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COATING OF CUTTING TOOL AND CAM MILLING STRATEGY INFLUENCE ON THE TOOL WEAR AND SURFACE ROUGHNESS

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Abstract

Presented paper was focused on the cemented carbide tool life with used of two different PVD coatings. The first one was TiN + AlTiN + CrAlSiN compared with coating of TiSiN during the same cutting conditions. The aim of experiment was found out and compared the wear of ball nose end mill and surface roughness parameter Ra during of three different finish milling strategies. For tool life test, DMG DMU 85 monoBLOCK 5-axis CNC milling machine was used. The cutting tool flank wear was measured on Zoller Genius 3s. Taylor Hobson Surtronic 3+ was used for surface roughness parameter Ra measurements. The results show different achieved surface roughness parameter of machined material C45 and tool life of ball nose end mills depending on used milling strategies and coatings.

Keywords: cutting; tool; wear; coating; roughness

1. Introduction

Due to increasing demands on product quality and the speed of development of new technologies, the machining process also requires constant improvement. One of the main causes in the improvement process are cutting materials that can greatly enhance machining efficiency. However, we cannot forget other very important aspects of cutting tools such as suitable geometry and cutting conditions. Last but not least, it should be stressed that today's cutting materials without the application of suitable coatings would not be suitable for most of the current applications.

Coated sintered carbides combine good substrate and coating features with the purpose of improving tool cutting properties and wear resistance. It is very important to choose and apply a coating that will be the optimal solution for the tool's desired function during individual technological operations and machining technologies. The thickness, hardness, friction coefficient, adhesion, and their resistance to oxidation and abrasion are taken into account in the application of the coating. In our research we were focused on two different type of coatings and their influence on the tool wear and Ra parameter of surface roughness.

Nowadays research of wear of milling tools isn’t focused in one field. The position of the tool in relation to the machined surface (inclination angle) has a strong impact on the cutting forces [1], [2] and [3]. In [4] is an influence of up and down-copying on tool wear and [5] on the surface roughness. Tian et al. [6] studied effect of cutting force to wear mechanisms for down and up copying.

Influence of inclination angles of cutting tool on wear of cutter after machining process are in [7] and [8]. Impact of different types of hard machining materials on the tool wear concretely Ti-6Al-4V [9], Hastelloy C-22HS [10], 3Cr13Cu [11], compacted graphite iron and graphite iron [12]. Zetek et al. [13] observed flank wear and measured cutting forces during the face milling of Inconel 718. They optimized size of edge radius and increased tool life about 20%. Kasim et al. [14] found that notch wear was the predominant failure mode during end milling of Inconel 718. Begic-Hajdarevic et al. investigated the effect of cutting parameters on surface roughness in up- and down milling. In major part of these publications was flank wear, the main criterion for evaluation of experiments. In our experiment arithmetical surface roughness - Ra and maximum flank wear - VB_{max} as a criterion were used. The research follows the author's previous article [15], where was found that contouring had better results than copy milling in specified criteria. In this research we use three best CAM strategies from all tested in previous experiments. These best CAM strategies was compared for two different type of coating during the similar cutting condition and tool geometry. Aim of this research was the find out the impact of coating of cutting tool to surface roughness.

2. Experiment

Experiment was focused on wear of ball nose end mills with two different type of coating with the same cutting conditions. The tools were tested during different type of finish milling strategies. Based on previous experiments, the three best machining strategies were used. The strategies were up and down contouring, while the surface was at angle 15 ° (Fig. 2). The first group of tools were coated with the TiN + AlTiN + CrAlSiN (Fig. 1). In the second one group were used TiSiN coating (Fig. 1). The material was medium carbon steel ISO C45 (AISI 1045) grade. Block material had dimensions of 200×100×100 mm. Model of workpiece was carried out in CAD system PowerShape 2018 and CAM strategies were created in PowerMILL 2018 Ultimate software.

Fig. 1. Coated tools used in experiment

For milling, DMG DMU 85 monoBLOCK 5-axis CNC milling machine was used. In the milling process was used air coolant. All tool life tests were carried out with the following parameters:

- cutting speed vc = 452 m/min,
- spindle speed n = 18000 min^{-1},
- feed rate vf = 2160 mm/min,
- axial depth of cut ap = 0,3 mm,
- radial depth of cut ae = 0,1 mm,
- feed per tooth fz = 0,06 mm,
- dry machining with air coolant.

Inclination angle of the machined surface was established on 15°. Angle of inclination was established according preliminary experiments. There was found out the best values of the tool wear. For this set up of inclination angle cutting tool in down milling principle machining with the tool centre (zero cutting speed) (Fig. 2). For the first evaluated criteria was defined of transverse surface roughness Ra 1,6 μm. The additional wear criterion was defined value of maximum flank wear VB_{max} = 0,15mm according preliminary experiments. Flank wear was measured in the Zoller Genius 3. Taylor Hobson Surtronic 3 + was used for measurement of surface roughness.

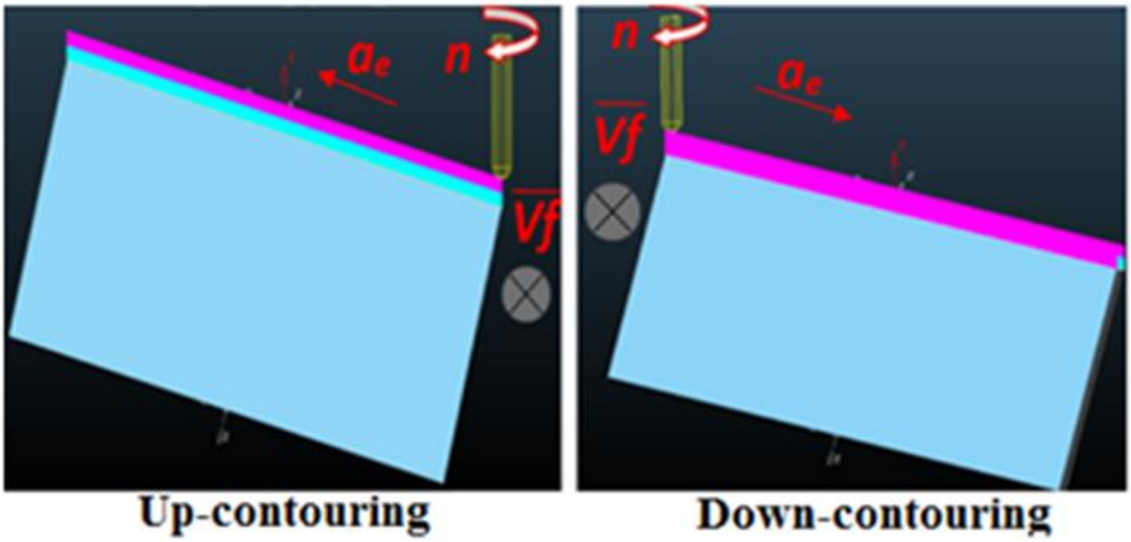

Fig. 2. CAM strategies used in experiment

3. Results

In the Fig. 3 you can see micrographs of maximal flank wear VB during all tested CAM strategies. It is obvious that in all principles of CAM strategies had triple-coating significantly better VB_{max} values than TiSiN during experiment condition. In this experiment was one principle of down contouring tested based on first research where was found that climb down contouring had better tool life than all kind of copy milling strategies. In this principle of milling was machining with tool centre a zero cutting speeds. Down contouring strategy caused the highest value of VB_{max} in experiments.

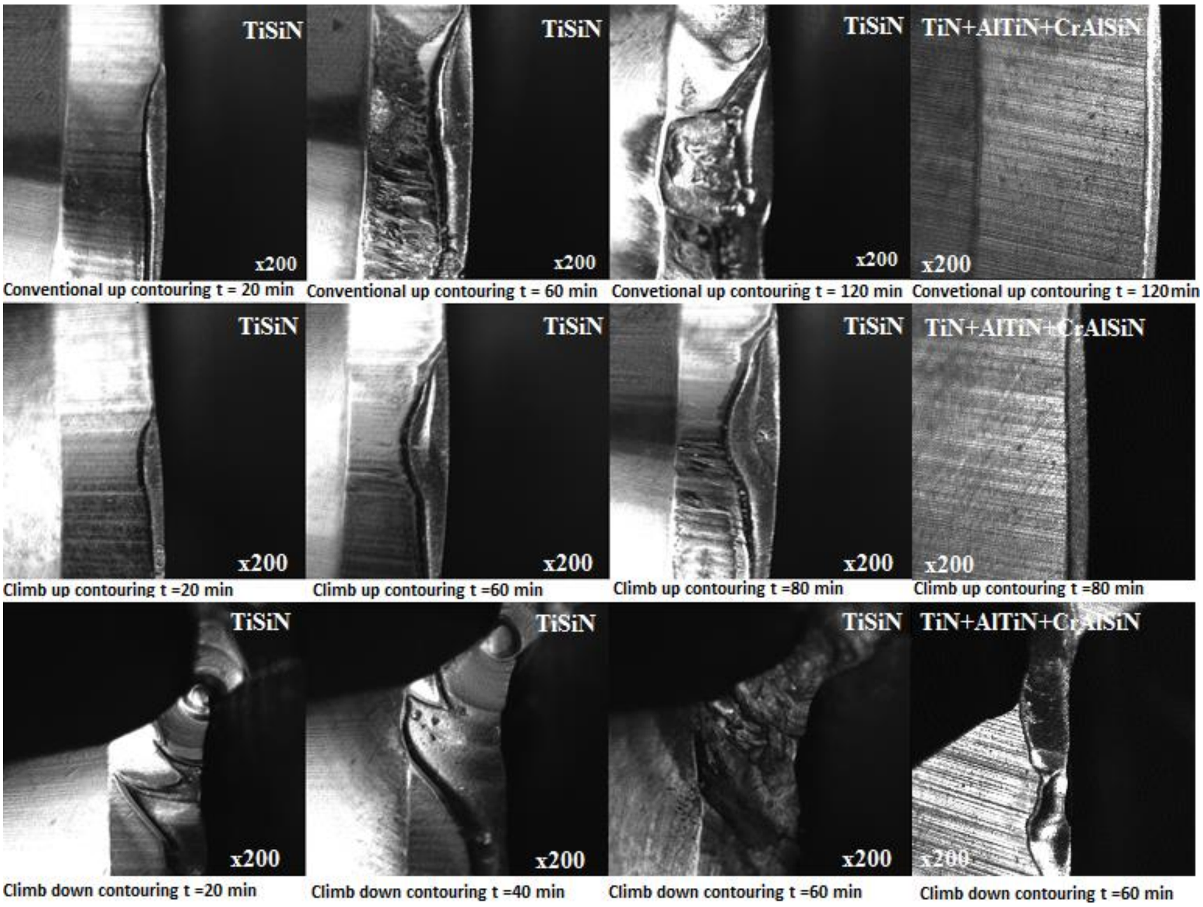

Fig. 3. Triple-coating vs TiSiN

TiSiN coating during used condition had delimitation wear of coated layer, which caused differences in tool life (180 min vs 105 min, 100 min vs 70 min, 60 min vs 35min) where first value represented triple-coating. In Table 1 are obtained values of flank wear during experiments for all strategies.

t (min)	Triple-Coating			TiSiN		
	Climb Up Conturing	Conventional Up Conturing	Climb Down Conturing	Climb Up Conturing	Conventional Up Conturing	Climb Down Conturing
	VB (mm)	VB (mm)	VB (mm)	VB (mm)	VB (mm)	VB (mm)
5	0,011	0,0395	0,04	0,051	0,05	0,0915
10	0,018	0,044	0,062	0,066	0,07	0,1675
20	0,04	0,055	0,096	0,1	0,091	0,2
40	0,063	0,0705	0,139	0,15	0,14	0,2675
60	0,081	0,078	0,159	0,19	0,117	0,5415
80	0,104	0,0855	0,185	0,22	0,21	
100	0,125	0,105	0,199		0,22	
130	0,154	0,1185			0,275	
160	0,165	0,154				
178		0,1615				
220		0,175				
267		0,197				

Table 1. VBmax values obtained in experiments

It is difficult to define of reason why delimitation wear was created. Reasons of obtained results may are quality of coating layer, surface after grinding process and inappropriately cutting condition for TiSiN. Triple-coating PVD layer was in all research criteria established as better solution. In the Fig. 4 is showed diagram of time dependence of flank wear.

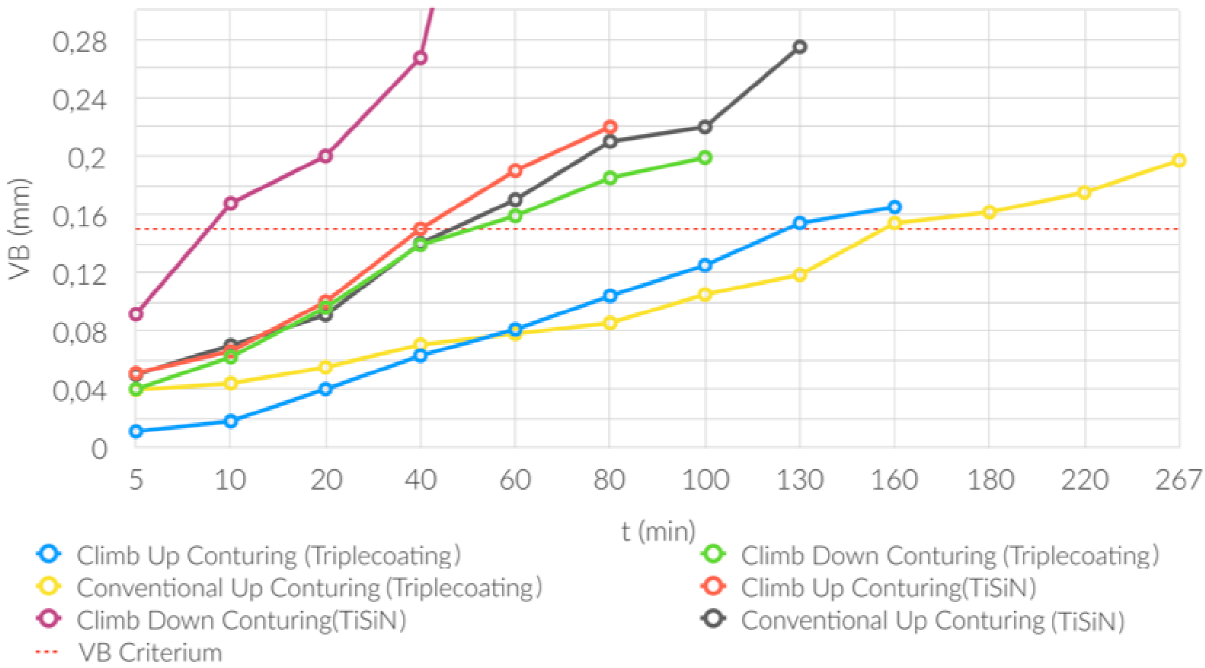

Fig. 4. Diagram of obtained VB_{max} values

For better explanation of deformations of cutting edge the Ra surface roughness parameter was used. In Table 2 are showed results of surface measuring in cross direction on the tool paths. When the surface roughness parameter Ra was evaluated, we determine that impact of flank wear was less than influence of CAM strategy. This fact was confirmed for conventional up – contouring strategies where was differences from VB = 0,118 mm with Triple-coating to VB = 0,275 mm with TiSiN. In these strategies was obtained the best values of surface roughness parameter. Roughness parameter Ra was influenced with the CAM strategy more than with coatings type because deformations of cutting edge was minimal. After coating delimitation of TiSiN was carbide deformation stable and that had positive influence on Ra.

t (min)	TripleCoating			TiSiN		
	Climb Up Conturing	Conventional Up Conturing	Climb Down Conturing	Climb Up Conturing	Conventional Up Conturing	Climb Down Conturing
	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)
5	0,39333	0,44666	0,56	0,40	0,45	0,56
10	0,41333	0,44666	0,57333	0,50	0,51	0,77
20	0,466667	0,61333	0,626667	0,65	0,48	0,91
40	0,99333	0,88666	0,54333	0,95	0,53	1,83
60	1,15333	0,74	0,86	1,01	0,87	0,98
80	0,78666	0,85666	0,82666	2,11	1,01	
100	0,83333	0,74666	1,61		1,16	
130	1,01333	0,40666			1,11	
160	1,60333	0,59333				
180		0,49333				

Table 2. Surface roughness parameter Ra results

In the figure below is showed time dependence of Ra with obvious differences for Ra criteria during strategy "climb down contouring". Reason why was Ra changed from 1,83 µm to 0,98 it is due to delimitation wear of TiSiN. After of total deformation of coated layer was cutting edge more stable and it caused better value of Ra. This phenomenon also manifested itself at strategy Conventional up contouring where was VB_{max} almost doubled and Ra criteria was not attained. CAM finish milling strategies "conventional up contouring" were the most advisable. Profile of cutting edge was minimal decreased and deformed and it caused advisable Ra values. We assumed that during this strategy was chip removal from cutting zone better than other strategies.

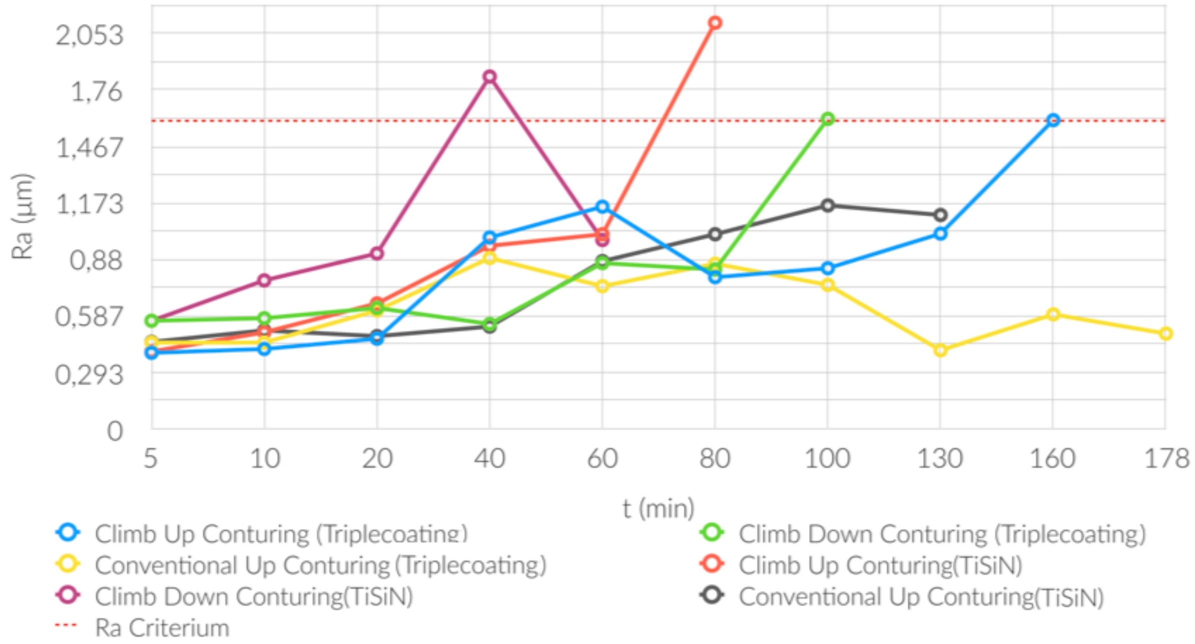

Fig. 5. Diagram of obtained Ra values

4. Conclusion

The article deals with the issue of end milling strategies with different cutting tools coating and their influence on the tool life. The aim was to investigate the wear of ball nose end mill for two different coatings (TiN + AlTiN + CrAlSiN and TiSiN). The results show, that thickness and type of coating had a significant effect on the flank wear of the tool in correlation with the Ra surface roughness parameter. Tools with TiSiN coating had significant delimitation wear. Reasons of obtained results in TiSiN may are quality of coating layer, surface after grinding process and inappropriately cutting condition for TiSiN.

Significant differences in tool life were obtained (180 min vs 105 min, 100 min vs 70 min, 60 min vs 35min) where first value represented triple-coating. In experiments was found that CAM finish milling strategies had significant impact on the tool life and surface roughness parameter Ra. CAM finish milling strategies "conventional up contouring" were the most advisable. Profile of cutting edge was minimal decreased and deformed and it caused advisable Ra values. We assumed that during this strategy was chip removal from cutting zone better than other strategies. This predication carried out less deformations of profile of cutting edge and better surface roughness Ra. Conclusion of presented paper and previous experiments carried out significant results. Triple-coating had better tool life and stability of machining process and the best strategy for milling with ball nose end mill is up-contouring. This research is going to continue for cutting tools with various cutting edge microgeometry when machining the difficult-to-cut materials.

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