Evaulation of cutting edge microgeomety for uncoated and coated end miling cutter

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Abstract. Within a mass production of commercially available cutting tools is their quality and cutting ability not always guaranteed. This study aims to compare the micro geometry of uncoated and TiN coated end mill in terms of cutting edge parameters (surface roughness parameters Ra, Rz and cutting edge radius r_n) before and after machining. Despite of higher purchasing costs for TiN coated cutting tool, experimental results shows that coated end mill was worn more than uncoated cutter. In a case of coated cutting tool, surface pre-treatment and coating itself significantly influence cutting edge micro geometry especially in machining with small-diameter tools. Therefore, it is necessary to consider whether the small-diameter tools should be coated or it is in many cases just matter of advertising

Keywords: end mill, wear, cutting edge, PVD TiN coating

Introduction

Tool micro-geometry (chamfer size or edge radius), coating and cutting conditions on machining induced surface integrity are one of the grand challenges that the research community is facing [1]. The roughness of the tool surface may also influence tool life. A large roughness value may imply that there are sharp peaks and valleys on the topography of the tool surface, which may be the sites for the initiation of crack under high tensile stress. It is suggested that the roughness of the tool surface should be less than Ra $\leq$ 0.3 μm [2]. Rodriguez [3] concluded that typical edge defects in a sharp cutting edge (without preparation) may be microbeakages, burrs, burns, poor surface roughness and irregularities, which generate low mechanical resistance, susceptibility to chipping and unstable cutting. Fulemova et al. [4] stated within experiments that tool life is increasing with increasing edge radius (in interval 5-15um). Tool wear on the flank face influences machined surface roughness more than the wear of rake face. Uhlmann et al. [5] investigated the influence the cutting edge radius on the tool wear. The cutting edge radius of end mill with was modified with machine tool which works on the principle of micro tumbling, where tools are fixed on holders and immersed in an abrasive lapping medium. The cutting edge radius depends on the type of lapping medium and also on processing time. It has been shown that preparation of cutting edge radius offers the possibility to decrease the variance of the tool wear up to 92 %. Bouzaki [6] shows the way to increase the cutting performance of PVD coated tools through size optimization and appropriate manufacturing of the cutting edge roundness. The focused micro-blasting causes carbide removals in the transient cutting edge region and worsens the wear behavior. In addition, the manufacturing of rounded cutting edges by honing, in combination with the fact that large cutting edge radii reduce the tool mechanical stresses, contributes to a significant increasing of the coated tool life time. Denkena and Biermann [7] stated review about development in cutting edge preparation, where different methods and technology are described. It stated that for rounded cutting edges the radius is still a frequently used parameter for characterizing the cutting edge microgeometry. Birmann and Steiner [8] analyzed different hard coatings for milling cutters. The best results were produced by AlCrN and TiAlN coatings in terms of tool wear. Due to their limited hardness TiN and CrN coated tools could not be qualified for machining task. It was recorded that the CrN coatings exhibited severe spalling of the coating cause of the chemical reactivity of the coating and the workpiece material. This paper compares the micro geometry of uncoated and TiN coated end mill in terms of cutting edge parameters.

2. Experimental details

The milling experiments were performed on 3 axis Emco Mill 155 vertical machining center with maximum spindle motor output 2.5 kW which makes it suitable for machining of small workpieces. The machine tool is equipped with Heidenhain TNC 426 controller. Cutting fluid Fuchs ECOOCOOL 2506 S+ was supplied to cutting zone by flooding which helps to remove chips from cutting lip and avoiding built–up material as well as to minimize heat generation in the tool/workpiece interface. Within the experiment, planar surface was milled on C45 block workpiece (58 x 150 x 58 mm).

Milling cutter employed in research was ground from HSS Co8 material produced by ZPS Company, **Fig.1**. Milling test were performed with uncoated and TiN coated tool. TiN were deposited using arc PVD method. Before coating the deposition substrates were subjected to argon plasma etching. Thickness of TiN coating was 2 μm. The major tool data are outlined in Tab. 1. Total machining area for each tested cutter was about

8700 mm^2. Cutting parameters (cutting speed v_c = 39 m/min, feed rate v_f = 170 m/min radial depth of cut a_e = 5 mm and axial depth of cut a_p = 0.5 mm) were kept as a constant during all experimental procedure.

Tab. 1. Milling cutter data.

Cutting tool data	Unit	End mill cutter
Tool type	[-]	Monolithic tool
Substrate material	[-]	HSS Co 8
Tool diameter (D)	[mm]	10
Shank diameter (d)	[mm]	10
Tool length (L)	[mm]	95
Flute length (l)	[mm]	45
Clearance angle	[˚]	12
No. of flutes	[-]	4
Helix angle ()	[˚]	40

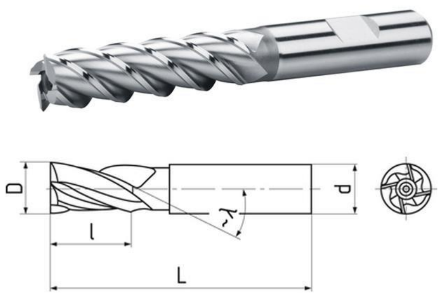

Fig. 1. End mill cutter.

The geometry of the cutting tools was measured using optical 3D measurement device Alicona IF-EdgeMaster. This device is used for measuring form, chipping and roughness of cutting edge. Within the experiment were cutting tools assessed in terms of micro geometry parameters before as well as after machining. Any change of cutting edge geometry represents specific kind of wear and therefore has direct impact on the tool life, quality and integrity of machined surface. Thus, the assessment of cutting edge parameters can be very useful.

3. Cutting edge micro-geometry parameters measurement

The main purpose of this study was to investigate wear behavior of cutting edge in terms of its influence on machining performance. Few extreme values of cutting edge radius obtained by initial measurements were excluded from further analyses because they could negatively affect the tool wear assessment. For instance, data from measuring of uncoated tool were revised due to visible defect on fresh cutting edge before machining. Cutting edge radius of second tooth is almost double size when comparing with the remaining teeth. Total average value of cutting edge radius in evaluating of teeth 1, 3 and 4 was r_n= 6.1 μm, while in a case of tooth number 2 is r_n =10.1 μm, as shown in **Fig. 2**. A similar situation, but with the surface roughness was observed within measurement of TiN coated cutter, see **Fig. 3.** Higher initial arithmetic surface roughness Ra was obtained on cutting edges number 3 an 4. However, there is no visible damage of cutting edge, and therefore were all data employed for further analyses without any change. Surface roughness Ra rises from about 0.73 μm on cutting edge number 1 to about 1.85 μm on cutting edge number 4 for coated tool. Micro geometry of tested tools was measured by optical surface profilomer before as well as after experimental procedure. From the **Fig. 2** and **Fig. 3** of both tested cutters after machining is clearly visible different types and stages of wear. Axial depth of cut was set to 0.5 mm and this is confirmed by the wear length. Regarding the cutting edges of uncoated tool, these have a very homogenous wear, mainly located on flank faces. The wear behavior of TiN coated monolithic cutter, with an effective edge radius from 10 μm to 17 μm is demonstrated in **Fig. 3**. Cutting tool with a larger cutting edge radius exhibits a worst cutting performance than uncoated one.

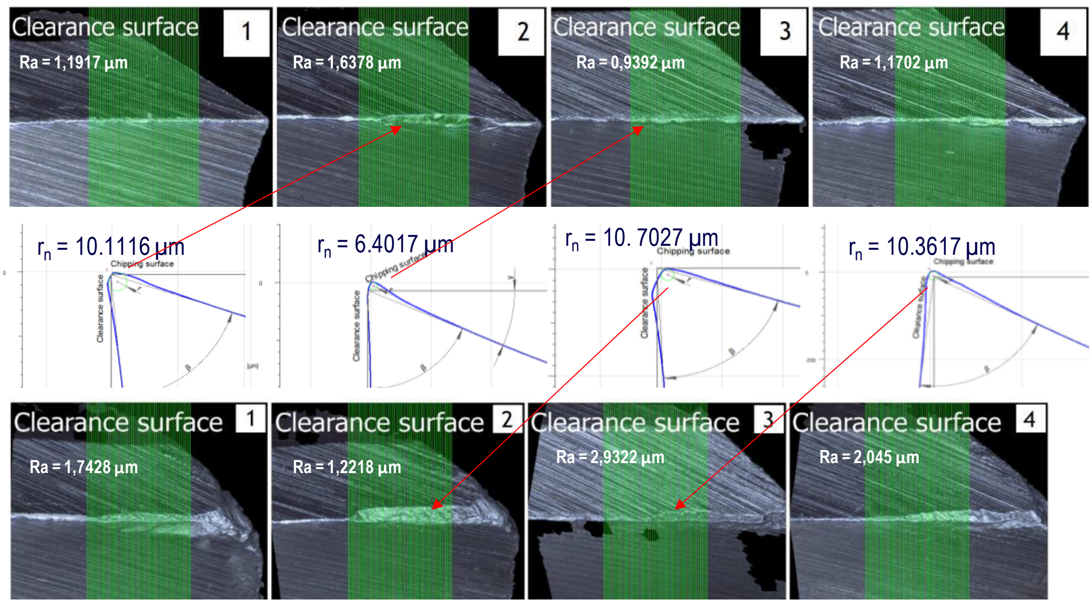

Fig. 2. Cutting tool edge radius before and after machining uncoated.

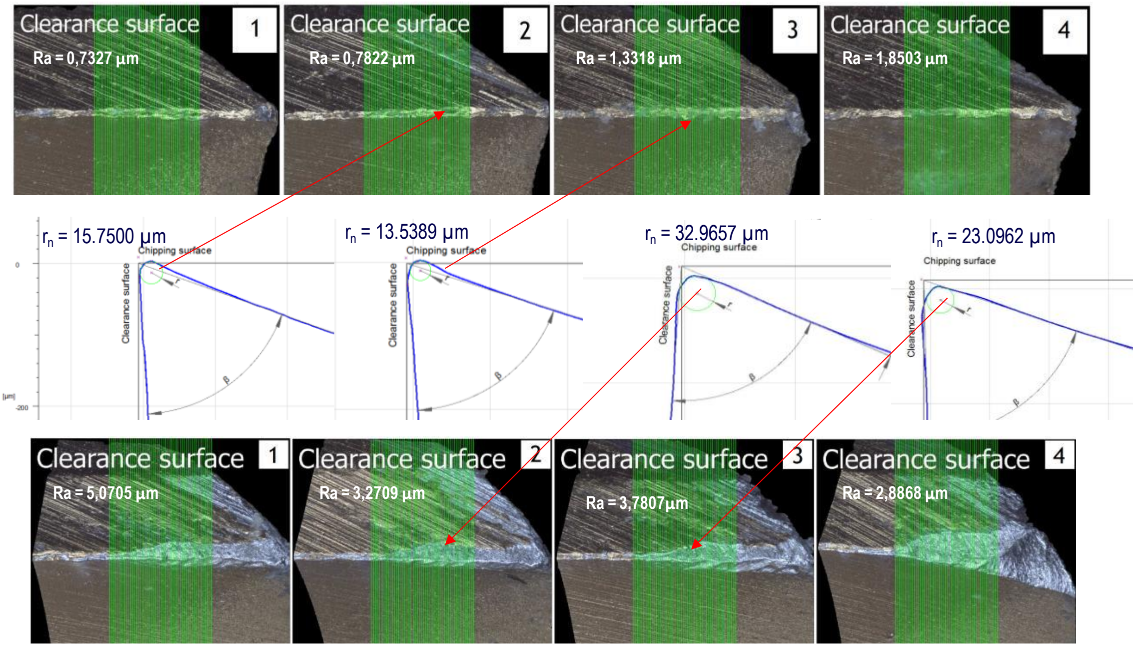

Fig. 3. Cutting tool edge radius before and after machining TiN coated.

In the case of end mills with TiN coatings the hardness value decreased from 63HRc to 55 HRc. It appears to be a significant reason for the higher tool-wear for mentioned coating (TiN). The other reason is the low hardness of these coatings. The decrease of mill (substrate) hardness was probably caused by increasing the deposition temperature over the annealing temperature of HSS steel (550 °C). Catastrophic failure was found on tooth number 4, where edge breakage is observed.

Table 2. Cutting edge data for uncoated tool.

	Measured parameters			
	Tooth Nr.	**Ra** [µm]	**Rz** [µm]	**r_n** [µm]
Before machining	1	1.20	4.06	5.02
	2	1.64	4.49	10.11
	3	0.94	2.67	6.40
	4	1.17	3.54	6.82
After machining	1	1.74	3.79	14.21
	2	1.22	2.84	10.70
	3	2.93	5.48	10.36
	4	2.02	4.29	8.43

Table 3. Cutting edge data for TiN coated tool.

		Measured parameters		
	Tooth Nr.	**Ra** [μm]	**Rz** [μm]	$\mathbf{r_n}$ [μm]
Before machining	1	0.73	2.53	17.45
	2	0.78	2.17	15.75
	3	1.3	3.96	13.53
	4	1.85	5.34	10.86
After machining	1	5.07	9.60	10.64
	2	3.57	7.82	32.97
	3	3.78	5.89	23.10
	4	2.88	5.36	27.49

The experimental data of cutting edge micro geometry parameters obtained during measurements with Alicona are listed in **Tab. 2** for uncoated tool and in **Tab. 3** for TiN coated tool, respectively. Each tooth was evaluated separately and the measurements were repeated several times to exclude measurement errors. However, experimental data doesn't show good consistency. Data indicate that larger cutting edge radius causes a larger tool wear, so there is assumed strong correlation between these parameters.

4. Results and discussion

Major investigated parameters in terms of tool wear were surface roughness parameters Ra and Rz as well as cutting edge radius r_n. **Fig. 4** shows that surface roughness parameter Ra of uncoated tool increased from 1.2 μm to about 1.98 μm, which is not significant change.

On the other hand, larger increase was observed on TiN coated cutter, where Ra parameter is almost three times higher, see **Fig. 4**. Lower initial surface roughness parameters Ra and Rz were measured on coated tool, but final Rz was again higher on coated tool. It can be seen that surface roughness values Rz of the cutting edge prior to machining were almost identical for both cutting tools. Cutting edge radius of uncoated tool before machining is relatively small, starting at 7.09 μm. A tool pre-treatment and coating itself leads to higher values of r_n, **Fig.5**. Deviation in radius between uncoated and coated tool is slightly below 50%. In relation to worn edge, it can be stated that the cutting radius differs by approximately 12.62 μm.

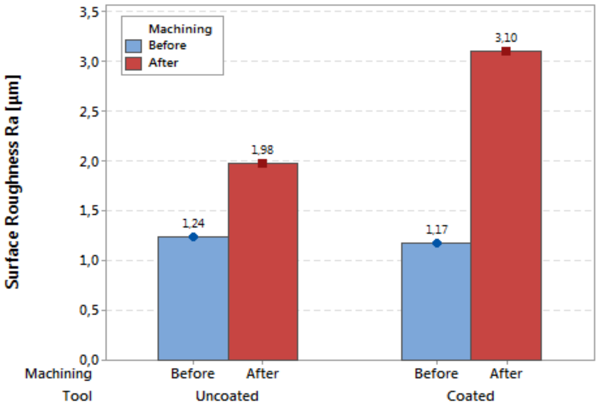

Fig. 4. Surface roughness Ra for new and worn tool.

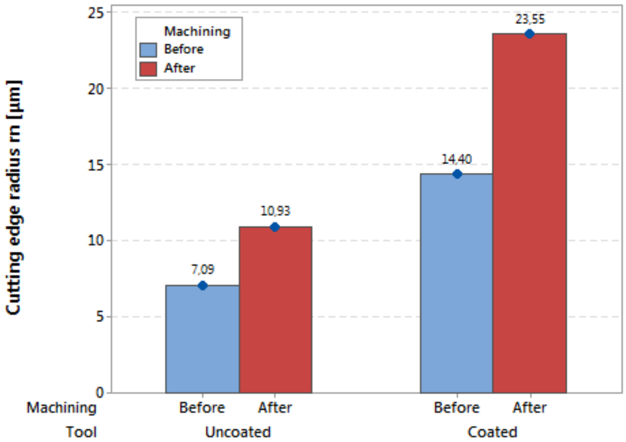

Fig. 5. Cutting edge radius rn for new and worn tool

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5. Conclusions

Surface roughness parameters as well as cutting tool radius were analyzed in terms of micro geometry and tool wear. The HSS Co8 tool sharpness has a considerable inflIuence on the tool life and cutting performance. Finally, a graphical evaluation of experimental results has been carried out. It has been shown that TiN coated cutter is characterized by the worst results across all investigated parameters. This can be caused by improper coating procedure or coating properties.

The microgeometry of cutting edges occupies a key role in complete process understanding. Interactions between tool parameters, cutting parameters and effects on the machining procedure are all influenced and therefore determined by the cutting edge microgeometry. Within machining processes, the impact of a microgeometry along the cutting edge on a tools' performance cannot be reduced to a single response.

Furter research activities are needed to examine influence of cutting conditions and different types of coating on the tool life in milling with HSS cutters. Future research needs to conduct machining experiments with different cooling techniques too.

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