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Droplet removal from PVD-coated micro-milling tools with the immersed tumbling process

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
The physical vapour deposition (PVD) process is widely used for the coating of cutting tools. The increased hardness and temperature stability permitted a higher cutting speed and longer tool life in comparison to uncoated tools. Within the PVD-process droplets of the target can be deposited on the coated surface. The consequence is an inhomogeneous surface of the cutting tools with an increased surface roughness. In this study, the immersed tumbling process is used for the droplet removal of micro-milling tools. The results show the functionality of the process for the droplet removal depending of the lapping media and process parameters in connection with the amount and size of the droplets.

Keywords: Immersed tumbling, coating, micro milling tools

1. Introduction

The PVD-process is appropriate for coating of micro-milling tools with hard coatings like TiN, AlTiN or CrN. The coatings can be deposited at temperatures in the range of 450 °C ≤ ϑ ≤ 550 °C and their increased hardness and layer thickness s_D in the range of micro meters allow a wide range of applications [1]. A negative effect within the arc-PVD-process is the deposition of droplets on the coated surfaces. They are created by ejection of liquid metal particles of the target material which solidify on the substrate. The consequences of droplets are inhomogeneous tool surface and residual stress [2, 3, 4].

In the following investigations coated micro-milling tools with droplets on the surface are prepared using the immersed tumbling process and the tool surface is analysed. Therefore, micro-milling tools with diameter D = 1 mm and D = 0.6 mm were coated and the preparation process on the coated milling tools were examined with a scanning electron microscope (SEM) and an optical measurement device InfiniteFocus from the company Alicona Imaging GmbH, Grambach, Austria.

2. Cutting edge preparation using immersed tumbling

The immersed tumbling process is used for polishing and cutting edge preparation of tools and workpieces. For the investigations a machine tool DF-3 Tools from the company Otec Präzisionsfinsih GmbH, Straubenhardt, Germany, was used. The tools were clamped into tool holders and dragged in a container filled with a lapping medium. Two independent drives move the tools over a planetary gear system through the container. In the experiments the lapping media H 4/400, HSC 1/300 and HSC 1/500 were used. H 4/400 consist of walnut shell granulate with grain diameter of 0.4 mm ≤ d_G ≤ 0.8 mm and a polishing paste with diamond particles. HSC 1/300 and HSC 1/500 are a mixture of walnut shell granulate with 0.8 mm ≤ d_G ≤ 1.3 mm for the lapping medium HSC 1/300 and 0.2 mm ≤ d_G ≤ 0.4 mm for HSC 1/500 with fine grained silicon carbide.

The micro-milling tools were prepared with the lapping medium H 4/400 and analysed with the optical measurement device InfiniteFocus. For tool diameter D = 1 mm a cutting edge radius r_β = 3.5 µm and a maximum chipping of the cutting edge $R_{s,max}$ = 0.52 µm on the major cutting edge S were measured. For tools with a diameter of D = 0.6 mm a cutting edge radius r_β = 7.1 µm and a maximum chipping of the cutting edge $R_{s,max}$ = 0.38 µm were measured. The cutting edge radii r_β ensure higher edge stability and reduce the residual stress of the coating on the cutting edges.

3. Tool coating

In the experiments tungsten carbide micro-milling tools with a diameter D = 1 mm and D = 0.6 mm of the company Walter AG, Tübingen, Germany, were used. The tools were PVD-AlTiN coated from the company Oerlicon Balzers Coating Germany GmbH, Bingen, Germany, with a layer thickness s_D = 1 µm. The tools were measured with the optical measurement device InfiniteFocus and SEM images were made, figure 1.

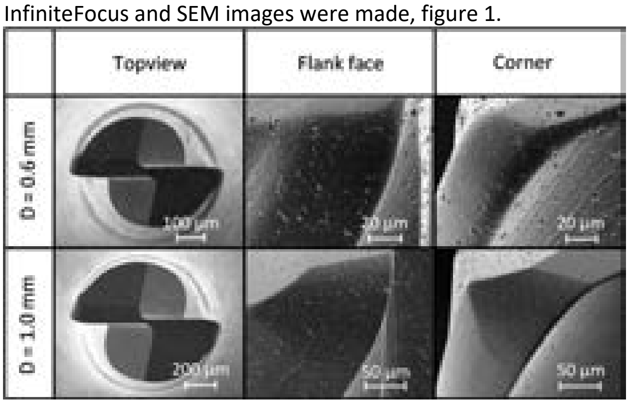

Figure 1. SEM images of coated micro-milling tools

The tools with D = 0.6 mm show big droplets on the surfaces and cutting edges. Tools of the diameter D = 1 mm have small droplets and an improved surface roughness on the flank faces A'_γ in comparison to the smaller tools. A cutting edge radius r_β = 3.9 µm and a maximum chipping of the cutting edge $R_{s,max}$ = 0.47 µm were measured for tools with D = 1 mm. For the coated tools with D = 0.6 mm a cutting edge radius r_β = 7.8 µm and a maximum chipping of the cutting edge $R_{s,max}$ = 0.56 µm of the major cutting edge S were measured.

4. Preparation of coated tools

The coated tools were prepared using the immersed tumbling process. Figure 2 shows the used process parameters of the immersed tumbling as well as images of the prepared tools. The rotational speed of the rotor n_R = 30 1/min and the rotational speed of the holder n_H = 25 1/min were equal in all preparation processes.

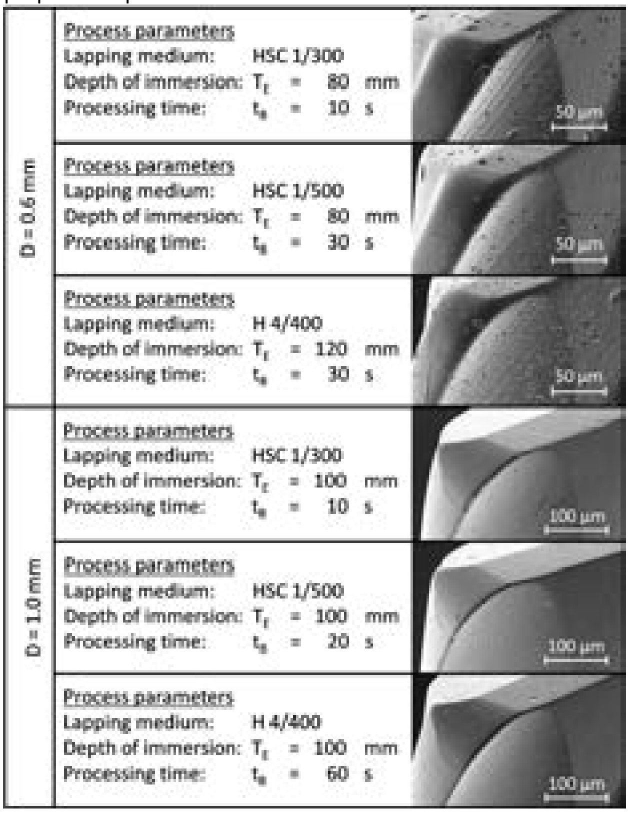

Figure 2. Preparation parameters and images of the prepared tools

The SEM images show a good droplet removal for the tools with diameter D = 1 mm. For tools with diameter D = 0.6 mm the bigger droplets could not be removed on the surface. In comparison with the HSC 1/500 and H 4/400 the HSC 1/300 has the highest abrasive effect. For tools with D = 1 mm the coating was weakened at the cutting edges and delamination took place. The tool with D = 0.6 mm shows decreased surface roughness and small scratches on the coated corner of the cutting tool. The smaller grains of the lapping media HSC 1/500 and H 4/400 led to good droplet removal for tools with diameter D = 1 mm. For tools with diameter D = 0.6 mm with bigger droplets the lapping pressure p and shear forces F_s were not high enough to remove the droplets. Only a polishing of the surfaces can be determined. All prepared tools showed better surfaces on the major flank faces A_α in comparison with the minor flank faces A'_α in consequence of the tool rotation in the process and direct flow pressure p on the major flank faces A_α. The maximum chipping of the cutting edge $R_{s,max}$ on the major cutting edge S as well as the surface roughness with the mean roughness depth Rz in the flutes were measured, figure 3. The results show a decreased fluctuation of the measured maximum chipping of the cutting edge $R_{s,max}$ for prepared tools. Furthermore, the mean roughness depth Rz in the rake face A_γ was improved by 56 % in comparison to the unprepared tools.

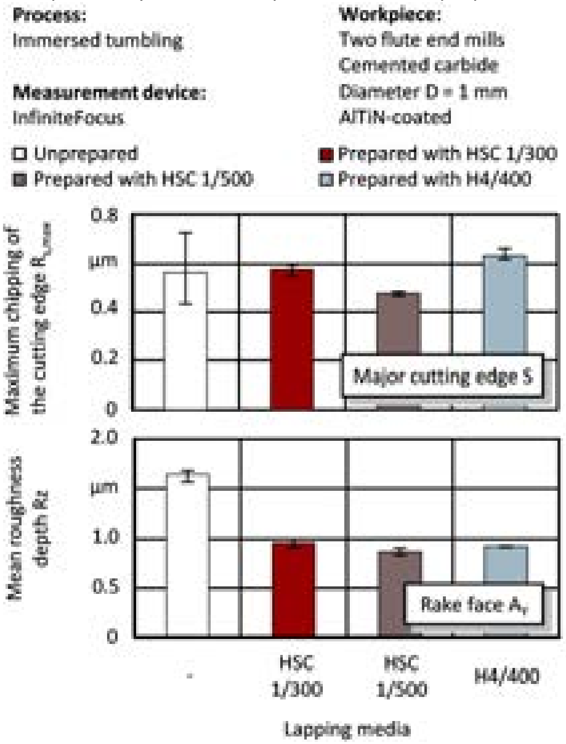

Figure 3. Maximum width of flank wear land VB_{max} of the major cutting edge S and mean roughness depth Rz on the rake face A_γ of prepared micro-milling tools

5. Conclusion

In the PVD-coating process droplets on the coated surface can be deposited. Within this investigation the applicability of the immersed tumbling process was analysed for droplet removal. The results show removed droplets due to the process depending on the process parameters and the used lapping media. The surface roughness of the rake face A_γ could be decreased.

In further investigations experiments for the definition of parameter settings for good droplet removal with decreased influence on the cutting edges are planned.

Acknowledgements

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