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Manufacturing of CVD diamond micro-end mills with electrical discharge machining

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Abstract
At state of the art micro-milling tools made of cemented carbide are widely used in industry. Nevertheless, these micro-milling tools suffer from fast and random tool breakage while cutting. To improve the wear behaviour of micro-milling tools new cutting materials have to be established. In this work electrical discharge machining (EDM) for manufacturing of micro-milling tools with cutting edges made of boron doped chemical vapour deposition (bdCVD) diamond were investigated. Wire-EDM and die-sinking-EDM were compared regarding the characteristics of the micro-tool´s cutting edges. It could be concluded that the wire-EDM process is suitable for manufacturing of micro-milling tools with cutting edges made of bdCVD diamond. With respect to the elaborated technologies for the wire-EDM process a cutting edge radius r_β = 3.9 µm and for the die-sinking-EDM process a cutting edge radius r_β = 5.4 µm could be measured.

Keywords: electrical discharge machining, micro-milling, diamond

1. Introduction

Micro-milling is a key technology for the manufacturing of complex micro-featured parts with a high versatility regarding machinable materials and workpiece structures. Uhlmann et al. [1] stated the increasing relevance for the production of high-precision components with micro-scale features with respect to a broad range of industrial sectors. Examples for high-precision components with micro-scale features are optical coupling units for data transfer, micro fluidic chips for in situ analysis, dental components, and precision engineering parts. These micro-featured parts can be machined by micro-milling or replicative technologies.

2. Micro-milling tools

At state of the art micro-milling tools made of cemented carbide are widely used in industry for machining various workpiece materials. Nevertheless, these micro-milling tools suffer from fast tool wear and random tool breakage while cutting. The fast tool wear leads to insufficient geometrical accuracy a_g and surface quality. Furthermore, the high variance of machining results affects the costs of the parts significantly. Different research activities were carried out to improve the wear behaviour of cemented carbide micro-milling tools. The following approaches are most promising:

- coating,
- optimisation of tool macro geometry,
- cutting edge preparation, and
- dedicated machining technologies.

For industrial application the coating and defined cutting edge preparation are in focus of research. The coating of the micro-milling tools improves the tool life, but chipping and delamination of coating still occurs [2, 3]. In comprehensive investigations micro-milling tools with a defined cutting edge preparation showed reduced flank wear land VB_{max} by 14 % [4]. Figure 1 illustrates a CrN-AlCrN-AlCrON-coated micro-milling tool after machining zirconium oxide for a path length l_c = 1.5 m. Breakage of the cutting edge and delamination of the coating are visible.

Process: Micro-milling	**Workpiece material:** Zirconium oxide
Process parameter:	**Tool:**
v_c = 60 m/min	Cemented carbide
f_t = 5 µm	CrN-AlCrN-AlCrON-coated
a_p = 500 µm	Two flute ball end mill
a_e = D	D = 0.5 mm

path length l_c = 1.5 m

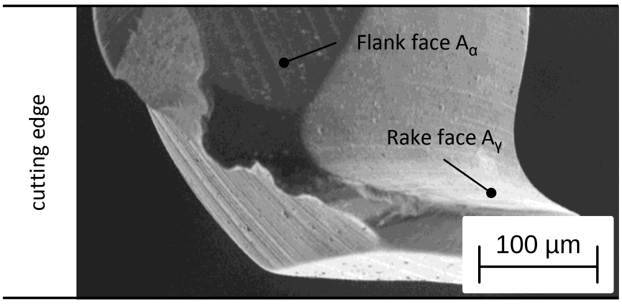

Figure 1. CrN-AlCrN-AlCrON-coated micro-ball end mill after machining zirconium oxide for a path length l_c = 1.5 m

New cutting materials to improve the wear behaviour of micro-milling tools have to be established. Cutting parts made of super hard cutting materials limit the aspect ratio of micro-milling tools with a diameter d ≤ 1 mm to aspect ratios a ≤ 1 due to high forces F while tool grinding. Grinding of super hard cutting materials like polycrystalline diamond leads to insufficient results. Therefore, new technologies for manufacturing of these micro-milling tools with wear resistant cutting materials have to be developed.

3. Experimental setup and machining results

In this work electrical discharge machining (EDM) for manufacturing of micro-milling tools with cutting edges made of boron doped chemical vapour deposition (bdCVD) diamond was investigated. Especially the wire-EDM and the die-sinking-EDM were compared regarding the characteristics of the micro-tool´s cutting edges. The investigations were carried out on the wire-EDM machine tool AC Vertex 1F with a relaxation generator from GF AGIE CHARMILLES, Geneva, Switzerland, and the die-sinking-EDM machine tool genius 1000 the cube with a static pulse generator from ZIMMER&KREIM GMBH & CO. KG, Brensbach, Germany. For the wire-EDM and die-sinking-EDM experiments two different electrode materials were used respectively. The wire-EDM electrodes were made of brass and zinc-coated brass. Deionized water was used as dielectric fluid. The die-sinking-EDM experiments were done with cemented carbide and graphite as electrode material with the dielectric IonoPlus IME from the company OELHELD GMBH, Stuttgart, Germany. For the experiments regarding wire-EDM the electrode material, the encoded voltage U_c, the encoded current I_c, and the number of trim cuts n_t were varied. The investigations of the die-sinking-EDM were done with respect to the electrode material, the discharge current i_e, the pulse duration t_i, and the flushing.

The measurement device InfiniteFocus G4 from ALICONA IMAGING GMBH, Graz, Austria, were used for the measurement of the cutting edge radius r_β, the chipping of the cutting edge $R_{S,max}$, and the K-factor K_c. For the measurement of the surface roughness Rz of the rake face the tactile contour and roughness measurement device HOMMEL-ETAMIC Nanoscan 855 from the company JENOPTIK AG, Jena, Germany, was used. Figure 2. illustrates the results of the EDM tests to identify suitable parameters for manufacturing of micro-milling tools with respect to the requirements of cutting edges. The bar chart shows the lowest and highest achieved values concerning the cutting edge characteristics for manufacturing by wire-EDM and die-sinking-EDM respectively. A cutting edge radius $r_\beta = 3.9$ µm, a maximum chipping of the cutting edge $R_{S,max} = 1.3$ µm, a K-factor $K_c = 0.8$, and a surface roughness of the flank face Rz = 0.25 µm could be achieved using wire-EDM with zinc-coated brass as electrode material, an encoded voltage $U_c = 8$, an encoded current $I_c = 50$, and a number of trim cuts $n_t = 1$. For die-sinking-EDM a cutting edge radius $r_\beta = 5.4$ µm, a maximum chipping of the cutting edge $R_{S,max} = 1.6$ µm, a K-factor $K_c = 0.7$, and a surface roughness of the rake face Rz = 0.27 µm could be achieved using cemented carbide as electrode material, a discharge current $i_e = 5$ A, and a pulse duration $t_i = 5$ µs without flushing.

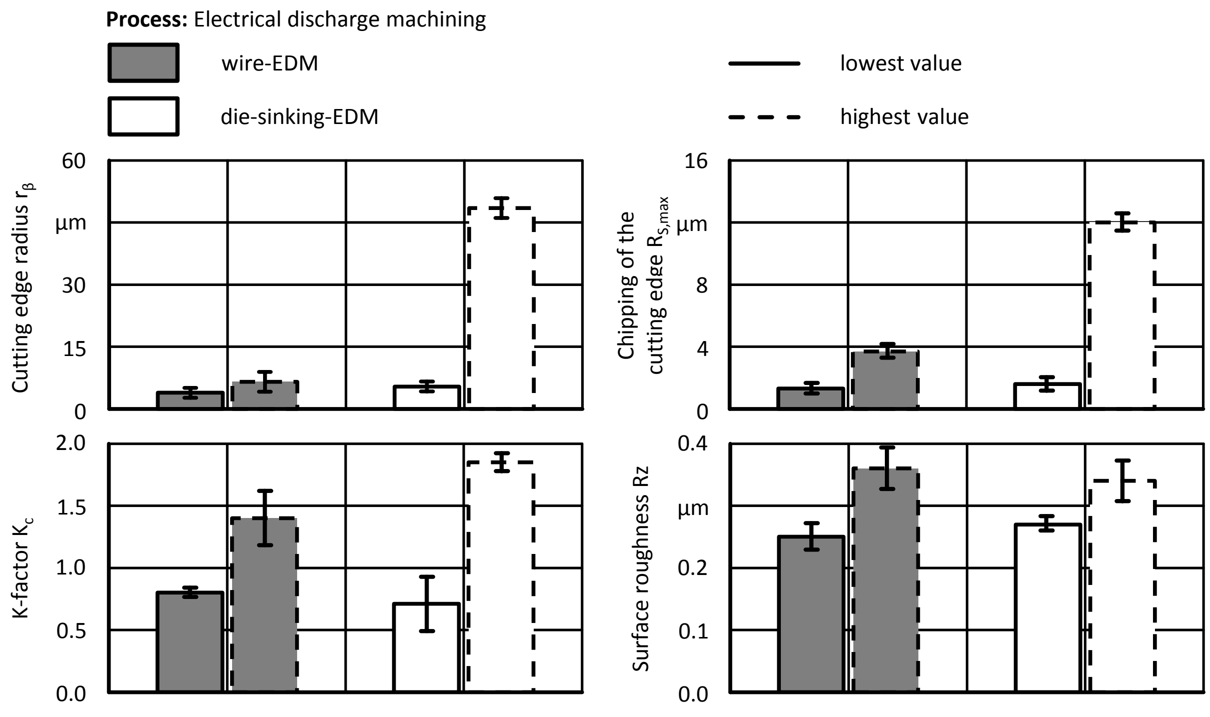

Figure 2. Results of the EDM tests

4. Conclusion

As a result of this work the successful application of EDM for manufacturing micro-milling tools with cutting edges made of bdCVD diamond could be shown. The findings concerning the comparison of the wire-EDM and die-sinking-EDM processes indicate the suitability of wire-EDM for manufacturing micro-end mills with cutting edges made of bdCVD diamond. This work is funded by the FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY (BMWI).

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