DRILLING OF HARDENED STEEL WITH MINIMAL QUANTITY OF LUBRICANT

Rodrigo Panosso Zeilmann, rpzeilma@ucs.br
Andréia Vanessa Finimundi, avfinimu@ucs.br
Diego Carlos Calza, dccalza@ucs.br
Machining Group, Dept. of Mechanical Engineering, University of Caxias do Sul, Caxias do Sul, Brazil.

Abstract. *This paper presents a study of drilling of a hardened steel DIN 1.2711 with the application of Minimal Quantity of Lubricant (MQL). The drilling process was chosen to evaluate the effect of lubrification with MQL, where the lubricant was applied with an external nozzle. An analyze the surface and the tool life was made to evaluate the process behaviour and to understand the factors which influence the drilling process with a minimal quantity of lubricant and severious cutting conditions. The results show a good potential in the drilling with MQL. The chips and the quality of the holes are gotten with characteristics next to the gotten ones with the emulsion application. The strong adhesion of material of the part in the edge and in the wall of the hole, was also presented as critical factor. One revealed that, of a general form, the lubrication effect satisfactorily is gotten with MQL.*

Keywords*: Tool wear, Surface texture, Roughness, DIN 1.2711 steel.*

1. INTRODUCTION

The metals machining occupies a position of great prominence of the industry metal-mechanics that is present in practically all the phases of the manufacture of components in the most different areas (Gonçalves *et al*, 2007). The drilling of metals constitutes great part of the machining processes and if compared with the others process is one of the difficult accomplishments, therefore it needs bigger refrigeration and aid in the transport of chips.

The participation of the drilling process with twist drills in the total machining processes is evaluated in the band of 20 to 25% and, nowadays, the drill is the tool manufactured in bigger amount and also the most spread out for the machining (König and Klocke, 2002). Thus, it's of great importance the accomplishment of studies on the behavior in wear of the tools in this process under severe conditions of reduction or cutting fluid elimination.

The cut fluids are of great importance for the accomplishment of the machining processes. These present primary functions that provide improvements in the superficial finishing of the parts, carry through lubrication with objective to reduce the attrition, reduce the wear of the tool and the consumption of energy, supply the refrigeration with function to eliminate heat without allowing that occur dimensional alterations in the parts, assist in the expulsion of the chip of the cut region, protect machines and tools against atmospheric corrosion (Novaski and Rios, 2004). The absence of these functions can cause increase of the temperature, that propitiate the wear mechanisms (increase of abrasion and adhesion), with reduction of the useful life. The reduction of refrigeration increases the transference of heat for the joint tool/workpeace/machine (Zeilmann *et al*, 2007).

However, in recent years the cutting fluid is suffering restrictions, due the diverse negative effect that they cause. When discarded of inadequate form, these can damage the resources of the ground and water, causing serious problems to the environment. Moreover, the cut fluids contain in its composition some elements as additive, bactericidal products of reactions, fungicides and to keep its stability that, indirectly are causers of illnesses to the men. Consequently, the use and elimination of fluids must obey the rigid rules of the ambient protection. For the companies, the costs related to the cutting fluids represent great amount of the total machining costs (Dhar et al, 2007).

To the reduction of these damages, two techniques come being widely studied: Minimal Quantity of Lubricant (MQL) application and the elimination of the use of these fluids (process with compressed air application), without the loss of the quality of the machined parts and the reduction most efficient of the effect of fluids on the way with the lesser generated amount, facilitating to the destination and adequate processing. The MQL concept can be defined as the atomization of a minimum amount of lubricant (up to 100 ml/h) in a compressed air flow. These minimum amounts of fluid are enough to reduce substantially the attrition in the tool and to prevent the material tack, considering that the contact area chip tool is very small (Costa *et al*, 2006).

The effects of the reduction of the cutting fluids use on the drilling process are little understood yet. Being thus, this work has for objective to evaluate the mechanisms and kinds of wear of the tool, the quality of the surface and the subsurface of the holes under the condition of MQL application, in the drilling process in the hardened DIN 1.2711 steel, with high-speed-steel (HSS) twist drills.

2. METHODOLOGY

For the development of the drilling tests, twist drills of high-speed-steel HSS had been used, with diameter of 8 mm. The holes had been carried through in full, without center holes, with use of the intermittent feed (prick-wood cycle) to facilitate the break and exit of the chip. The depth of each machined hole corresponded to 40 mm (five times the diameter of the drill, l/d = 5). Table 1 shows the main features of the tool.

Table 1. Tool features

Tool Type	Diameter d [mm]	Number of edges	Material	Class	Coating	Angle of point	Clearance angle [α]	Angle of rake [γ]
Twist drill (DIN 338)	8	2	HSS	M2	-	118°	10 - 13 º	6 - 8 º

The drills had been used under condition of MQL application, with outflow of 40 ml/h and 4 bar of pressure. Figure 1 illustrates the drilling process under external MQL application, in which the used oil atomizer was a Tapmatic II.

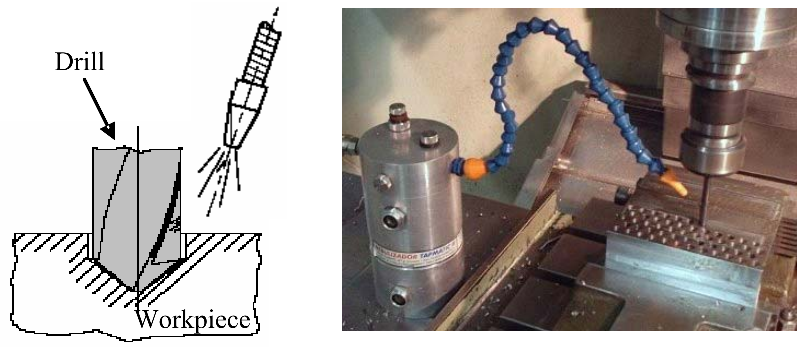

Figure 1. Drilling process carried through with external MQL application.

The used workpiece was a DIN 1.2711 steel, with hardness between 38 and 43 HRc and was fixed at zero grad degree in relation at the table of the Center Machining. Table 2 shows the chemical composition from the machined material.

Table 2. Chemical composition of the workpiece DIN 1.2711 steel (Swiss Steel International, 2005).

C [%]	Cr [%]	Mo [%]	Ni [%]	V [%]
0.55	1.10	0.50	1.70	0.10

Preliminary tests had been made to define the cutting conditions for the final tests. Table 3 shows the variation of the used cutting parameters in the preliminary tests. These initial cutting conditions are based on previous experimental tests and research in the region companies.

Table 3. Cutting parameters used in the preliminary tests.

Cutting speed v_c [m/min]	Feed per tooth f_z [mm]	Increment i [mm]
7; 10; 12; 15	0.017; 0.025; 0.030; 0.080	1; 1.5; 3

After the analysis of the results from the preliminary tests, these was defined the cutting parameters to use in the experimental tests. Table 4 shows the selected cutting parameters.

Table 4. Cutting parameters used in the tests.

Cutting speed v_c [m/min]	Feed per tooth f_z [mm]	Increment i [mm]
12	0.017	1.5

The experimental tests were carried through in a Dyna Myte Center Machining, model DM 4500, with maximum rotation of the spindle of 6000 rpm and 7.5 kW of power.

The end tool life criterion was maximal flank wear $VB_{máx}$ = 0.60 mm or the occurrence of micro-cracking in the cutting edge, considering that to occur first. The drills had been observed and measured each 2 machined holes. For the visualization of the tool wear an optic microscope with a connected camera CCD and a Scanning Electron Microscope (SEM) were used.

For the measurement of the roughness (R_a, R_z, and $R_{máx}$) had been used a Roughness Tester Taylor Hobson, model Surtronic 3+. The measurements had been carried through at the initial (begin) and final (end) of the holes, in three different angles, as show Figure 2.

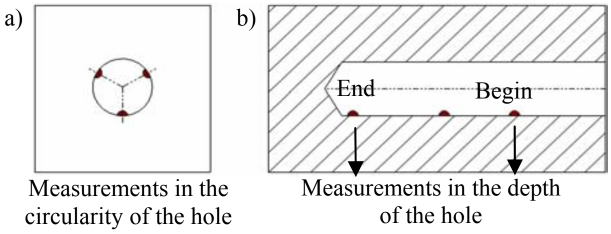

Figure 2. Measurement positions of the roughness.

3. RESULTS

For all tests, the end tool life criterion was the maximal flank wear, caused for the great abrasion at the corner of the tool. In the drilling with MQL application, the tools had machined 23 holes (0.92 m), with a dispersion of 22%. In this condition, only one few lubricant quantities go to interface tool / wall of the hole, however, sufficient to guarantee a minimal lubrication, and without generating the thermal shock to the tool.

Figure 3 shows, after the test, one drill after drilling of 18 holes, in three distinct photographs - face, flank and the corner.

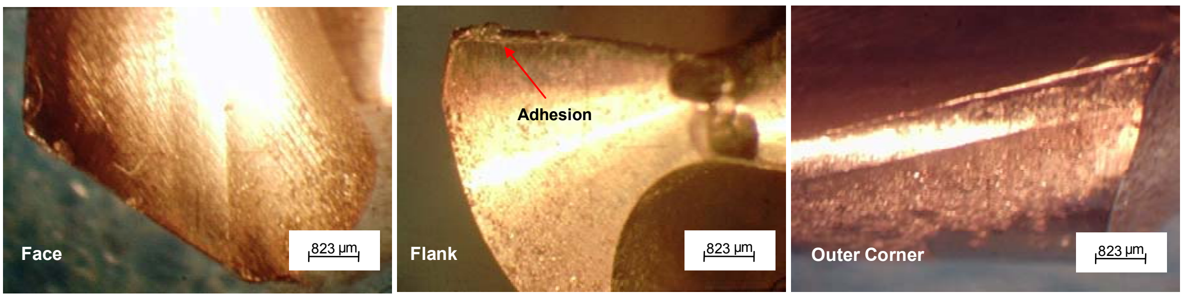

Figure 3. Photograph of the face, flank and the corner.

It is possible to verify the existence of material adhered on the edge. This adhesion can be explained by the difficulty of the lubricant oil film in bigger depths, for external application of MQL (Zeilmann, 2003). The corner is the region of bigger cutting speed and, of this form, greater temperature and meets supported in these little mass (the corner). For verify the adhesion of material on the tool, Figure 4, illustrates photographs of the flank wear of the tool carried through with a SEM, after machining of 0.72 meters (18 holes). Due to great amount of material adhered on the edge it was not possible to carry through the measurement of wear for this condition. Of this form, for a machined length of 0.64 m (16 holes) had been measured values of $VB_{máx}$ = 0.28 mm.

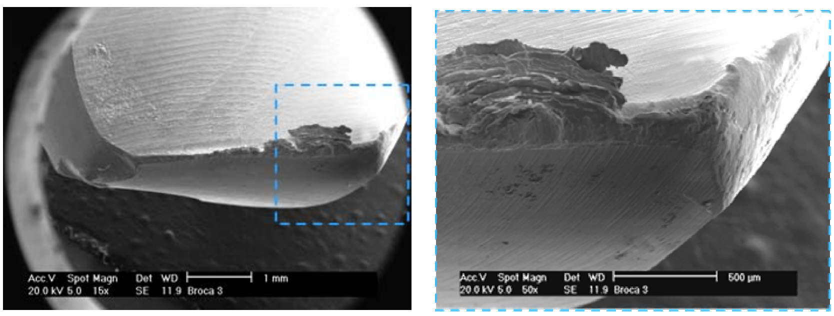

Figure 4. Photograph of flank wear with a SEM.

The results gotten for the behavior of roughness in these experiments are shown in form of graphs. The values located in the following graphs correspond to the averages of the three measured positions, for the gotten values at the beginning of each hole.

Figure 5 shows the behavior's graph of roughness throughout the number of holes for the condition with MQL application for the beginning position of each hole.

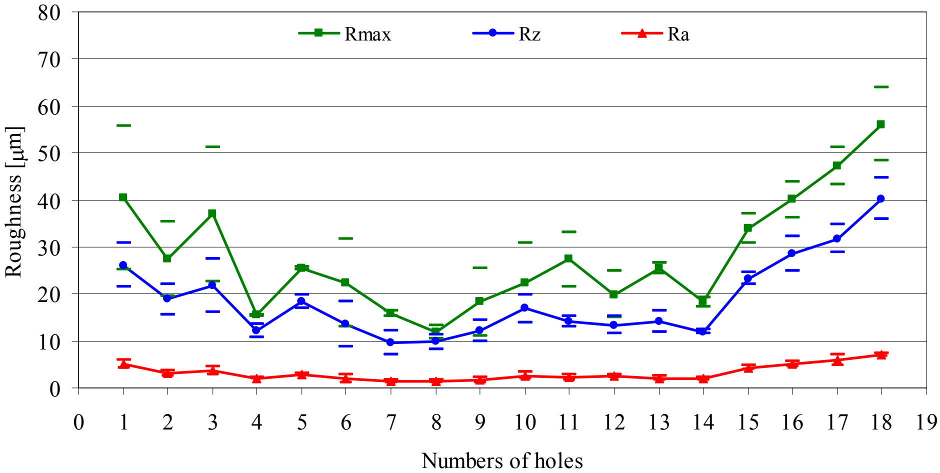

Figure 5. Graph with the behavior of the roughness of the machined surface.

Analyzing the roughness graph, it is possible to perceive that the biggest values of Ra and Rz were respectively 7.28 and 44.54 µm. It has been noted there was a great variation of values of the roughness throughout of the numbers of holes.

In the first hole the value of the roughness sufficiently was raised and this can be related on condition of the conservation of the edge that, due to lubrication microfilm, keeps the edge's new state for a bigger period of time. For this condition, the lubrication function is assured by the minimal amount of oil in the interface tool / wall of the hole, reducing the attrition without removing the amount of heat significantly, what it facilitates the cutting of the material.

In the last holes it is observed a roughness increase, due the great amount of adhered material on the edge of the drill and either due to the rounding of the weared edge, provoked by the cut severity.

This fact appoints the wear influence of the tool under the surface quality of the workpiece (König and Klocke, 2002; Zeilmann *et al,* 2007). In this case, the tool wear is occasioned by the fact that only a small amount of lubricant obtains to come close itself of the interface tool / wall of the hole, of form that, with the increase of the depth, the lubricant's proprieties decrease (due the increase of the temperature, loss of viscosity and until the cutting fluid vaporization) and from certain point it starts the dry attrition and begins a tack process (Zeilmann, 2003).

The roughness values measured of isolated form don't supply subsidies for a rigorous evaluation of the surface integrity of the hole. Examples of this are the roughness data shown previously, where the adhered material under the surface masks the values. Therefore, are necessary other information for a better evaluation under the real surface quality of the hole. This can be done looking the wall of the holes and analyzing the plastic deformations generated in the cut.

The Fig. 6 shows photograph of the wall texture in the beginning and in the end of the hole obtained for rilling with MQL application.

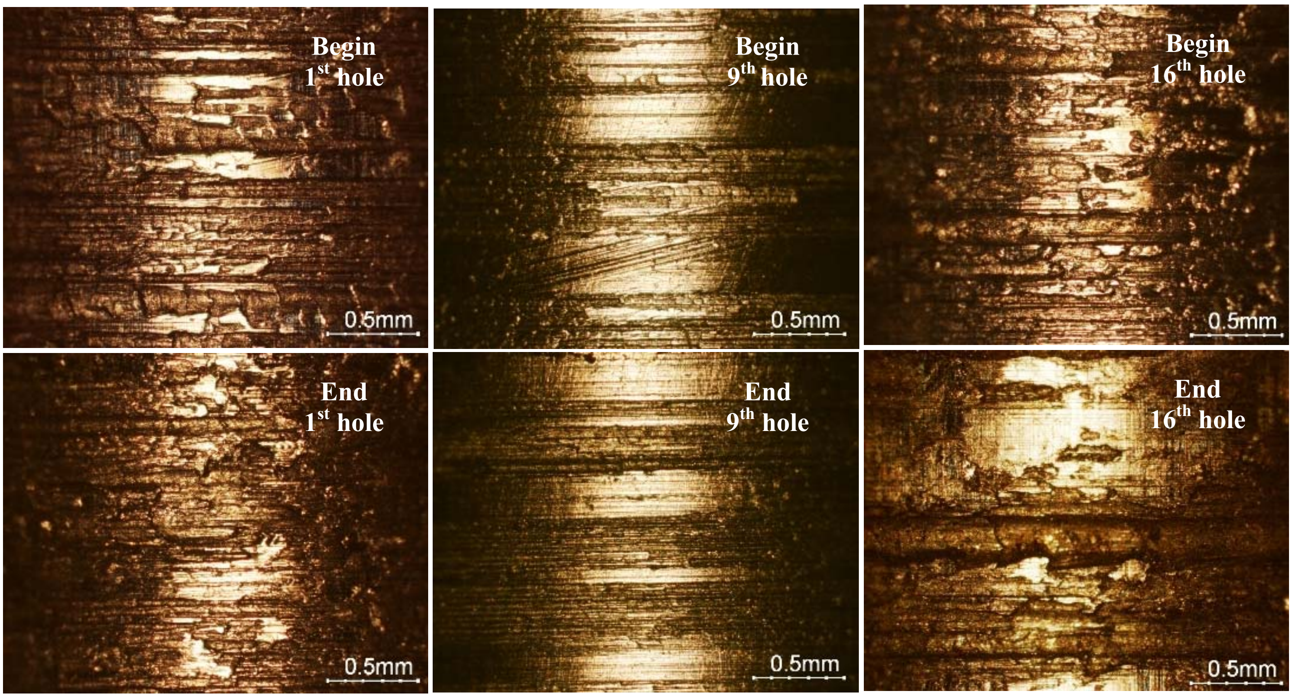

Figure 6. Photograph of the wall to the 1st, 9th e 16th holes.

In the Figure 6 it is possible to perceive there are some differences between begin and end of the hole. But the bigger differences are from 1st to 16th hole. View Figure 5 too. To 1st hole the wall presents poor surface quality, as already evidenced with analyze of roughness. In the begin and in the end of the 9th hole, the surface presented of cleaner form and the mark of the edge on the surface, because the edge have now a little wear. However, in the begin and in the end of the 16th the texture of the wall of the hole is poor again, because now the edge is degraded. And in the end of the holes there is more difficulty of evacuation of the chip too.

The Figure 7 shows the plastic deformation found in the holes. For the 1st hole the found plastic deformation was 15 µm depths in the end of the hole. In the 16th hole was found plastic deformations in the depth of 50 µm in the end of the holes.

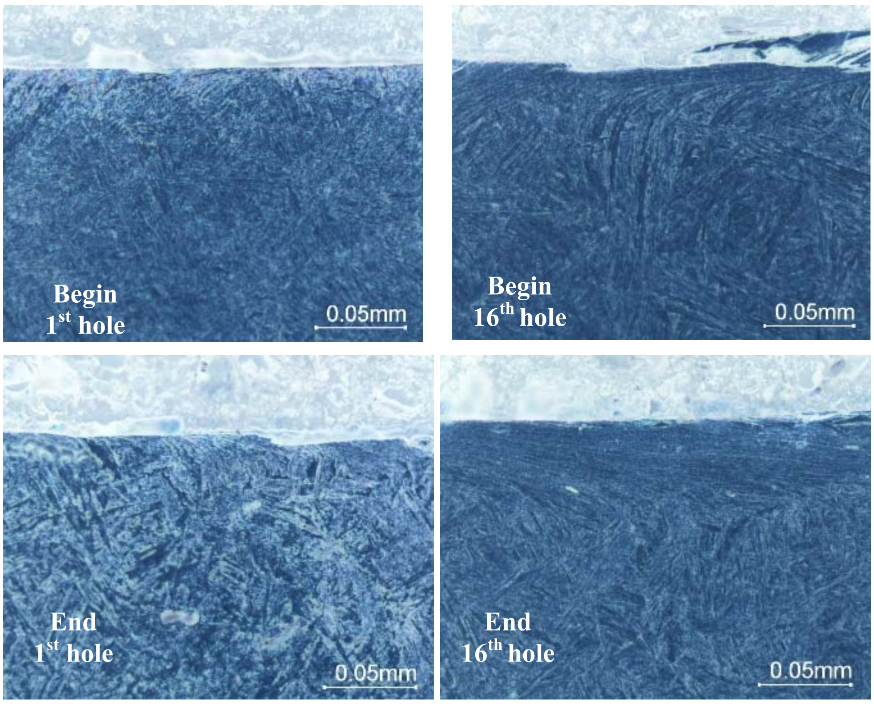

Figure 7. Photograph with detail of the plastic deformation to 1st and the 16th holes.

This fact demonstrates the greatest influence of the wear of the tool on the plastic deformations after machining. The plastic deformations had been analyzed and measures in the transversal section to the hole, resultant of the tangential speed, where the contact with the wall is more intense.

4. CONCLUSION

For all tests, the registered criterion of the end of life was the maximal flank wear, caused for the great attrition between the corner and the wall of the surface. The wear of the flank was predominant in the tests, being caused mainly for the abrasion mechanism.

To drilling with MQL application the material adhesion was verified on the edge of all tolls and that's can be a problem to measurement the flank wear.

The roughness has a great variation of values throughout of the numbers of holes, especially to the end holes, because the maximal flank wear is very intense on the end of the tool life.

The plastic deformation found in the holes were 15 µm depths to the 1^{st} hole and 50 µm to the 16^{th} hole. And the explication was the big tool wear too.

5. REFERENCES

Costa, E. S., Machado, A. R., Rosa, S. N., Souza Jr. E. A. "Qualidade dos furos usinados com diferentes métodos de lubrificação e refrigeração", Revista Máquinas e Metais, São Paulo, n. 484, p. 140-161, maio 2006.

Dhar, N. R.; Islam, M. W.; Mithu, M. A. H. "An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel", Journal of Materials Processing Technology, 47, p. 748-753, 2007.

Gonçalves, P. S. C.; Bianchi, E. C.; Aguiar, P. R. "Reduzir, reusar, reciclar: o princípio dos 3R em processos de usinagem", Revista Máquinas e Metais, São Paulo, n. 493, p.122-133, Fevereiro, 2007.

König, W., Klocke, F."Fertigungsverfahren. Drehen, Fräsen, Bohren", Springer-Verlag. 7. Auflage. Berlin, 2002.

Novaski, O.; Rios, M. "Introdução teórica a vantagens de uso na usinagem de aços liga", Revista Máquinas e Metais, São Paulo, n. 460, p.214-223, Maio, 2004.

Zeilmann, R.P. "Furação da liga de titânio Ti6Al4V com mínimas quantidades de fluido de corte", 2003. 170 f. Tese (Doutorado Engenharia Mecânica) - UFSC, Florianópolis-SC, 2003.

Zeilmann, R. P.; Nicola, G. L.; Finimundi, A. V.; Santin, R. "Diferentes condições de uso de fluidos lubrificantes e refrigerantes", Revista Máquinas e Metais, São Paulo, n. 493, p.110-123, Março, 2007.

6. RESPONSIBILITY NOTICE

The authors Rodrigo Panosso Zeilmann, Andréia Vanessa Finimundi and Diego Carlos Calza are solely responsible for the printed material included in this paper.