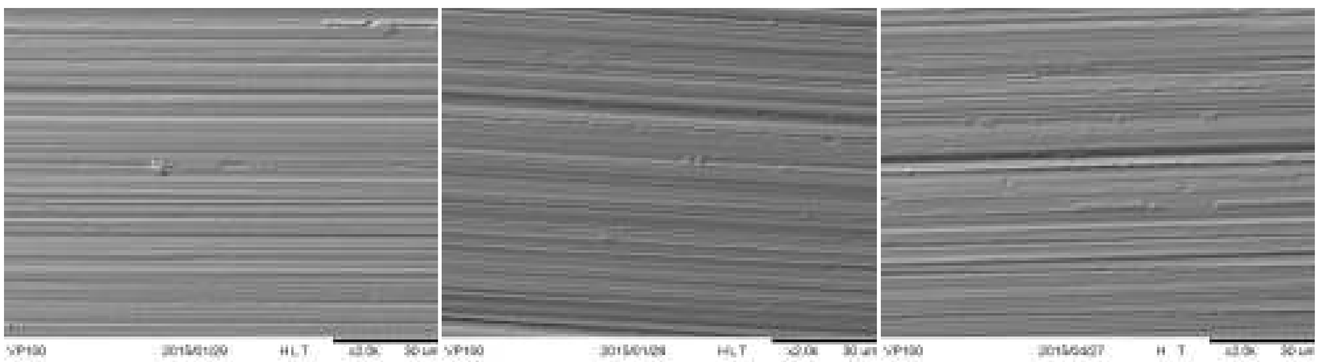


Figure 4 – Microhardness measurements: (a) a_e = 20 µm; (b) a_e = 40 µm; (c) a_e = 60 µm.

By analysing the SEM images of VP100 steel in Fig. 5(a), (b) and (c), can be observed some scratchings marks as a result of the geometry of the abrasive grains that pass through the surface, as well presence of side flow material due plastic deformation. No significant difference between nozzle type and positioning on the machined surface images were observed. From Fig. 6 (a) –(d) can be also observed that surface marks are very similar, irrespective the cutting conditions.



(a) (b) (c)

Figure 5 – SEM analysis for the condition N1-P1: (a) a_e = 20 µm; (b) a_e = 40 µm; (c) a_e = 60 µm;

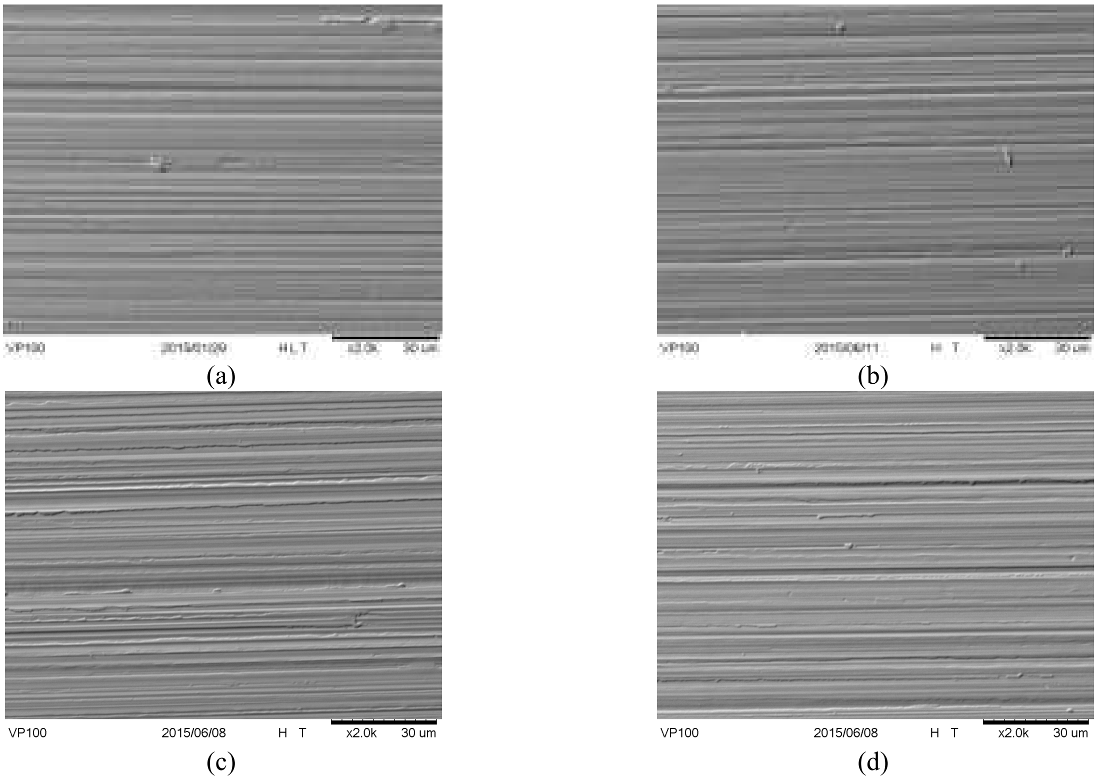


Figure 6 – SEM images of the machined surfaces after grinding with different conditions of nozzle type and its positioning using a_e = 20 µm: (a) N1-P1; (b) N1-P2; (c) N2-P1; (d) N2-P2.

4. CONCLUSIONS

According to the results obtained after grinding VP 100 steel grade under the conditions investigated in this work, the following conclusions can be drawn:

- The lowest value of surface roughness (Ra = 0.09 µm) was recorded after machining with the two plastic flexible nozzle at the tangential position (N2-P1) and a_e = 20 µm;
- The surface roughness increased with depth of cut as expected, except for the conventional nozzle at tangential position (N1-P1) for a_e = 40 and 60 µm;
- Use of two plastic flexible nozzle (N2) outperformed the conventional (N1) in terms of finishing;
- Variation in the depth of cut values affected the microhardness as expected. In general, drop in hardness was more pronounced after machining with the highest depth of cut of 60µm in distances closer to the machined surface.
- No significant difference on the microhardness values was observed after machining with different nozzles and its positioning.

5. ACKNOWLEDGEMENTS

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