euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Wear behaviour of diamond coated micro-milling tools during micro machining

E. Uhlmann[1,2], Y. Kuche[2], D. Oberschmidt[1], J. Polte[2]

[1]*Fraunhofer Institute for Production Systems and Design Technology IPK, Germany*
[2]*Institute for Machine Tools and Factory Management IWF, Technische Universität Berlin, Germany*

yves.kuche@iwf.tu-berlin.de

Abstract
Graphite electrodes are used in the die sinking process for manufacturing of micro structured tools in the die and mould fabrication. They are machined using the micro-milling process. During the cutting process graphite grains have strong abrasive effects on the cutting edges and lead to high tool wear. Consequences are short path length l_c and geometrical errors. One approach to reduce tool wear is the tool coating with diamond. The diamond coating changes the cutting edge micro geometry which has influences on the process behaviour. In this paper, the wear behaviour of micro-milling tools with diameter D = 0.5 mm and different micro geometries is analysed and discussed. The results show better wear behaviour for prepared and coated tools.

Keywords: Micro-milling tools, coating, tool wear

1. Introduction

The hot filament chemical vapour deposition (HFCVD) is an appropriate process for the diamond coating of complex cutting tool geometries [1, 2]. High hardness h and wear resistance allow an improved cutting performance for different materials [3]. Diamond coated WC-Co cutting tools showed advantages in comparison to uncoated tools especially for the machining of graphite. Fine grained graphite is difficult to machine, because of abrasive graphite grains which were broken out of the material during machining [4, 5]. Within the cutting process the cutting edge micro geometry influences the cutting performance, the tool wear, the surface quality of the machined workpiece, as well as the cutting force F_c. The diamond coating consisting of an etching process as well as the HFCVD-coating changes significantly the cutting edge radius r_β as well as the chipping of the cutting edge R_s.

Further investigations show the wear behaviour of prepared and diamond coated micro-milling tools during machining graphite. Thereby the influence of the cutting edge micro geometries will be analysed and discussed.

2. Micro-milling tools

Tungsten carbide micro-milling tools with diameter D = 0.5 mm were analysed. Therefore, an optical measurement device InfiniteFocus from the company Alicona Imaging GmbH, Grambach, Graz, Austria, was used. The tools were divided in 4 groups. Tool group 1 and 2 were unprepared, group 3 and 4 prepared with immersed tumbling process. After the preparation the tools of group 2, 3 and 4 were coated with a multilayer diamond coating.

The immersed tumbling process can be used for the cutting edge preparation and polishing of workpieces and cutting tools. Therefore, a machine tool DF-3 Tools from the company Otec Präzisionsfinish GmbH, Straubenhardt, Germany, was used. The workpieces are fixed in tool holders and immersed in an abrasive lapping medium. Within the investigations the lapping media of the type HSC 1/300 and H 4/400 were selected. HSC 1/300 is a mixture of 30 % silicon carbide with a grain diameter $d_G \approx 2$ µm and 70 % walnut shell granulate with a grain diameter $0.8\ \text{mm} \leq d_G \leq 1.3$ mm. H 4/400 consists of walnut shell granulate with a grain diameter of $0.4\ \text{mm} \leq d_G \leq 0.8$ mm and a polishing paste containing diamond particles. The machine tool has two independent drives, the main drive and the drive for the holders.

Tool group 3 was prepared with the lapping medium H 4/400, a rotational speed of the rotor $n_R = 40$ 1/min, a rotational speed of the holder $n_H = 80$ 1/min, and with processing time $t_B = 120$ s. Tool group 4 was prepared with the lapping medium HSC 1/300, a rotational speed of the rotor $n_R = 20$ 1/min, a rotational speed of the holder $n_H = 40$ 1/min, and with processing time $t_B = 60$ s. The depth of immersion was $T_E = 100$ mm in both preparation processes.

The tools were coated with multilayer diamond coatings of the type CCDia Carbon Speed from the company CemeCon AG, Würselen, Germany, with a layer thickness $s_D \approx 3$ µm. Figure 1 shows scanning electron microscope (SEM) images of the tools.

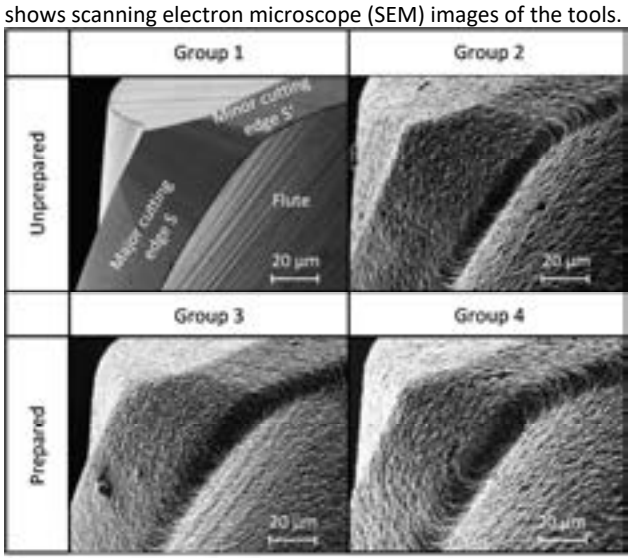

Figure 1. Prepared and coated micro-milling tools

The cutting edge radius r_β and the maximum chipping of the cutting edge $R_{s,max}$ were analysed with the InfiniteFocus.

The measurement results of the coated tools showed increased cutting edge radii with an average of $\Delta r_\beta = 4.1$ µm in consequence of the etching process and the diamond coating itself. The highest radius increase occurred at the unprepared cutting tools with $\Delta r_\beta = 4.8$ µm. Furthermore, a maximum chipping of the cutting edge $0.63\ \mu m \leq R_{s,max} \leq 0.90\ \mu m$ was measured. The lowest maximum chipping of the cutting edge $R_{s,max}$ was measured for tool group 3 and the highest maximum chipping of the cutting edge $R_{s,max}$ for the unprepared and coated tools of group 2.

3. Micro-milling of graphite

The milling experiments were carried out with a five-axes high precision machine tool PFM 4024-5D from the company PRIMACON GMBH, Peissenberg, Germany. The machine tool has a position accuracy $P_a = 1$ µm and a high frequency spindle Precise MFW 1260 from the company FISCHER AG, Herzogenbuchsee, Switzerland, with a rotational speed n = 60,000 rpm. An ultra fine grained graphite EDM3 from the company POCO GRAPHITE, INC., Texas, USA, with grain diameter $d_G < 5$ µm was used. For the experiments a rotational speed n = 31,800 rpm, a cutting speed $v_c = 50.4$ m/min, and a feed per tooth of $f_z = 25$ µm were selected. The width of cut was $a_e = 250$ µm and the depth of cut was $a_p = 150$ µm.

4. Wear behaviour of the micro-milling tools

During the experiments the tool wear was analysed with a SEM after different path lengths l_c. The maximum width of flank wear land VB_{max} was measured and the results of the different tool groups compared, figure 2.

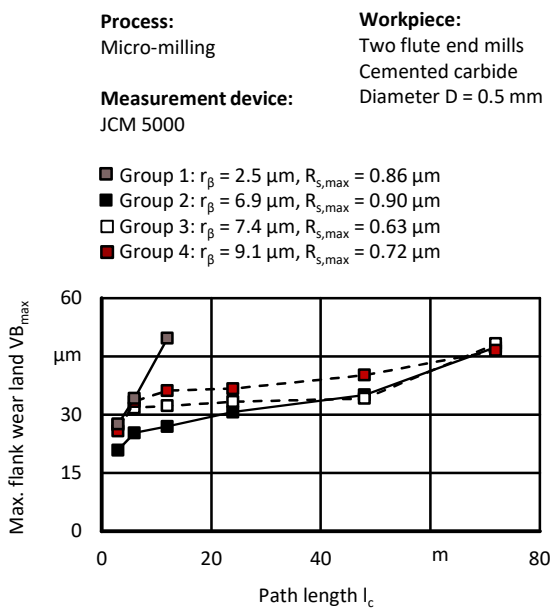

Figure 2. Maximum width of flank wear land VB_{max} of used micro-milling tools

With uncoated micro-milling tools the maximum flank wear land of the main cutting edge $VB_{max} = 50$ µm was reached after a path length $l_c = 12$ m. After a path length $l_c = 24$ m the tools show strong wear on the cutting edges and the experiments with this group were stopped. The maximum flank wear land VB_{max} of the coated tools was reached after a path length $l_c \approx 80$ m. The cutting tools with higher cutting edge radii r_β show increased maximum flank wear land VB_{max} till a path length $l_c = 12$ m and have a longer constant wear behaviour till the path length $l_c = 80$ m. Crater wear on the rake face A_γ was detected and the layer thickness s_D decreased over the path length l_c. The tools of group 2 and 3 showed failure of coating after a path length $l_c = 48$ m, shown in figure 3. Best results can be shown for tool group 4 with continuous wear behaviour over the path length l_c and no failure of the coating after a path length $l_c = 48$ m.

The experiments with the coated tools were stopped after a path length $l_c = 216$ m. A strong displacement of the cutting edges was detected.

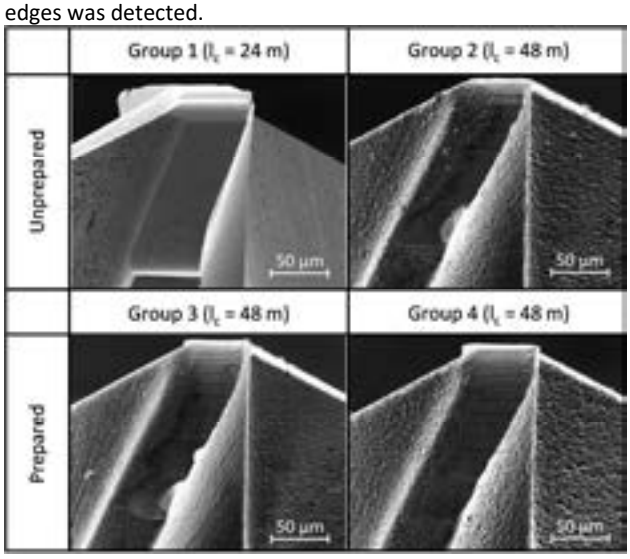

Figure 3. SEM images of tool wear on the major cutting edge S

5. Conclusion

Diamond coated micro-milling tools are widely used for machining graphite. The coating process changes the cutting edge micro geometry which influences the process behaviour.

In this contribution micro-milling tools with diameter D = 0.5 mm were prepared and HFCVD-diamond coated. In cutting experiments with graphite EDM3 the tool wear was examined and discussed. The results show better wear behaviour for prepared cutting tools with increased cutting edge radii r_β in comparison to unprepared coated tools.

Acknowledgements

This article is based on investigations of the research project "Definierte Schneidkantenpräparation zur Prozessoptimierung beim Mikrofräsen" (UH 148 / 100-2), which is kindly supported by the German Research Foundation (DFG).

References

[1] Uhlmann, E.; Lachmund, U.; Brücher, M.: Wear behaviour of HFCVD-diamond coated carbide and ceramic tools. Surface and Coatings Technology 131 (2000), p. 395 – 399.

[2] Uhlmann, E.; Koenig, J.U.: CVD diamond coatings on geometrically complex cutting tools. CIRP Annals - Manufacturing Technology 58 (2009), p. 65 – 68.

[3] Gracio, J.J.; Fan, Q.H.; Madaleno, J.C.: Diamond growth by chemical vapour deposition. J. Phys. D. 43 (2010), p. 374017 – 374039.

[4] Almeida, F.A.; Scramento, J.; Oliveira, F.J.; Silva, R.F.: Micro- and nano-crystalline CVD diamond coated tools in the turning of EDM graphite. Surface & Coatings Technology 203 (2008), p. 276 – 276.

[5] Pierson, H.O.: Handbook of carbon, graphite, diamond and fullerenes: properties, processing and applications. Noyes Publications, New Jersey, 1993.