TOOL WEAR IN HIGH SPEED MILLING OF HARDENED STEEL

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Abstract. *This paper presents a study of the tool wear in High Speed Machining (HSM) of hardened steel. The used hardened steel was the AISI H13 with hardness between 52 and 54 HRc. High speed milling experiments were developed to evaluate the wear mechanisms for finishing endmill with ball nose and for roughing mill with round insert cutter. The analysis was limited the flank wear. In both processes the tool life was measured and the tests were developed for different cutting conditions for dry machining and different tools. The results show a good tool life for finishing endmill, for this tool the adhesion and the chipping were the limit for a longer lifetime. For roughing mill with round insert cutter the process was restricted to the small depths and moderated cutting speed, and the abrasion mechanism was the main wear on the cutting edge.*

Keywords: *HSM, Finishing, Roughing, Cemented carbide, Lifetime*

1. Introduction

Die and molds industries are using the process of High Speed Machining (*HSM*) with the intention of reducing manufacturing stages. As various authors (Urbanski *et al., 2000,* Altan *et al.*, 2001, Coldwell *et al.*, 2003, *Outeiro and Astakhov, 2004)* mention*,* the reduction or elimination of detained processes, as the Electrical Discharge Machining (*EDM*) and manual finishing process, are some of the main advantages of *HSM* technology. Moreover, the reduction of the manufacturing time of a mold and the increase of the quality of the parts are consequences of this technology. However, (Schutzer *et al.,* 2001, Hilbig and Klewenhageb, 2001, Dolinsek *et al.,* 2001) believes that, due the process' sort of characteristics and the objective of taking all of this technology's advantages, it is necessary the use of specially prepared and balanced tools for this purpose.

Nevertheless, there is little explicit knowledge concerning the behavior of these cutting tools in High Speed Machining of hard materials.

The High Speed Milling is used, mainly, in the finishing operation. However, the use of this technology for the roughing process is necessary for reduction of manufacturing time. Recently, (*Outeiro and Astakhov, 2004)* has presented as a result, finding cutting parameters that make possible the increase of the production range is one of the reasons why experiments may be essential to using *HSM* effectively.

Ghani *et al.* (2004) have informed that during the machining, the tools are subject to mechanical and thermal demands and also to friction against the chip and surface of the piece. Based on studies (Kalpakjian and Schmid, 2001), these factors wear the tool down and decrease its useful life, also causing inadequate surface quality, what can compromise the viability of the process. Thus, a better understanding of the mechanisms of wear and types of the cutting tools is essential to guarantee the effective use of the tool, security and quality of the machining.

Kopac (2002) affirmed that more recent investigations in the segment of *HSM* are directed on the four characteristics areas: mechanisms of chip formation, mechanisms of tool wear, problems of machining of hard materials, and machined surface integrity including a quality of surface.

The fact of existing many other variables in the process, such as tool length and machining strategy, makes the quantification of the tool life and surface quality an even more difficult task to accomplish. As a result, extensive experiments on behavior of wear as well as experiments on variation of the cutting parameters are needed, in order to select optimized proper cutting for each and every machining situation.

Therefore, this work presents a study on wearing behavior of tools in machining of hardened steel AISI H13, with hardness between 52 and 54 HR_C. The experiments were developed to evaluate the mechanisms of wear in ball nose end mills, to the purpose of finishing, and, in round insert cutter, to the roughing. Both experiments were developed with dry machining.

2. Experiments

2.1. Finishing

The experiments for finishing process have carried out in Machining Center MIKRON, model VCP 800, with maximum rotation of the spindle of 20000 rpm and 40 kW of power.

The workpiece was fixed in an 45º inclination angle towards the Machining Center's table. A vertical upward milling was chosen in the single direction raster.

Ball nose end mill tools of cemented carbide had been used, of two grades: P10/M10 and K20/30, with 6 mm of diameter and both TiAlN coated. Table 1 shows the main characteristics of the tools.

Table 1. Characteristics of tools for finish milling

Tool type	Diameter d [mm]	Number of edges	Tool material	Cemented carbide	Coating	Rake angle γ_o [°]	Clearence angle α [°]	Radius r_n [mm]
Ball nose	6	2	Micrograin of WC	P10/M10	TiAlN	0 – 3	13 – 15	0.05
				K20/30		7	9	

For the P10/M10 tool class, the manufacturer indicates the following parameters of cut: v_c = 210 - 270 m/min, a_p < 0.60 mm, a_e < 0.60 mm and f_z = 0.10 mm. For K20/30 tool class, the manufacturer indicates: v_c = 325 m/min, a_p = 0.12 mm, a_e = 0.06 mm and f_z = 0.05 mm.

Methodology for finishing

In preliminary experiments, two conditions of relation length/diameter of the tool (l/d = 4 and 8) have been tested. Furthermore, the parameters, effective velocity of cut (v_e), axial depth of cut (a_p) and feed per tooth (f_z), have been varied. After measurement and statistic analysis of the values of roughness, the cutting parameters for the condition l/d = 4 have been selected.

It is worth saying that we selected this conditions of l/d as well as the cutting parameters to be used in the wearing behavior experiments. According to Zeilmann *et al* (2003, 2005a), the reasons for that were the shorter values of roughness and small dynamic instability (vibrations) presented during the cut. The selected parameters of cut were v_e = 326 m/min, a_p = 0.15 mm, a_e = 0.20 mm and f_z = 0.15 mm.

The tool life`s evaluation was carried out on the basis of the wear behavior observed and measured along the cutting time. Then, the tool life criterion was $VB_{máx}$ = 0.20 mm. The length (a) and the width (b) of the chipping, that appeared along the experiments were also monitored. Nevertheless, the main parameters of surface quality have been measured.

2.2. Roughing

The experiments for roughing process, have been carried out in a Machining Center HERMLE, model C800 V, with maximum rotation of 24000 rpm and 23 kW of power. Developing the experiments needed the use a tool with 16 mm of diameter and two types of round inserts of cemented carbide with different protective coatings: P10 TiN/TiAlN and P10 TiN.

The workpiece was fixed being the machining plan the 0° (zero degrees) in relation to the table of the Machining Center. Besides that, it was used up milling in top cutting.

Methodology for roughing

In the preliminary experiments, where P10 TiN/TiAlN insert was used, we tested the parameters; effective velocity of cut (v_e), axial depth of cut (a_p), radial depth of cut (a_e) and feed per tooth (f_z). After measurement of maximum flank wear ($VB_{máx}$), the following cut parameters have been selected: v_e = 265 m/min, a_p = 1.0 mm, a_e = 0.80 mm; f_z = 0.20 and 0.50 mm.

However, for wear behavior evaluation, the two types of inserts (P10 TiN/TiAlN and P10 TiN) were tested for the same pre-determined cutting and volume parameters of machined material. During the experiments, the tool life criterion for the inserts was a 17368 mm^3 of machined material.

According to Zeilmann *et al* (2005b, 2005c), it could be understood that the tool life obtained with a flank wear ($VB_{máx}$) after the machining of the definitive volume, can be used as a criterion for a comparative evaluation of differents tools.

3. Results

3.1. Finishing

In fig. 1 it is possible to see the curves of maximum flank wear behavior ($VB_{máx}$) obtained for P10/M10 and K20/30 tools, respectively.

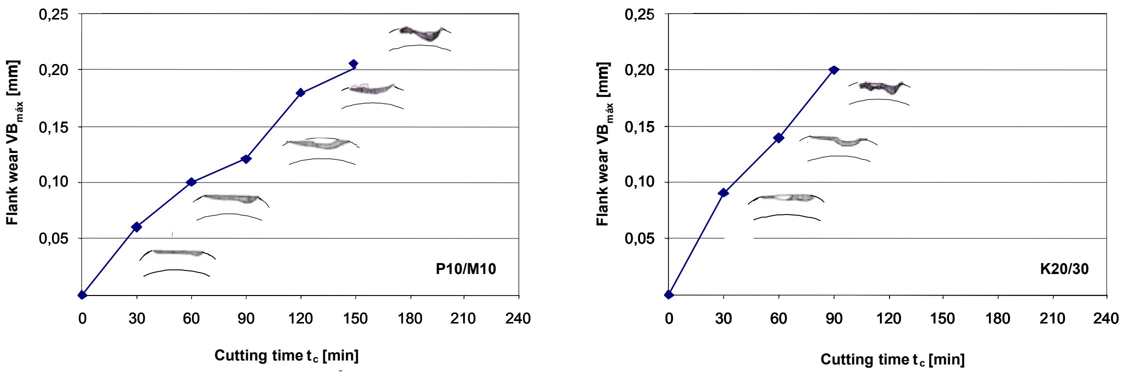

Figure 1. Behavior of maximum flank wear $VB_{máx}$ P10/M10 and K20/30 tools, respectively.

The curves of wear behavior present a similar trend for the two grades of tools tested. For P10/M10, at the first moments, there is an accentuated wear, due to the accommodation of the cutting edge. Between 30 and 90 minutes of cut the curves show a lower inclination. Therefore, after 90 minutes, there is a increase of the wear that already presents chipping since the 60 minutes of cut. Thus, the tool life was of 150 minutes, according to pre-defined criterion $VB_{máx}$ = 0.20 mm. For K20/30, however, the curves show a more accentuated inclination in comparison to the P10/M10. Because it has presented more toughness grade, the K20/30 tool shows bigger flank wear for the same cutting time. For the K20/30 tool, the tool life was 90 minutes. The figure 1's pictures represent the flank wear. For 150 minutes of cut, the P10/M10 tool presented average values of R_a = 1.65 μm. For a 90 minutes of cut, the K20/30 tool presented average values of R_a = 0.90 μm. On the other hand, for the same cut time (90 min.) the tool P10/M10 presented R_a = 0.66 μm.

Figure 2 shows photograph of flank and face of the P10/M10 tool after 150 minutes of cut. It is possible to observe abrasion marks on the flank and chipping on the face. The tool suffered a wear lower in the cutting edge. The chipping in the face that remained unchanged for the last 60 minutes of cut. Moreover, the occurrence of ruptures of the type "beach marks" can be observed, indicating fragile fracture.

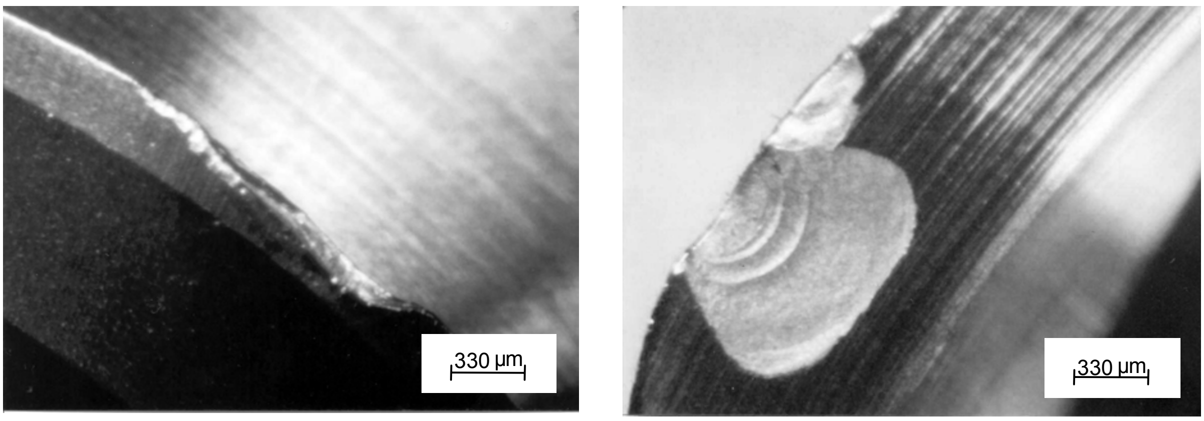

Figure 2. Flank and face of P10/M10 tool after 150 min of cut.

Figure 3 shows photograph of flank and face of the K20/30 tool after 90 minutes of cut. It is possible to observe a mark of contact and adhesion, located right below the flank wear. This mark can be due to the deformed and welded material of the workpiece along the clearence tool. In the face photograph it can be seen the formation of chipping and, also, the ocurrence of ruptures of the type "beach marks".

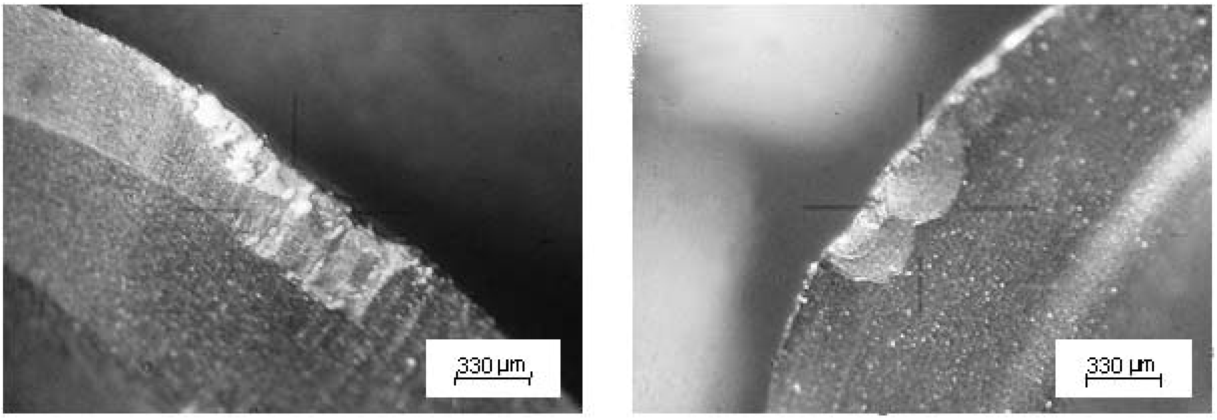

Figure 3. Flank and face of K20/30 tool after 90 min of cut.

According to the tool life criterion $VB_{máx}$ = 0.20 mm, the tool life of carbide P10/M10 was 150 minutes, while K20/30 was 90 minutes. The K20/30 resists the impact better than the wear, for it presents a more toughness grade. For that reason, it has smaller wear values for the chipping, but it achieved the tool life criterion in 40% lower time than P10/M10 tool.

During the machining, flank wear and tool face chipping formation were observed. Due to the kinds of wear verified during the experiments, abrasion and adhesion were the most frequent mechanisms. Chipping can be associated to tool cutting edge impact and also to the presence of hard inclusions that exist in the workpiece material.

The surface quality, for the two classes of tested tools, presented an increasing along the cutting time, with no uniform areas that can be associated to wear and cutting edge stabilization. Consequently, for the lifetime of 150 minutes (P10/M10), the surface quality was maintained at R_a below 2 µm and $R_{máx}$ below 9 µm. On the other hand, to K20/30 tool, the surface quality was maintained below 1 µm R_a and below 6 µm $R_{máx}$. However, for 90 minutes of cut, P10/M10 tool presented 27% lower roughness than as K20/30 tool.

3.2. Roughing

Figure 4 and Figure 5 show respectivelly the flank wear of insert P10 TiN/TiAlN and P10 TiN for 17368 mm^3 of removed material with f_z = 0.20 mm and f_z = 0.50 mm, respectively.

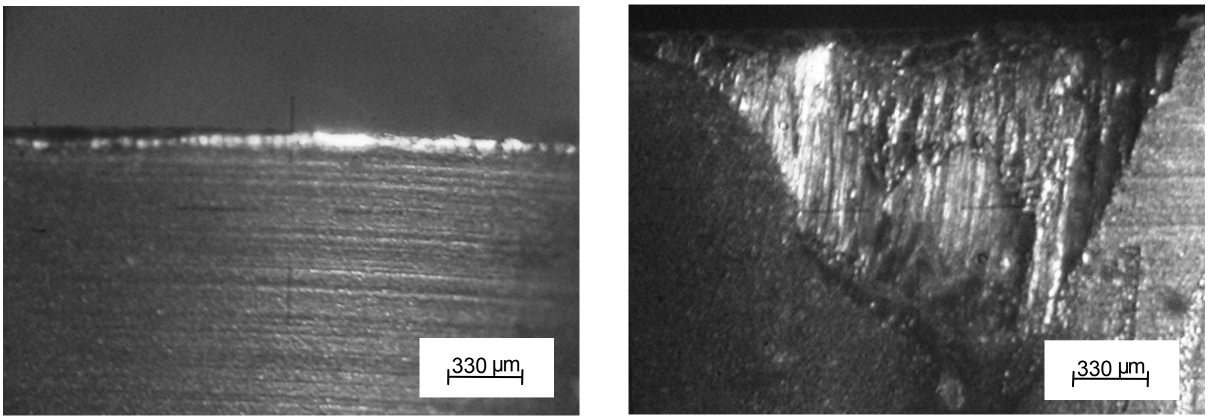

Figure 4. Flank tool; v_e = 265 m/min; a_p = 1.0 mm; a_e = 0.80 mm; f_z = 0.20 mm and f_z = 0.50 mm, respectively.

In figure 4, to f_z = 0.20 mm, the insert incurred a maximum flank wear ($VB_{máx}$) of 0.14 mm and it is possible to observe a small mark of abrasion on the flank. For this condition the chip presented arc shape (ISO 3685, 1977) and shear type. For f_z = 0.50 mm one observes high flank wear with abrasion marks and great amount of adhesion and measured $VB_{máx}$ of 1.33 mm. The chip, for f_z = 0.50 mm, presented crack shape.

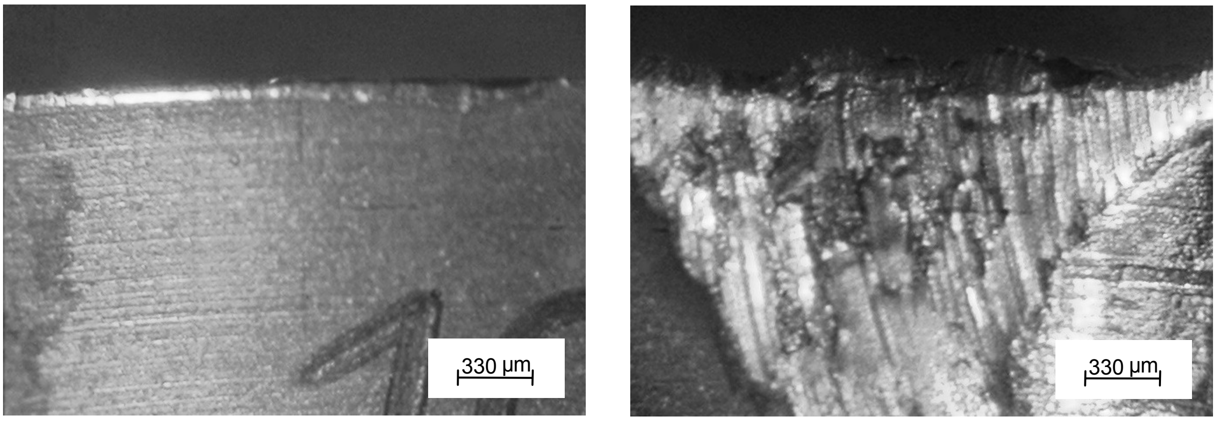

Figure 5. Flank tool; v_e = 265 m/min; a_p = 1.0 mm; a_e = 0.80 mm; f_z = 0.20 mm and f_z = 0.50 mm, respectively.

In Figure 5, to f_z = 0.20 mm, the insert incurred $VB_{máx}$ of 0.15 mm and a small mark of abrasion on the flank is observed. The chip presented arc shape and shear kind. To f_z = 0.50 mm it is possible to observe bigger flank wear than the P10 TiN/TiAlN. The flank wear $VB_{máx}$ was 1.97 mm. Besides that, abrasion marks and adhesion to the flank as well observed. The form of the chip was classified as indefinite and its type as chip of rupture.

Both tested inserts, P10 TiN/TiAlN and P10 TiN, presented a behavior similar to the flank wear considering the tested f_z variations (0.20 mm and 0.50 mm). The influence of the feed per tooth, on the wear of the tool for the same volume of machined material (17368 mm³) is considerable. By reducing 60% of the f_z there will be a reduction around 90% of flank wear. It was also observed that the influence of the cutting speed (150 – 304 m/min) in the preliminary experiments was not significant.

4. Conclusions

This study verified the behavior wear of cemented carbide tools in High Speed Milling process. According to the tool life criterion, $VB_{máx}$ = 0.20 mm, the ball nose P10/M10 tool has 150 minutes lifetime and, the K20/30 tool has 90 minutes lifetime, in the finishing process. During the machining, flank wear and chipping formation on the tool face were observed. Due to the types of wear verified during the experiments, abrasion and adhesion were the most frequent mechanisms. Chipping can be associated to tool cutting edge impact and also to the presence of hard inclusions that exist in the workpiece.

In the roughing process, it is important to highlight that the machining carried out with high feed per tooth parameters and radial depth of cut (f_z = 0.50 mm and a_e = 0.80 mm) influences tool life in the significant way.

Therefore, the combination f_z = 0.20 mm and a_e = 0.80 mm resulted lower wear length for P10 TiN/TiAlN and P10 TiN tools, $VB_{máx}$ were 0.15 mm and 0.14 mm, respectively. Considering the same volume of removed material, the combination f_z = 0.50 mm and a_e = 0.80 mm presented a notable flank wear's increasing. Besides that, the abrasion mechanism was predominant in the roughing experiments.

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