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SURFACE INTEGRITY OF AISI H13 TOOL STEEL IN END MILLING PROCESS

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ABSTRACT

This paper presents the detailed investigation of surface integrity when end milling AISI H13 tool steels using P10 TiN coated carbide and P20 uncoated cermets tools. The machining parameters studied were cutting speed (224 m/min – 355 m/min), feed rate (0.1 mm/tooth – 0.25 mm/tooth) and depth of cut (0.3 mm-0.8 mm). The detailed microstructure analysis shows that worn out tools caused over heated of the machined surface and changed the microstructure of the work material. That change increased the hardness of the work material's machined surface, which is very hard and brittle, and generally referred as a white layer. The width formation of microstructure changes, increased with the increase in wear land and feed rate. A maximum of 550 HV was measured directly underneath the generated surface, i.e. 30% more as compared to the hardness of the basic material. This information is useful for the die and mould maker to select the best cutting condition to avoid such increase in hardness.

Key words: surface integrity, AISI H13 tool steel, carbide tools, end milling

1. INTRODUCTION

Surface integrity is the description and control of the many possible alterations in a surface layer caused during machining, including their effects on the material properties and the performance of the surface in services. It is also concerned primarily with the host of effects below the visible surface or so called subsurface alterations in a machining process. Field (1998) and Roger (1971) elaborated the surface integrity as the description and control of the many possible alterations in a surface layer caused during machining, including their effects on the material properties and the performance of the surface in service. The subsurface characteristics occur in various layers of zones. Abrao *et al*. (1995) found changes in surface texture and hardness together with subsurface microstructural alterations when cutting hardenable steels with ceramic and PCBN tool materials. Field (1998) presented various machining surface alteration results including drilling, turning and milling in his technical paper. Surface integrity in different machining processes was investigated by Leskovar and Peklenik (1982), Bryne *et al*. (1997) and Mercer 2009). Prediction of machined surface is also an important area of research as done by Lu and Coastes (2008).

The rapid development in technology has great contribution to machining efficiency and productivity. However, severe machining conditions can cause damage on the surface as well as the beneath layers, which can lead to breakage of machined parts (Leskovar & Peklenik, 1982). Subsurface microstructural alterations are important in machining hardened steels, since the imposition of laps, tears and microcracking, are likely to occur (Abrao *et al*., 1995). The subsurface characteristics occur in various layers of zones. According to Abrao *et al*. (1995) two main types of microstructural change may occur when machining hardened steel, depending on the maximum temperature reached at the workpiece surface and subsurface. If the temperature exceeds the austenitisation limit, austenite will transform to produce an un-tempered martensitic structure after quenching. This is a very hard and brittle structure, and generally referred as a white layer. According to Barbacki (2003), thickness of the white layer, its hardness and stress level, can be determined as functions of the main turning parameters of cutting speed, depth of cut and tool wear. In EDM process, the white layer is the layer that has been heated to the point of a molten state, but not quite hot enough to be ejected into the gap and be flushed away. (Mercer, 2009). The EDM process has actually altered the metallurgical structure and characteristics in this layer as it is formed by the unexpelled molten metal being rapidly cooled by the dielectric fluid during the flushing process and resolidifying in the cavity. Therefore the formation of white layer in EDM is different phenomenon as compared in machining process.

AISI H13 is a chromium based tool steels and it is used in industries for making hot work die steel and plastic mold to increase production rates and longer tool life (H13, 2009). The unique characteristics of this material as claimed by the manufacturer are good thermal shock and fatigue resistant, superior machinability and polishabilty. The purpose of the study was to investigate in detailed the microhardness changes and subsurface alterations when end milling AISI H13 tool steels using P10 TiN coated carbide and P20 uncoated cermet tools when the flank wear land (V_B) reach 0.2mm and 0.3mm for P20 and P10 respectively.

2. EXPERIMENTAL DETAILS

The machining trials were carried out on a Cincinnati Milacron Sabre 750 *VMC* in dry condition, as recommended by the tool supplier for the specific workmaterial. The insert used was flat end mill P10 TiN coated carbide and P20 uncoated cermets tools. In order to avoid the influence of tool run-out on wear measurements, only one edge of the insert was used for cutting whereas the other edge was ground flat. During the milling operation the insert was periodically removed from the tool holder, and the flank wear on the tool was measured accordingly. The length of each cutting path was set at 0.103 m. The tool wear on the flank face was measured after the first path. The measurement frequency of the tool wear required would then depend on the rate of the wear growth. The measured parameter to represent the progress of wear was the maximum tool wear VB_{max}. The detailed geometry of the two fluted end milling cutter assembly and detailed insert dimensions are shown in Figures 1 and 2 respectively

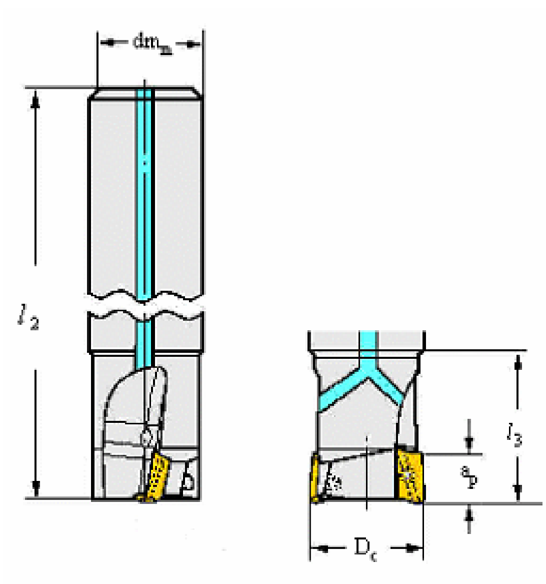

Figure 1 Two fluted end milling cutter assembly (Tool holder dimension: D_c = 25 mm, dm_m = 25 mm, l_2 = 210 mm, l_3 = 50 mm, maximum a_p = 10 mm, $\kappa_r = 90^0$

The chemical compositions of the carbide and cermets tools in percentage by volume were shown in Tables 1 and 2 respectively. The work-piece material was AISI H13 tool steel which was heat-treated to HRC50±3. Table 3 shows the chemical composition of the work material in percentage by weight. Table 4 shows the machining parameters used according to semi-finishing and finishing conditions for the work material.

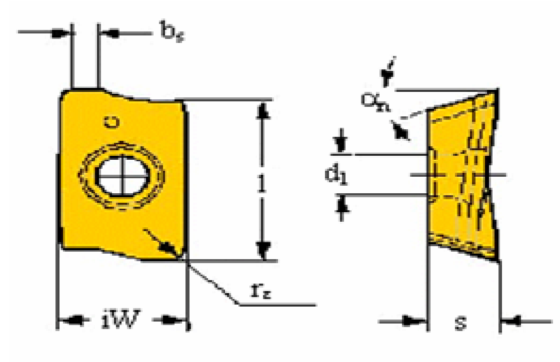

Figure 2 Insert shape and dimensions (Insert dimension: l = 11 mm, iW = 6.8 mm, d_1 = 2.8 mm, s = 3.59, b_s = 1.2 mm, r_ε = 0.8 mm, $\alpha_n = 21^0$)

Table 1: The chemical composition of carbide tool in percentage by volume

Co	WC	TaC
16.4	82.6	1.1 % vol. Cr_3C_2

The density and hardness of the tool is 14.47 g/cm^3 and HV1600 respectively. The TiN coating is categorized as visible.

Table 2: Chemical composition of cermets tool in percentage by volume

Ni	Co	Wc	TaC	NaC	TiC	TiN	Mo_2O
6	8.9	8.4	5.3	1.7	35.4	32.1	3.8

The density and hardness of the tool are 7.27 g/cm^3 and HV1400 respectively.

Table 3: Chemical composition of work-material in percentage by weight

C	Si	Mn	P	S
0.37	0.9	0.46	0.014	0.02
Ni	Cr	Cu	Mo	V
0.11	5.34	0.4	1.25	1

There were nine experimental runs carried out using L9 orthogonal array provided in Taguchi method as follows in table 4. There were eight samples prepared for further investigation for surface integrity, i.e. four samples from P10 and four samples from P20 cutting tools respectively. All the selected samples were mounted into a mould with a mixture of fast cure epoxy resin, epo-kwick hardener and conductive filler. The ratio of resin with conductive filler and conductive filler with hardner were 1:5 and 1:1 respectively. When the epoxy mounting resin solidified, the specimen was ground and polished using a semi automatic polishing unit. Rough grinding was performed on a wet metallographic grinding paper of grit P240, followed by P400 and P600.

Table 4: Machining parameters used in the experiment

Experiment run	Cutting speed (m/min)	Feed rate (mm/tooth)	Depth of cut (mm)
1	244	0.1	0.3
2	244	0.16	0.5
3	244	0.25	0.8
4	280	0.1	0.5
5	280	0.16	0.8
6	280	0.25	0.3
7	355	0.1	0.8
8	355	0.16	0.3
9	355	0.25	0.5

Axial depth (a_p) of cut is kept constant at 3 mm.

These grits were selected because they could remove a minimum of approximately 0.02 micron of material thickness. Later the grinding was continued with 3 µm polycrystalline diamond suspension. Finally a colloidal silica polishing suspension was used to obtain a mirror like surface. The sample was etched using 2% of Nital solution. After etching, the sample was viewed and photographed under the optical microscope.

3. MICROHARDNESS AND SUBSURFACE MICROSTRUCTURAL ALTERATIONS

The microhardness measurements were taken using a Vickers indentor with a 25 gm load applied for 10 seconds. A hardness variation between the surface layer and the bulk material was measured. Figure 3 shows the microhardness variation when machining AISI H13 tool steel using worn out P10 tools. An analysis of result shows that the changes of microhardness did not occur beyond the depth of 30 µm. A maximum of 550 HV was measured directly underneath the generated surface as indicated in Figure 3 with abusive machining using Test 6 condition of the P10 tool. The increase in hardness was reaching up to 30% in relation to the hardness of the basic material. This changes in hardness is a heat-affected zone (HAZ), caused by thermal energy (Roger, 1971). Higher microhardness readings were obtained from the worn tools with uniform flank wear land (Test 6 and 8). The catastrophic failure with uneven form of fracturing and chipping on the Test 3 cutting edge caused a lower microhardness reading. This was due to the uneven contact between the worn edge and the workpiece surface. When this happened, the heat generated between the two mating surfaces was lower than that with the uniform wear land. The mating surfaces between the uniform wear land tool and the workpiece surface were fully intact as compared with the uneven wear land. Figure 4 shows the microhardness changes when using P20 tools for abusive machining with AISI H13 hardened steel. A maximum of 510 HV was measured underneath the machined surface. The increase of hardness was about 19% when compared with the basic material. The microhardness readings show similar values for all the selected test conditions due to the flank wear land was fixed at about 0.2 mm. However, one should note that 0.2 mm flank wear land was high enough to cause the subsurface microstructural alterations. Generally, both figures show a similar pattern. The microhardness values were at the highest values just beneath the machined surfaces. They started to decrease at certain length before increasing back and being constant when they reached the hardness of the basic material. The microhardness readings for P10 were found bigger than P20 due to the bigger sizes of flank wear land. The range of flank wear land for P10 tools was between 0.25 – 0.33 mm, whereas the flank wear land for P20 tools was fixed at about 0.2 mm.

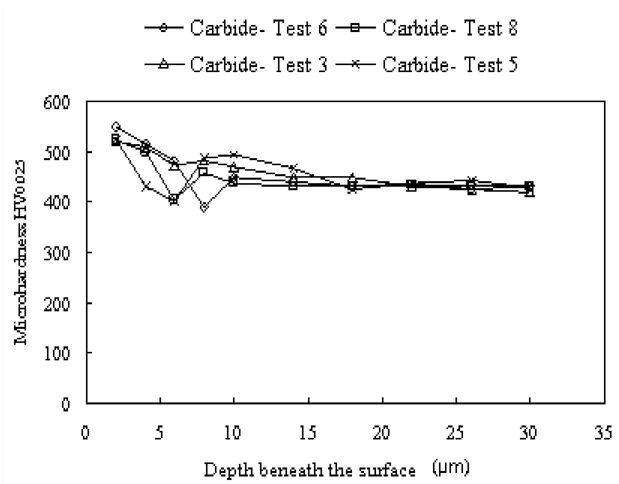

Figure 3: Microhardness variation when machining AISI H13 tool steel using worn out P10 tools

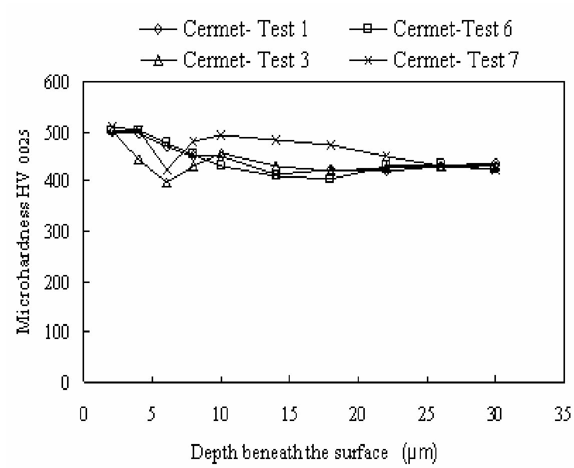

Figure 4: Microhardness variation when machining AISI H13 tool steel using worn out P20 tools

Generally, a white layer of heat-affected zone (HAZ) was observed running from the machined surface until about 4 μm depth as shown in Figures 5-7 for worn tool at 10x magnification. Metallurgical changes are caused by thermal, mechanical, and chemical energy (Roger, 1971). Barbacki and Kawalec (1977) found that the increasing wear of the cutting tool significantly affects the extent of alterations in the surface layer. In this investigation, the mechanical and physical changes such as surface roughening and microscopic surface pitting as found by Roger (1971), and, Gatto and Dillulo (1971) were observed and indicated in the figures. Milling using P10 tools resulted in deeper penetration due to bigger flank wear land of 0.3 for these tools. According to Barbecki (2003), the thickness of white layer is a function of tool wear (*VB*). In general the subsurface alteration of AISI H13 using both cutting tools in milling process is better even at V_B =0.3, than using EDM process as described by Mercer (2009).

Figure 5 and 6 show the microstructural when milling using P10 tools. Figure 7 shows the micrograph of the microstructure changes when machining using P20 tool.

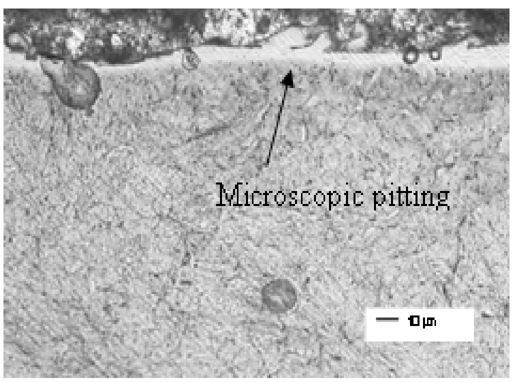

Figure 5 Subsurface alterations using P10 at cutting speed of 224 m/min, feed rate and radial depth of cut of 0.8 mm.

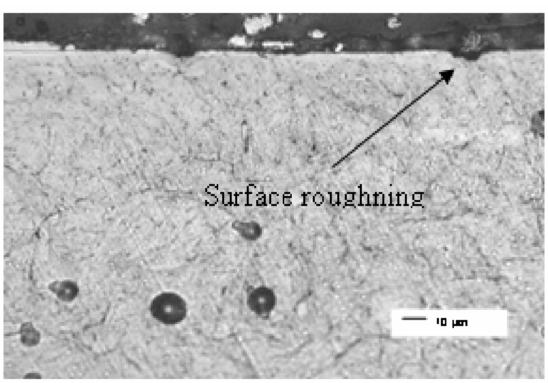

Figure 6 Microstructural changes when using P10 tool at flank wear land of 0.3 mm, when machining at cutting speed of 355 m/min, feed rate 0.1 mm/tooth, and radial depth of cut of 0.8 mm.

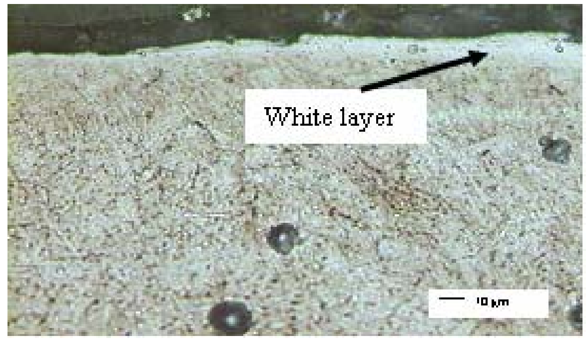

Figure 7 Subsurface alterations using P20 at flank wear of 0.2 mm, when machining at cutting speed of 280 m/min, feed rate of 0.25 mm/tooth, and radial depth of cut of 0.3 mm

4. CONCLUSIONS

The study of the subsurface microstructure shows that a white layer of heat-affected zone (HAZ) was observed. Analysis of the micrographs show that the bigger flank wear land in P10 that resulted in deeper penetration on microstructural changes as compared to P20. The changes of microhardness did not occur beyond the depth of 30 μm. A maximum hardness of 510 HV was measured directly underneath the generated surface i.e. 30% more in relation to the hardness of the basic material. This information is useful for the die and mould maker to select the best cutting condition to avoid such increase in hardness. Milling has proved to obtain better surface integrity than using EDM process in producing die and mould.

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