Micro Pencil Grinding Tools: Manufacturing, Application, and Results

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Abstract

In this paper the manufacturing process of micro pencil grinding tools, the application of these tools and the results of machining tests are presented. The tools are manufactured on a desktop sized machine tool. The manufacturing process includes the structuring process, the tool optimization by micro-EDM, and the electroplating process for embedding CBN or diamond grains. The achievable tool dimensions and tool characteristics are shown. The manufactured micro pencil grinding tools are tested on different materials like tungsten carbide, hardened steel and quartz by using a high precision 3-axis machine tool. Furthermore, the limits of these micro pencil grinding tools are analyzed by varying the process parameters infeed and feed speed. The results of these tests are presented and discussed.

1.Introduction

To miniaturize products and their involved micro technical components in brittle materials like tungsten carbide, ceramics and hardened steel, micro pencil grinding tools (MPGT) are applied [1]. To implement such complex 3-dimensional microstructures like micro fluidic devices, microreactors, micro embossing tools and components for measurement techniques tools with different characteristics have to be produced, tested and analyzed.

2. Tool Manufacturing

A desktop-sized machine tool was developed to manufacture and optimize MPGT with different grains and grain sizes [4]. In this machine tool the complete manufacturing process is included in one setup. This allows an automated tool manufacturing, including the tool grinding process, the tool optimization by micro-EDM and the tool coating in only 15-20 min. To structure the tool, a fine grained (grain size 0.2 µm and bending strength of 4000 N/mm^2) tungsten carbide (WC) blank is clamped in a micro high speed air bearing spindle with max. rotation speed of 7.5 kHz. By using a second rotating air bearing spindle (2 kHz) with segmented grinding wheels a cylindrical micro pin is directly ground on the rotating WC shank. The grinding wheels have different grain sizes for pre- and fine-grinding. Follow the grinding process the tool blank can be machined optionally in the µEDM device. Therefore, the micro tool blank is positioned automatically over the µEDM electrode in a dielectric reservoir. To implement the machining of MPGTs with diameters down to 20 µm by µEDM, µEDM-electrodes of a very high precision required [2]. With the described tool grinding process it is possible to produce WC electrodes with diameters down to 10 µm at a length of 200 µm. In the dielectric reservoir the electrode´s tip has to be at the centre of the cylindrical tool tip at a distance of 8-10 µm. After alignment of the tool to the electrode, the pulse generator is started. The Z-axis is moved towards the electrode with a feed of 1.5 µm/sec. After the detection of the first discharge the WC blank is moved down automatically with a feed of 0.8 µm/sec and the material on the centre of the tool face is removed. During the EDM process, the tungsten carbide shaft is propelled through the spindle air turbine. The rotation leads to exceptionally centred holes [3]. After ultrasonic cleaning, the micro tool tip is electroplated with nickel-embedded diamond or CBN grains in the coating module. Results of this coating process are a homogeneous layer with grains embedded in nickel with a very high quality of reproducibility and a comparably large chip space [4]. The desktop sized machine tool and the described automated manufacturing process allow for the production of MPGT with diameters down to 4 µm (Figure 2), EDM-optimized tools with 20 µm diameter coated with nickel-embedded diamond or CBN grains with different grain sizes.

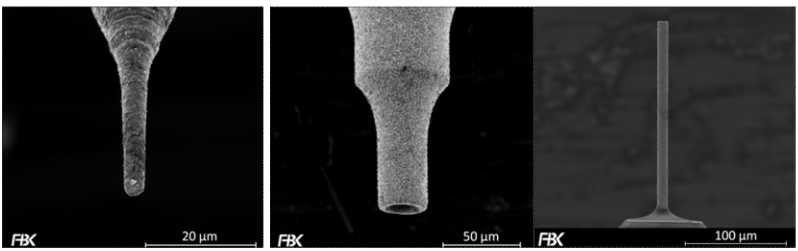

Figure 2: MPGT with 4 µm diameter and nickel-embedded CBN-grains (left); µEDM-optimized MPGT (diameter 30µm) (middle) and µEDM-electrode (diameter 10µm by length of approximately 200µm) (right) [3]

3. Application and Results

The manufacturing of micro devices and microstructures, like embossing tools to emboss glass, demands a very high structure accuracy and surface quality. To achieve this reason MPGT with embedded diamonds were tested. Therefore, grooves were ground with different process parameters in WC. These structures were analyzed with respect to groove flatness, surface roughness and grinding performance. The results demonstrate the need further tool optimization. Better results in regard to the surface flatness of the groove were obtained using MPGT, optimized by µEDM (Figure 3). The measure of surface roughness for the cylindrical MPGT is 5.5 nm and for the optimized MPGT Ra is 6.9 nm. However, it has to be mentioned that these values are lower than the minimum measurable surface roughness of 100 nm recommended by the manufacturer. Therefore, they can only be regarded as an approximate indicator of the real roughness value.

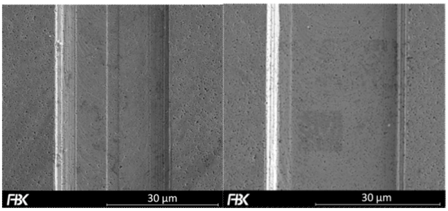

Figure 3: grooves in WC machined using a MPGT (left) and a optimized MPGT (right)

The application of MPGT with embedded CBN grains allows the micro structuring of carbon steels. Grinding tests with MPGT (30 µm diameter, CBN grain size 1-3 µm) in hardened steel AISI 4140H (42CrMo4 (60HRC)) with different process parameters were carried out and analyzed. The rotation speed of the grinding spindle for all grinding test was 1 kHz. In addition to the analysis of grinding performance, surface roughness and flatness, the dependence of burr formation and burr size on feed speed (Figure 4) and infeed was demonstrated.

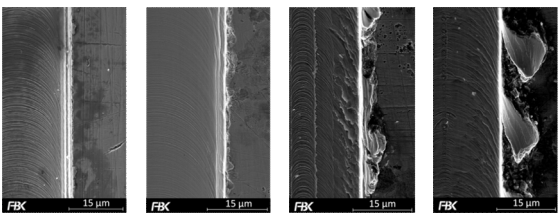

Figure 4: burrs of grinding grooves (3 µm deep) in AISI 4140H (42CrMo4 (60HRC)) with different feed speed; feed speed from left to right: 0.1, 0.3, 0.6 and 0.9 mm/min

The limit of CBN MPGT (tool breakage) in regard to feed speed was assessed at 0.9 mm/min at 0.3 µm infeed. In regard to infeed it was possible to machine 12 µm deep grooves at a feed speed of 0.1 mm/min.

The grinding performance and influence on tool wear of the manufacturing process were analyzed by manufacturing of a high-frequency micromechanical columnar quartz resonator for mass detection. The manufacturing strategy and process parameters were optimized in regard to the best manufacturing results. For example, high tool wear involved breaking out parts of the grinding layer and finally tool breakage (shown in Figure 5). It was possible to produce a prototype with column dimensions of 18x36x62 µm with an adapted manufacturing strategy and optimized process parameters.

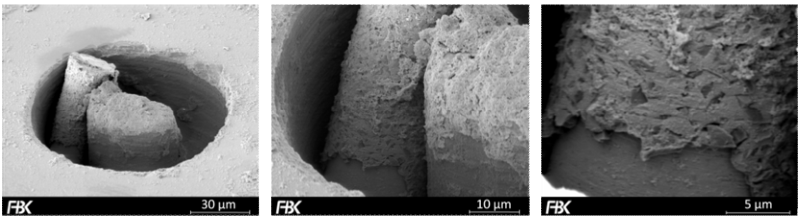

Figure 5: microstructure in quartz with broken MPGT (30µm diameter) (left, middle), broken out grinding layer and worn diamond grains (right)

4. Conclusion

In this study tools with diameters down to 4 µm were coated with nickel embedded diamond or CBN. The limits of CBN micro pencil grinding tools (30 µm diameter) in regard to feed speed were assessed at 0.9 mm/min at 0.3 µm infeed. In regard to infeed it was possible to machine 12 µm deep grooves at a feed speed of 0.1 mm/min. Tools down to 20 µm diameter were optimized by µEDM. Better results in regard to the surface flatness of the groove were obtained.

Acknowledgement

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