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Geometric deviations of ground micro-milling tools and their influences on the cutting performance

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Abstract
For micro-milling tools with decreasing diameter D < 0.5 mm the requirements for the manufacturing rise up and the risk of geometrical deviations of the cutting edges increase. In this investigation industrial produced micro-milling tools with a diameter of D = 0.2 mm made of cemented carbide were analysed. Micro-milling tools with variable macro geometry were selected and used for the machining of mould steel. The influence of the geometrical deviations on the wear behaviour and the surface roughness of the machined steel were examined. It is shown that the variable tool geometry lead to wear of the minor cutting edges S'. Furthermore, an influence on the surface roughness of the machined workpiece is determined.

Keywords: micro-milling, tool geometry, wear

1. Introduction

In industry the micro-milling process is widely used for the manufacturing of micro features. To get a high quality of micro milled components a high process accuracy and process stability are required [1]. Therefore, the design and quality of micro-milling tools are decisive.

The micro-milling tool geometry can be divided into micro- and macrogeometry. The microgeometry is the active part of the cutting tool which includes the cutting edge radius r_β as well as the chipping of the cutting edge R_s. Many investigations considered the reduction of the chipping of the edge R_s and the stabilisation of the cutting edge with cutting edge preparation technologies [2, 3]. The macrogeometry describes the dimension of the tool such as the rake angle γ_0, wedge angle β_0 or the clearance angle α_0 [4].

In the following the analyses of micro-milling tools with variable macrogeometry after the grinding process and their influence on the tool wear and surface roughness of the machined mould steel are presented.

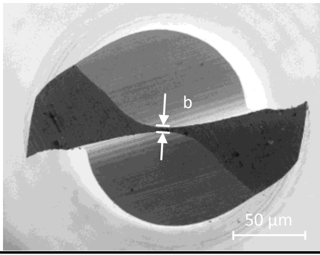
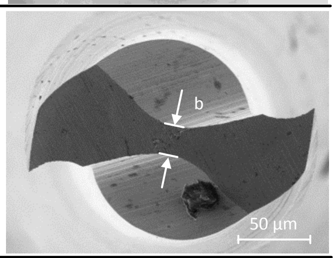
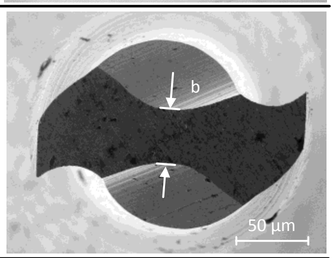
2. Micro-milling tools

Within the investigations uncoated micro-milling tools with a diameter D = 0.2 mm made of cemented carbide were used. To analyse the micro-milling tools they were measured with an optical measurement device InfiniteFocus of the company ALICONA IMAGING GMBH, Graz, Austria. Further images with a Nikon NeoScope JCM 5000 benchtop scanning electron microscope of the company JEOL LTD., Tokyo, were made.

The measurement results show sharp cutting edges with a measured cutting edge radius $r_\beta = 2.1$ µm and a maximum chipping of the edge $R_{smax} = 0.45$ µm on the major cutting edge S. On the minor cutting edge S' a cutting edge radius with $r_\beta = 1.8$ µm and maximum chipping of the edge $R_{smax} = 0.48$ µm was measured.

Table 1 shows SEM images of the cutting tools. The new tools show a variable geometry of the minor cutting edge S' with the two minor flank faces A'_α. The width of the flanks changes between the tools. The smallest bridge between the two flanks in the centre of the tool was measured with b = 2.7 µm and the biggest with b = 36 µm. The measured diameters D and the tool clearance angle with $\alpha_0 = 12$ ° are constant for all measured tools. Reasons for the variable tool geometry after the grinding process could be disturbing influences like temperature fluctuations or wear of the grinding wheels.

Table 1. Micro-milling tools with geometrical deviation.

Cutting tool with small minor flank faces A'_α (Tool group A)	
Cutting tool with normal minor flank faces A'_α (Tool group B)	
Cutting tool with large minor flank faces A'_α (Tool group C)	

3. Milling experiments

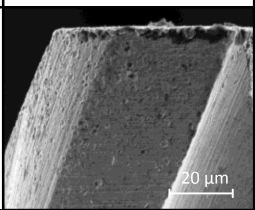
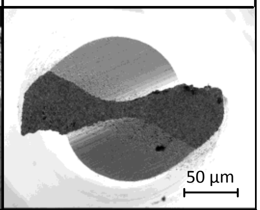
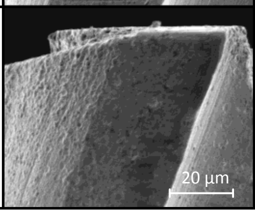
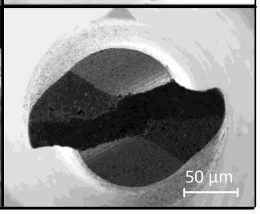
To investigate the influence of the cutting edge geometry of the micro milling tools a mould steel of the type M261 extra, X13NiMnCuAl4-2-1-1, of the company BÖHLER EDELSTAHL GMBH & CO. KG, Kapfenberg, Austria, was machined. A 5-axes micro-milling machine tool PFM 4024-5D of the company PRIMACON GMBH, Peissenberg, Germany, was used. The machine tool has a positional deviation of Pa < 4 µm. A high-frequency spindle with a rotational speed n ≤ 60.000 rpm and a polygonal toolholder TRIBOS of the company SCHUNK GMBH & CO. KG, Neckar, Germany, were used.

Within the experiments a rotational speed of n = 50.000 rpm, a feed per tooth of f_z = 4 µm and a cutting speed v_c = 31.4 m/min were selected. The width of cut a_e as well as the depth of cut were a_p = 15 µm.

3.1 Tool wear

Table 2 shows images of the major flank faces A_α and the minor flank faces A'_α of applied micro milling tools of tool group A and C. After the path length of l_c = 8 m the milling tools show strong wear of the minor flank faces A'_α. In comparison to table 1 an increasing bridge width b between the two flanks in the centre of the tool occurs. The measured tool clearance angle is α_0 = 0 °. It can be concluded that the length l of the tools decrease and the depth of cut a_p changes during the process.

Table 2. Tool wear of the tool groups A, B and C after the machining of steel with a path length of l_c = 8 m.

	Major flank face A_α	Minor flank faces A'_α
Tool group A small minor flank faces A'_α		
Tool group C large minor flank faces A'_α		

3.2 Surface roughness of the machined workpiece

After the milling experiments the arithmetical mean deviation Ra and the mean roughness depth Rz of the machined workpiece were measured. Here a tactile measurement device nanoscan 855 of the company JENOPTIK AG, Jena, Germany, was used.

Figure 1 presents the measurement results. The surface which was machined with tools of the group B showed the lowest roughness in comparison to the results of the other tool groups. An arithmetical mean deviation Ra_C = 0.08 µm and a mean roughness depth Rz_C = 0.63 µm could be measured. With an arithmetical mean deviation Ra_A = 0.14 µm and Ra_C = 0.13 µm as well as a measured mean roughness depth Rz_A = 0.80 µm and Rz_C = 0.78 µm the surface roughness of the machined workpiece with tools of the groups A and C is nearly equal. However, by using tools of the tool group A with small minor flank faces A'_α the standard deviation s is 3.4 times higher for the arithmetical mean deviation Ra and 2.5 times higher for the mean roughness depth Rz compared to tools of the group C.

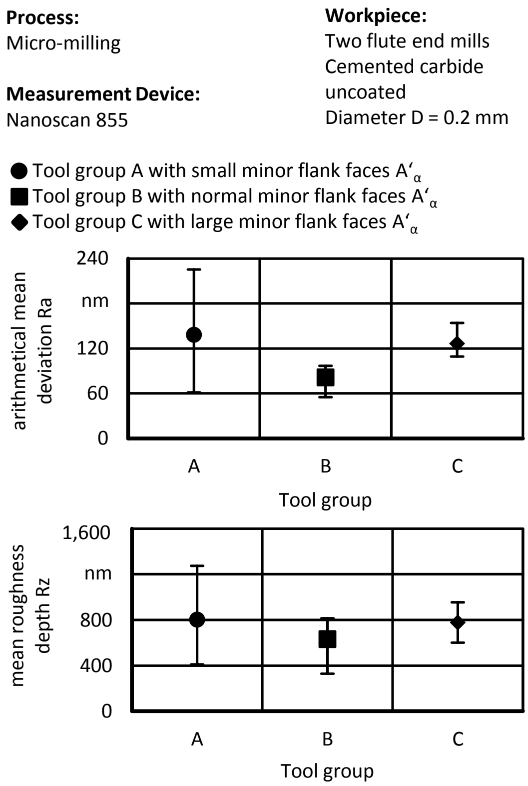


Figure 1. Surface roughness of the machined mould steel.

4. Conclusion

In this contribution industrial manufactured micro-milling tools were analysed and geometrical deviations of their macrogeometry were shown. It is presented that some tools have a variable size of the minor flank faces A'_α probably in consequence of changing contact conditions of the grinding wheels within the grinding process. The tools with these deviations were divided in two groups and they were used for the machining of a mould steel. Further investigations of the tool wear showed high abrasive wear of the minor cutting edges S' and the minor flank faces A'_α. A consequence is the decrease of the depth of cut a_p as a result of the reduced length l of the micro-milling tools. Investigations of the surface roughness of the machined workpiece show bigger standard deviations s for tools with small minor flank face A'_α in comparison to tools with a large minor flank face A'_α.

Future investigations will concentrate on the measurement of the changing depth of cut a_p as a result of the strong wear for micro-milling tools with D < 0.5 mm and the compensation.

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