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Influence of cutting edge preparation on the performance of micro milling tools

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Abstract

A main reason for premature tool failure in micro milling is the irregular wear behavior of the cutting tools. An approach to improve the tool wear behavior is a defined cutting edge preparation using immersed tumbling. A particular challenge is the cutting edge preparation of micro milling tools with small diameters $D \leq 0.5$ mm. High loads within the preparation process can lead to outbreaks of the cutting edge and tool breakage. Furthermore, the influence of changed cutting edge geometry regarding the process behavior has to be more examined for these tool diameters. In this paper, micro milling tools with a diameter $D = 0.2$ mm will be prepared and the influence on the cutting process will be presented and discussed. The experiments will show a better wear behavior for the prepared tools and an improved surface roughness on the machined workpiece.

Keywords: micro milling; cutting edge; wear; machining

1. Introduction

A reason for premature tool failure of micro milling tools is the wear of the cutting edges. Grain outbreaks as well as an increased chipping of the edge occur during the grinding process. These could be reasons for an increased tool wear, process variations and a varying surface roughness of the machined workpiece.

With decreasing tool diameters and process parameters the influence of the cutting edge micro geometry increase. The cutting edge radius r_β is significant for the behavior of the chip formation. For a ratio of the chip thickness to the minimum chip thickness $h < h_{min}$ no chip formation occurs and ploughing effects dominate. Previews investigations of *Sokolowski* [1] have shown the depending of the cutting edge radius r_β to the minimum chip thickness h_{min}. The material will be compressed beneath the cutting edge and elastic- and plastic deformations dominate the cutting process [2].

Former investigations have shown the improvement of tool wear for cemented carbide inserts or conventional milling and drilling tools by the cutting edge preparation with brushing, blasting or laser machining [3, 4]. A technology to stabilise the cutting edge and to decrease the chipping of the edge of micro milling tools is the immersed tumbling [5, 6, 7]. The immersed tumbling process is characterised by a uniform comprehensive preparation of shank tools. *Uhlmann* and *Löwenstein* [5] investigated the cutting edge preparation employing immersed tumbling and magnet finishing. With this preparation technologies cutting edge radii of $r_\beta \approx 6$ µm were produced. Decreased cutting forces and tool wear were occurred. Further investigations with prepared micro milling tools with diameter $D = 1$ mm, cutting edge radii $r_\beta = 8$ µm and a maximum chipping of the cutting edge $R_{s,max} = 0.3$ µm showed decreased tool wear [6].

In the following experimental investigations the suitability of the immersed tumbling for micro milling tools with a diameter $D \leq 0.5$ mm was analysed. Therefore, micro milling tools with a diameter $D = 0.2$ mm were prepared employing the immersed tumbling process and the mould steel X13NiMnCuAl4-2-1-1 was machined.

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Nomenclature

a_e	width of cut
a_p	depth of cut
A_α	major flank face
D	diameter
d_G	grain diameter
F_a	active force
f_z	feed per tooth
l_c	path length
n_H	rotational speed of the workpiece holder
n_R	rotational speed of the rotor
n_W	rotation speed of the workpiece
P_a	position accuracy
Ra	arithmetical mean deviation
$R_{s,max}$	maximum chipping of the cutting edge
Rz	mean roughness depth
r_β	cutting edge radius
t_B	processing time
T_E	depth of immersion
v_c	cutting speed

2. Cutting Edge Preparation

For the investigations a machine tool of the company OTEC PRÄZISIONSFINISH GMBH, Straubenhardt-Feldrennach, of the type DF-3 Tools was used. The tools are fixed in tool holders and immersed in an abrasive medium. Over a planetary gear two drives cause a relative movement of the tools in the media. The cutting process is mainly caused by ploughing and furrowing of the abrasive grains on the workpiece. Figure 1 shows the machine tool and the machine kinematics.

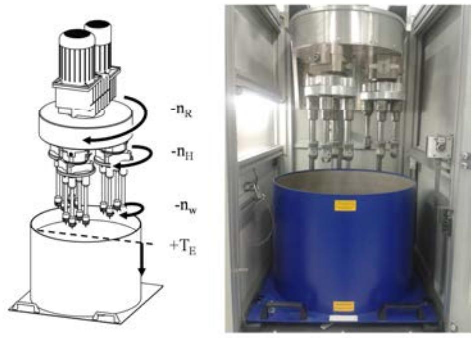


Fig. 1. Kinematics of the DF-3 Tools.

The experiments were carried out with micro milling tools of the company GESAU WERKZEUGE FRABRIKATIONS- UND SERVICE GMBH, Glauchau. The uncoated two flute end mills are made of micro grain cemented carbide. They have a measured hardness HV = 1.533 kN/mm^2 and a diameter D = 0.2 mm.

For the preparation of the micro milling tools two different lapping medias are used. The first one with the product name HSC 1/300 is a mixture of 30 % silicon carbide (SiC) with a grain diameter $d_G \leq 0.2$ mm and 70 % walnut shell granulate with a grain diameter 0.8 mm $\leq d_G \leq$ 1.3 mm. The second one with the product name H4/400 consists of a mixture of walnut shell granulate with a grain diameter 0.4 mm $\leq d_G \leq$ 0.8 mm and a polishing paste containing diamond particles [6].

For the investigations six tool groups, each with three micro milling tools, were formed and the tool groups 2 till 6 were prepared by using the DF-3 Tools. To investigate the influence of the prepared cutting edges with different cutting edge radii in the range 2 µm $\leq r_\beta \leq$ 6 µm various parameter settings were used. The process parameters are given in Table 1. For all preparations the rotation direction of the holders and the rotor were clockwise.

Table 1. Process parameters of cutting edge preparation.

Tool group	Group 2	Group 3	Group 4	Group 5	Group 6
Lapping media	H4/400	H4/400	HSC 1/300	HSC 1/300	HSC 1/300
rotational speed of the rotor n_R	40 1/min	40 1/min	20 1/min	40 1/min	40 1/min
rotational speed of the workpiece holder n_H	40 1/min	40 1/min	20 1/min	40 1/min	40 1/min
depth of immersion T_E	100 mm	100 mm	80 mm	80 mm	80 mm
Processing time t_B	30 s	180 s	180 s	240 s	360 s

Subsequently, images using a scanning electron microscope SEM were made and the tools were measured with an optical measurement device InfiniteFocus of the company ALICONA IMAGING GMBH, Graz, Austria.

Table 2 shows the SEM Images. It is shown that the cutting edge radii r_β increase with each tool group.

Table 2. Major cutting edges S of the tool groups.

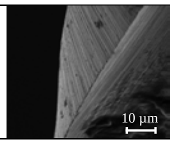
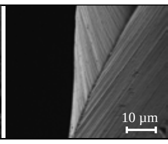
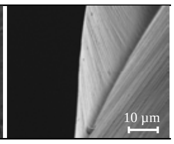
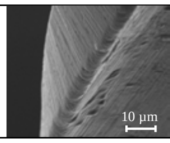
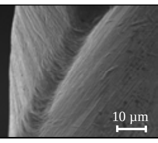
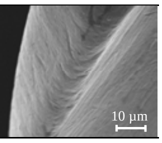
Tool group	Group 1	Group 2	Group 3
Major cutting edge S			
Tool group	Group 4	Group 5	Group 6
Major cutting edge S			

Figure 2 presents the results of the measured minor cutting edge S' with the cutting edge radius r_β in chart a and the maximum chipping of the cutting edge $R_{s,max}$ in chart b.

The results in chart a show an increase of the cutting edge radius r_β for higher processing time t_B with both lapping medias. For tool group 1 which were unprepared, a cutting edge radius r_β = 2.1 µm was measured. With the lapping media H4/400 and the process parameters as shown in Table 1 a cutting edge radius r_β = 2.5 µm in tool group 2 and