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Boron-doped CVD diamond micro-end mills for machining titanium

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

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

mitchel.polte@iwf.tu-berlin.de

Abstract
In industry micro-milling tools made of cemented carbide are widely used. However, these micro-milling tools suffer from fast and random tool breakage during the machining of hard to machine materials. Therefore, in preliminary work micro-milling tools with cutting edges made of boron doped chemical vapour deposition (bdCVD) diamond were developed. In this work new micro-milling tools were successfully applied for machining titanium grade 2. Comprehensive cutting tests were carried out to analyse the influence of the spindle speed n, the feed per tooth f_t, and the depth of cut a_p on the surface roughness. Further experiments addressed the wear behaviour of the developed micro-milling tools. After a path length l_c of 10 m a maximum width of flank wear land VB_{max} of 29 µm were observed.

Keywords: micro-milling, diamond, titanium

1. Introduction

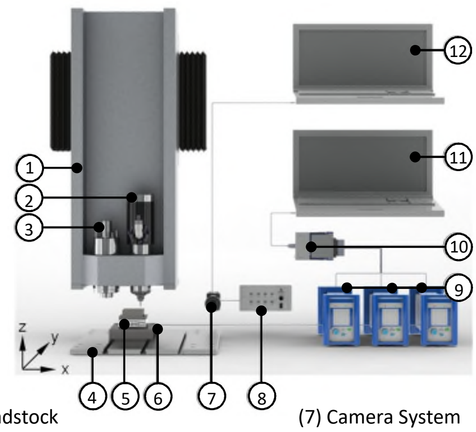
Micro-milling is a key technology for manufacturing of complex micro-featured parts with a high versatility regarding machinable materials and workpiece structures. At state of the art micro-milling tools made of cemented carbide are widely used in industry. Nevertheless, these micro-milling tools suffer from fast and random tool breakage while cutting. These phenomena lead to insufficient surface roughness and geometrical inaccuracy. Different research activities were carried out to reduce tool wear of micro-milling tools made of cemented carbide. Therefore, the micro-milling tools are coated by physical vapour deposition (PVD) or chemical vapour deposition (CVD) processes with various hard layers.

The most promising approach is the cutting edge preparation. For cutting edge preparation of micro-milling tools different technologies are known. UHLMANN ET AL. [1, 2] successfully applied immersed tumbling for cutting edge preparation of micro-milling tools. In comparative cutting tests with common micro-milling tools and micro-milling tools with cutting edge preparation the maximum width of flank wear land VB_{max} could be reduced by 14 %. Nevertheless, there is a strong demand from industry for micro-milling tools with improved wear resistance.

To reduce the wear of micro-milling tools new cutting materials have to be established. Grinding of superhard cutting materials like polycrystalline diamond leads to insufficient results. Therefore, new technologies for manufacturing of these micro-milling tools with wear resistant cutting materials were developed. In previously 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 [3].

2. Experimental setup

Manufactured bdCVD diamond micro-milling tools were applied for machining titanium grade 2. Fundamental cutting experiments were carried out to analyse the developed tools during cutting. For the cutting tests the High-Precision machine tool Wissner Gamma 303 HP from WISSNER GESELLSCHAFT FÜR MASCHINENBAU MBH, GÖTTINGEN, Germany, with ball bearing guideways was used and is shown in figure 1.



(1) Headstock
(2) Spindle No. 1
(3) Spindle No. 2
(4) Machine Table
(5) 3-Component Dynamometer
(6) Interface
(7) Camera System
(8) Light Control
(9) Charge Amplifier
(10) A/D-Converter
(11) Force Measurement PC
(12) Wear Measurement PC

Figure 1. Experimental setup for the cutting tests

The bdCVD diamond micro-milling tools had a radius r = 1.5 mm, a rake angle $\gamma = 0\,°$, a number of teeth $n_t = 1$, and a cutting edge radius $r_\beta = 4.6$ µm.
For the cutting tests the spindle speed was varied in the range $5{,}000\ 1/\text{min} \leq n \leq 40{,}000\ 1/\text{min}$, the feed per tooth $5\ \mu m \leq f_t \leq 35\ \mu m$ and for the depth of cut $a_p = 50$ µm and $a_p = 100$ µm were investigated. A piezoelectric dynamometer

MiniDyn 9256C2 from the company Kistler Instrumente AG, Winterthur, Switzerland, was used for cutting force acquisition.

3. Cutting tests

Comprehensive cutting tests were carried out to analyse the influence of spindle speed n and feed per tooth f_t on the surface roughness Ra for cutting titanium grade 2 with manufactured bdCVD diamond micro-milling tools. The findings of this investigation are shown in figure 2. The surface roughness Ra was measured with a tactile contour and roughness measurement device HOMMEL-ETAMIC Nanoscan 855 from the company JENOPTIK AG, Jena, Germany. For the feed per tooth in the range of $5\ \mu m \leq f_t \leq 35\ \mu m$ an increasing surface roughness Ra could be observed, with the exception of a spindle speed n = 10,000 1/min. The lowest surface roughness Ra = 27 nm could be achieved with a spindle speed n = 5,000 1/min, a feed per tooth $f_t = 5\ \mu m$, and a depth of cut $a_p = 50\ \mu m$. Therefore, an optimal ratio of the feed per tooth to the cutting edge radius $f_t/r_\beta \approx 1$ was identified. During the experiments process forces in the range of $2.52\ N \leq F_{Pr} \leq 21.17\ N$ could be detected.

In additional experiments the wear behaviour of the new micro-milling tools as well as the surface roughness Ra along the path length l_c were investigated. After a path length $l_c = 10$ m a maximum width of flank wear land $VB_{max} = 29\ \mu m$ and a surface roughness Ra = 0.025 µm were measured.

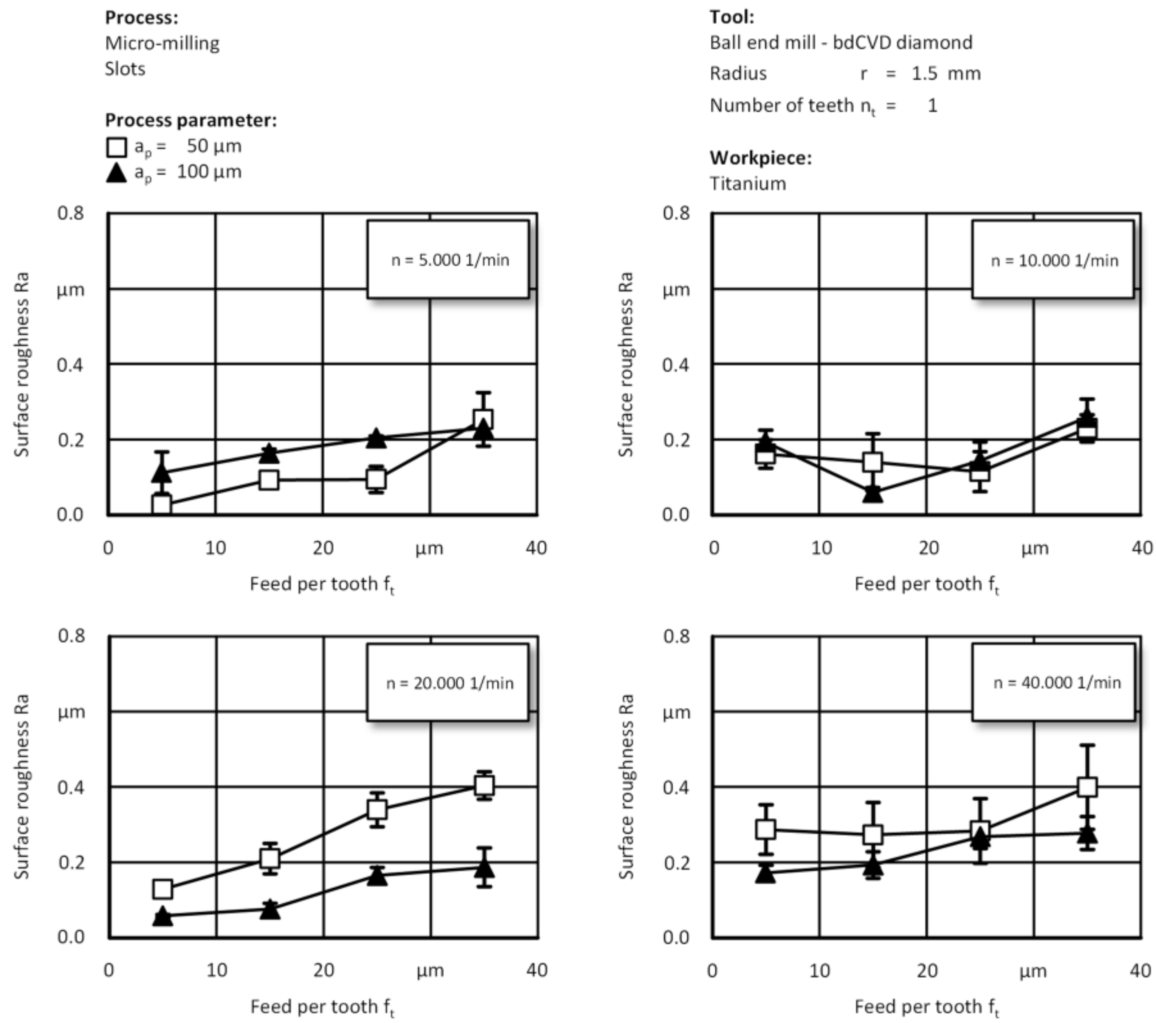


Figure 2. Cutting results concerning surface roughness Ra

4. Conclusion and Outlook

As a result of this work the successful application of the developed bdCVD diamond micro-milling tools for machining titanium grade 2 could be shown. After a path length $l_c = 10$ m a surface roughness Ra = 0.025 µm could be achieved. In further research activities the machining of other hard to machine materials like cobalt-chromium-alloys and zirconium oxide for dental parts will be addressed. This work was funded by the FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY (BMWI).

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