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Experimental investigations of modified base body geometries of micro pencil grinding tools applied in 16MnCr5

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Abstract
The application of micro grinding pencil tools (MPGT) provides a suitable method for micro structuring technical surfaces in hard and brittle materials. In order to enable further optimization of the ground structures, the base body geometry of MPGT could be modified. This could possibly have a positive effect on the metalworking fluid supply or the quality of the structures.
In this paper, the effect of different base body geometries of electroless plated MPGT with a cBN grit size of 5-10 µm on the surface quality of machined groove walls, the tool wear, and the burr formation is investigated experimentally. As workpiece material, 16MnCr5 (AISI 5115) hardened at 660 HV30 was used. MPGT geometries with circular cross sections are compared against MPGT geometries with triangular, square, and D-shaped cross sections.
The results show that the burr formation is not influenced by the cross-sectional geometry of the base body of the tool. In contrast, the surface quality of the machined groove walls varies widely as well as the tool wear. It can be concluded that the application of MPGT with non-circular cross-sections does not influence the quality of the micro structured surface in the workpiece material 16MnCr5 for the proposed base body geometries. The effect on other workpiece materials is the subject of future investigations.

Grinding, micromachining, microstructure, wear

1. Introduction

Micro grinding with micro pencil grinding tools (MPGT) enables the manufacturing of complex surface structures in hard and brittle materials [1] as well as in hardened steel [2]. The abrasive layer of MPGT can be produced using electroplating [3], sintering [4] and chemical vapor deposition (CVD) [5]. A fourth option that was recently introduced by Park et al. is an electroless plating process, that functions as an alternative to traditional electroplating processes [6]. The process is autocatalytic – meaning that the substrate functions as the catalyst that initiates the chemical reaction. During the process, a nickel-phosphorous layer is formed on the substrate surface at a constant growth rate. Superabrasives, i.e. cBN or diamond, come in contact with the substrate and are embedded in the layer, making it a dispersion layer [7]. This dispersion layer has a high contour accuracy, and is especially resistant to abrasive wear [8] as well as corrosion [9].

One approach to increase the tool life is to optimize the application of metalworking fluids (MWF). Another promising possibility is the modification of the base body. By grinding noncylindrical base bodies, the active outer tool diameter is interrupted offering cutout volumes for a better transport of metalworking fluid to lubricate and cool the contact zone. It could be shown that such tools can be manufactured with high contour accuracy [10].

In this paper, the tool manufacturing process and four different tool geometries are presented. The experimental setup and the process parameters are described. Finally, the results are discussed and concluded.

2. Tool manufacturing process

For the experiments, MPGT with full cylindrical, D-shape, triangular, and square base body geometries were manufactured (Figure 1). These are precisely reproducible geometries, which is considered advantageous for experimental evaluation. A tool blank made of high speed steel was fitted with a cone via a conventional grinding process to reduce the amount of material which has to be removed via the subsequent precision grinding of the base body. This is conducted on a high precision circular grinding machine equipped with dicing blades as grinding wheels.

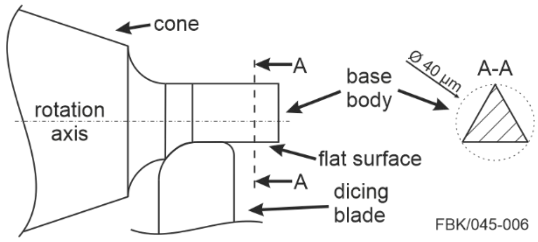

Figure 1. base body grinding (exemplary triangular base body)

In the first step a cylinder was ground, which is the standard cylindrical base body. Afterwards a certain number of flat surfaces was ground on the flanks, depending on which geometrical shape was to be manufactured. As shown in Figure 1 the circle of the inscribed triangle has a diameter of 40 µm. This represents the nominal diameter of the base body and was held constant for all geometries examined. In the next step an abrasive layer was provided by an electroless plating process with a nickel-phosphorous-dispersion-layer. The size of the cBN grits was 5-10 µm [7]. The active tool diameter was kept constant at 50 µm to ensure the comparability between the different tool types. Due to the modified base body

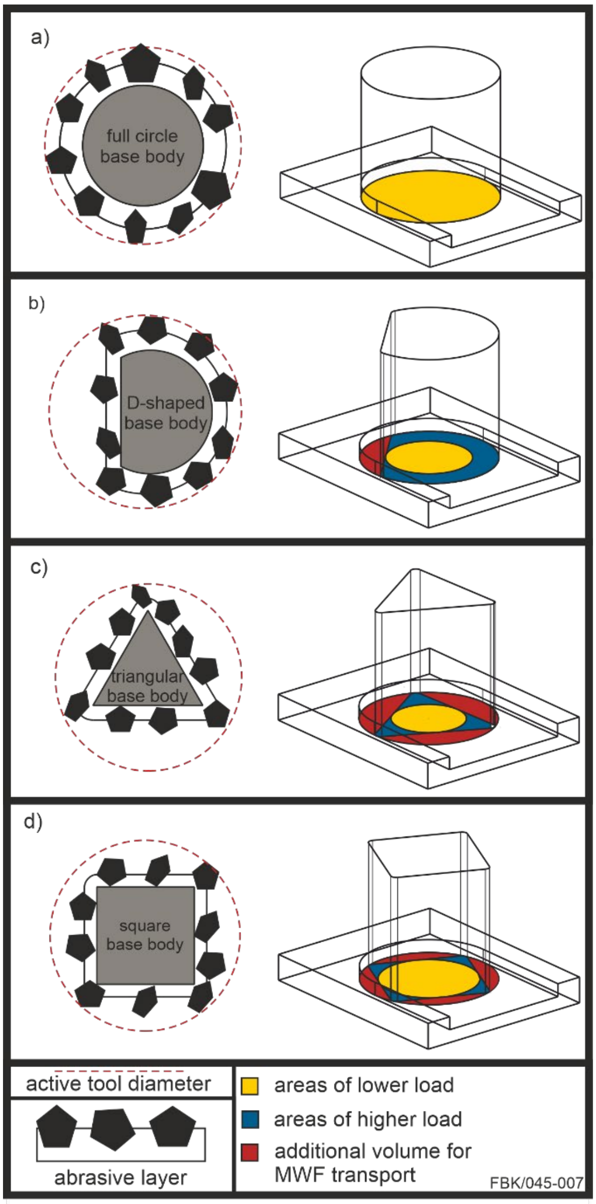

Figure 2. MPGT geometries: a) full cylindre, b) D-shape, c) triangular and d) square base body with classification of the load areas in the contact zone due to the geometry

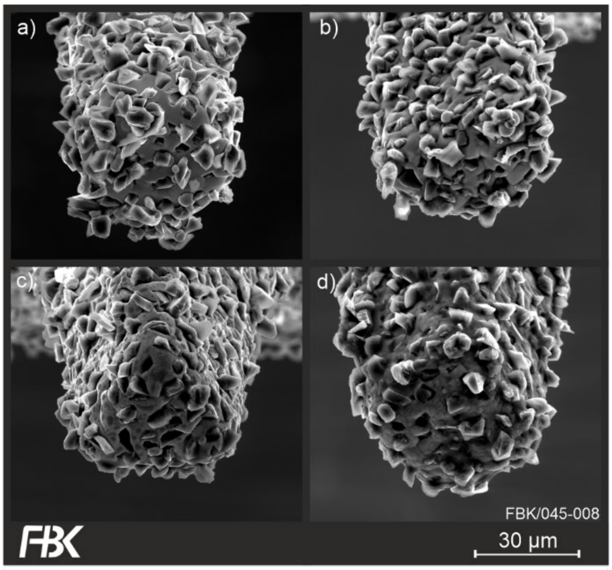

Figure 3. SEM images of plated MPGT with a) cylindrical, b) D-shape, c) triangular, and d) square base body

geometries the tool/workpiece contact at the front face and the circumference can be divided in areas of higher and lower loads for the abrasive layer; further, potential areas for the MWF transport are indicated (Figure 2). Figure 3 shows SEM images of MPGT with modified base body geometries ready for the application.

3. Experimental setup

The grinding experiments were carried out on the ultra precision machine tool Nano Grinding Center (NGC) [11]. The machine tool properties and the process parameters are given in Figure 4. For the experiments, the rotational speed was set at 150,000 min^{-1} and the feed rate was set at 50 mm/min while the depth of cut is 0.5 µm. To reach a nominal channel depth of 10 µm, pendulum micro grinding was applied [2] resulting in a total of 20 tool passes. The tool path starts at the edge of the workpiece and reverses parallel after 5 mm of travel forming a U-shape with a total length of 10 mm. Twinmax, a commercial product by the Steidle GmbH[1], was used as MWF in a submerged cutting system. The submerged cutting system consists of a pool in which the machining of the workpiece takes place below the fluid level of the MWF [2].

The grinding experiments were carried out on 16MnCr5 (AISI 5115) hardened at 660 HV30. The workpiece dimensions were 20 mm x 10 mm x 5 mm and the surface was polished to ensure a precise determination of the initial tool/workpiece contact by optical observation via a video microscope. In addition, the polishing enables a better evaluation of the micro grinding results, as the ground microstructures are clearly distinguishable from the unmachined surface even if they are just a few micro meters deep. To realize a constant depth of cut, the workpiece surface was aligned to a plane-parallelism of <0.5 µm to the cross-table axes.

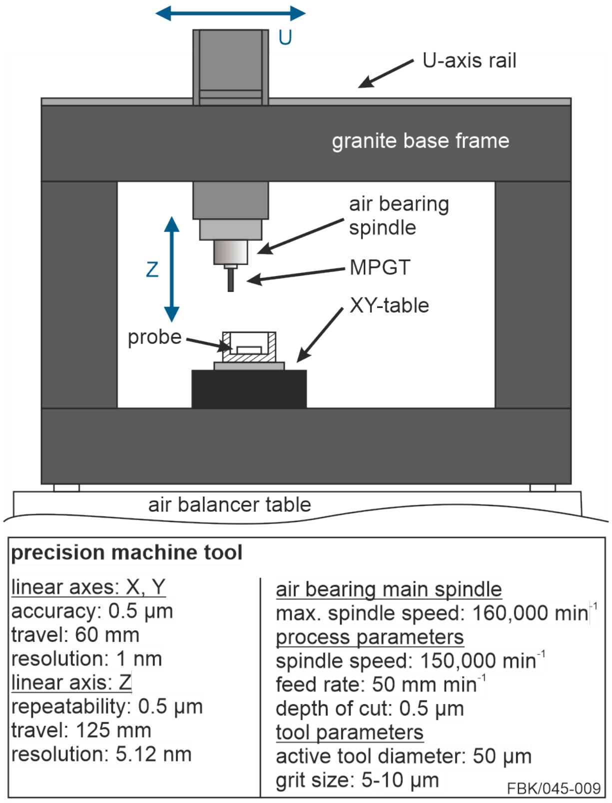

Figure 4. experimental setup and process parameters [11]

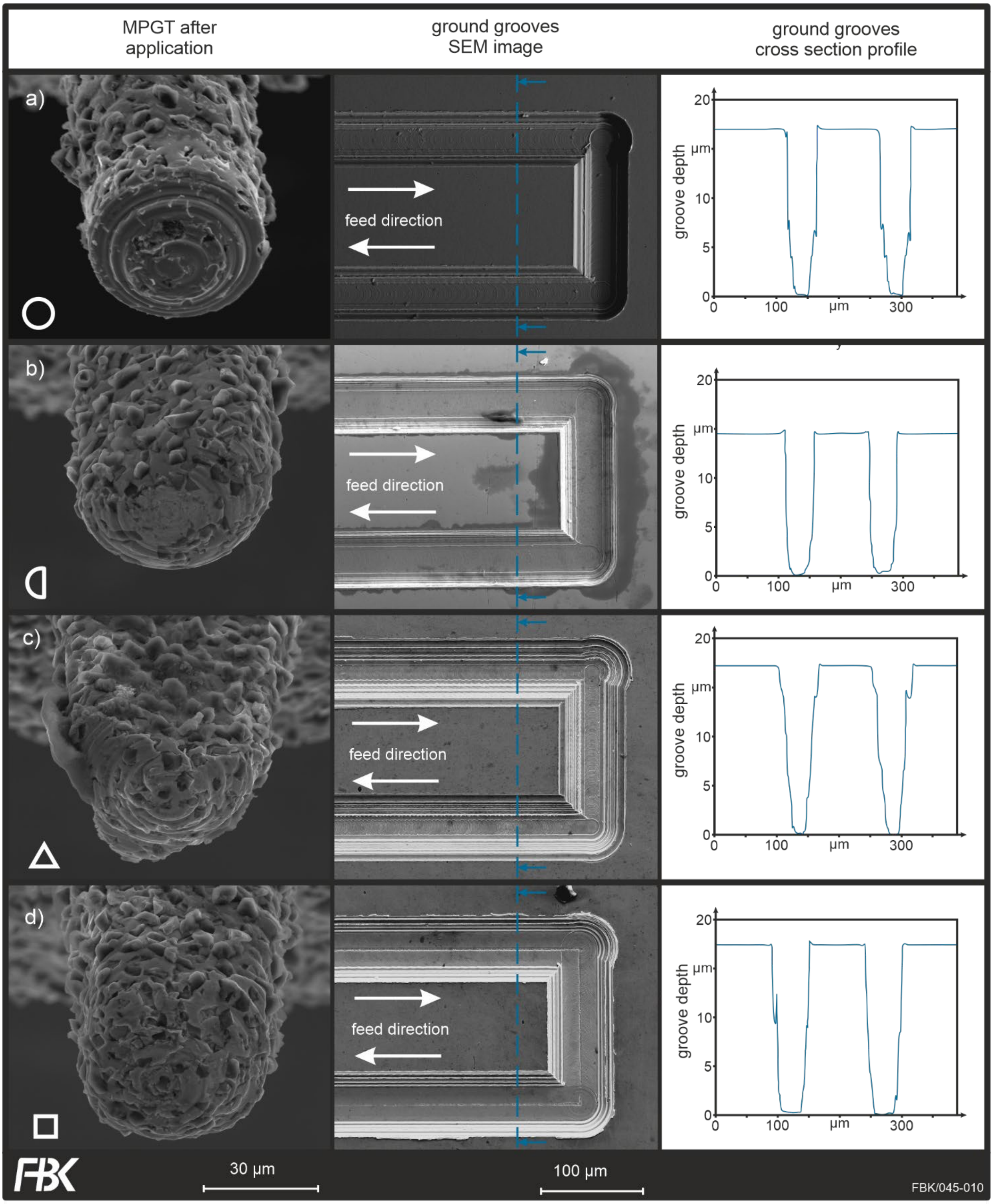

Figure 5. evaluation of MPGT and ground grooves: a) full circle, b) D-shape, c) triangular and d) square base body

The tools and the machined grooves were evaluated by means of scanning electron microscope (SEM) images. A confocal microscope NanoFocus µsurf explorer with a 20x objective (NA 0.4) was used for the measurements of the height profiles to characterise the groove walls. This allows measurements to be performed with a resolution of 6 nm in the vertical direction and 1.6 µm in the lateral direction. All experiments were executed three times per tool geometry and the results are presented with a representative example.

4. Experimental results

Figure 5 shows the different MPGT types after their application, a top view of the ground structure as SEM image, and a cross section profile measured with the confocal microscop. The cylindrical MPGT exhibits concentrical wear marks at the face, especially at the edges. The ground structure has a trapezoidical cross section shape resulting from the step-like transition from the workpiece surface to the groove bottom. Due to their size, the individual steps of the groove wall, that are visible in the SEM-images, cannot be differentiated with a confocal microscope, since their width is smaller than 1 µm. On the other hand, measurable steps can lead to measurement errors. These show up as overshoots, so-called batwings [12].

The D-shape MPGT in figure 5 b) shows comparable wear as the cylindrical tool (figure 5 a)), while the concentrical wear marks are interrupted at the cutout. The wear is more pronounced on the outer diameters than in the area of the axis of rotation, which also leads to a pronounced step structure in the area of the groove wall and a trapezoidal cross section profile, visible in the corresponding SEM image and the cross section profile.

The triangular tool (figure 5c)) shows excessive wear at the corners of the triangle. A cone shell surface is formed while the center of rotation represents the highest point. As it can be seen in figure 5 c), the tool corners are highly rounded and the wear marks are interruped at every cutout. A comparison with the corresponding cross section profile of the ground structure shows that this wear affects the profile's appearance directly. This trapezoidal cross section has the highest difference between the groove bottom width and the nominal groove width. The application of the triangular MPGT lead to a low contour accuracy of the ground structure. The high corner wear of the MPGT with triangular base body is attributed to the increased surface pressures and the reduced abrasive layer.

Figure 5 d) shows the MPGT with square base body after its application. The wear at the corners is lower compared to the MPGT with triangular base body and is therefore at a similar level to the round and D-shape tool types. The interruption of the wear marks at the cutout is less pronounced.

This is attributed to the fact that the modified base body geometry results in a reduction of active abrasive grits in the grinding process.The transport of MWF does not seem to have been improved or it cannot compensate this disadvantage.The Tool wear always leads in the direction of a cylindrical tool. No significant influence of the tool shape on the burr formation can be determined.

5. Conclusion and outlook

In this study the influence of different base body geometries of MPGT on their wear behaviour and the ground grooves was investigated. For this purpose, electroless plated MPGT with different base body geometries were manufactured and applied in 16MnCr5. SEM images and cross-sectional profiles taken with a confocal microscope were used to evaluate the results.

In general, the main wear of a tool occurs at its outer circumference. The MPGT with full cylindrical and D-shaped body are rounded along their arched circumference (full for cylindrical, partial for D-shape). For the MPGTs with triangular and square bodies, the corners wear most.

The MPGT with modified body geometry partly show significantly increased wear, which has a direct effect on the contour accuracy of the ground grooves. A further disadvantage of the MPGT with modified base body geometry is the increased manufacturing effort, since all cut-outs on the base body have to be ground individually and the waste is larger after the electroless plating process.

By providing the MPGT with cutouts, a part of the active grinding layer is removed. This disadvantage could not be compensated by the additional MWF transport for the proposed geometries. Furthermore, no influence of the base body geometry on the burr can be determined.

Further investigations with MPGT with modified base body geometry will be conducted on workpiece materials such as quartz glass or silicon. These allow a higher depth of cut. This would increase the surface area of the abrasive layer on the circumference of all tools which is in contact with the workpiece. This could promise a more efficient application of the tool due to the fact that the circumference is more involved in the grinding process. Also, the MWF application for cylindrical MPGT becomes more difficult at higher depths of cut, which could be compensated by the additional room for MWF in the cutouts.

Acknowledgments

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[1] "Naming of specific manufacturers is done solely for the sake of completeness and does not necessarily imply an endorsement of the named companies nor that the products are necessarily the best for the purpose."

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