Tool-Development for Diamond Micro Chiseling

L. Schönemann, E. Brinksmeier, C. Flucke, R. Gläbe
LFM – Laboratory for Precision Machining, University of Bremen, Germany

schoenemann@lfm.uni-bremen.de

Abstract

This publication is focused on the tool-development for the recently introduced Diamond Micro Chiseling (DMC) process [1]. This process allows the generation of prismatic microstructures at a size between 50 µm and 500 µm, which cannot be manufactured by conventional processes like turning, milling or planning [2]. Prismatic geometries are achieved by using specifically designed V-shaped diamond tools, a special tool kinematics and an ultraprecise 5-axis machine tool.

Representative examples of these structures are corner-cube retroreflectors in the abovementioned size. The diamond tool geometry thus represents a significant factor for the feasibility of the process and the obtainable quality of the microstructures. In the design process of the tool's geometry various technical and economical factors have to be taken into account and weighted against contradicting requirements.

1 Introduction

The basic concept of the Diamond Micro Chiseling (DMC) process is to generate concave prismatic microstructures by cutting multiple facets using a V-shaped diamond tool. In contrast to a turning process, the DMC tools are rotated by 90° along the shaft-axis resulting in a configuration where the rake and clearance face are switched (cf. Fig. 1).

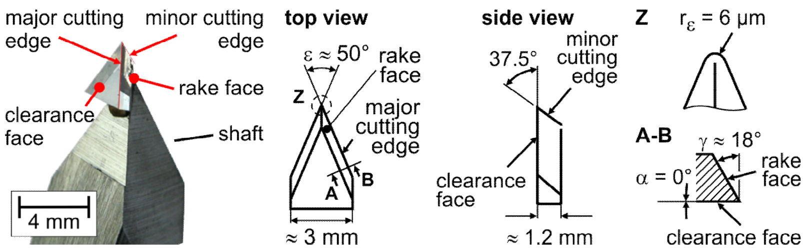

Fig. 1: Standard tool geometry for Diamond Micro Chiseling

The initial tool design featured an included angle of $\varepsilon = 50°$, a rake angle of $\gamma = 18°$ and a clearance angle of $\alpha = 0°$, allowing the machining of pyramidal cavities with up to seven facets. The nose of the tool can either be sharp or rounded. Tools with large corner radii ($r_\varepsilon > 6\ \mu m$) can be used in combination with a large undeformed chip thickness which is necessary for reducing process times. Finer tools with radii below $r_\varepsilon = 6\ \mu m$ are used for finish cuts with a low undeformed chip thickness.
The tools initially designed for the DMC process featured a comparably small natural diamond with a sharp cutting edge. The shaft of the tool was design with a length of *30 mm* for obtaining a high stiffness.

2 Novel Tool Design

The conventional tool design was used in several cutting experiments, which revealed several disadvantages of the design: The sharp cutting edge proved to be susceptible to chipping or even tool failure when applying large undeformed chip thicknesses. In some cases, the diamond was even completely detached from the shaft. Additionally the length of the shaft acted as a limiting factor in the achievable geometry spectrum. Due to these disadvantages, the tool design had to be completely reworked. In recent designs, larger synthetic diamonds with a rounded cutting edge ($r_\beta = 100\text{-}200\ nm$) were introduced (Fig. 2).

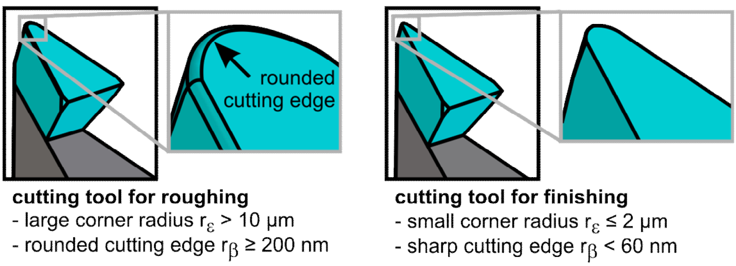

Fig. 2: Cutting edge geometry of DMC tools

Additionally, the length of the shaft was increased to *40 mm* in order to increase the achievable geometry spectrum (Fig. 3, right). The clearance face is tilted along the major cutting edge resulting in an intrinsic clearance angle of $\alpha = 2°$ and thus preventing friction between the tool and the workpiece (Fig. 3, left). These novel tools are expected to offer improved stability and wear resistance.

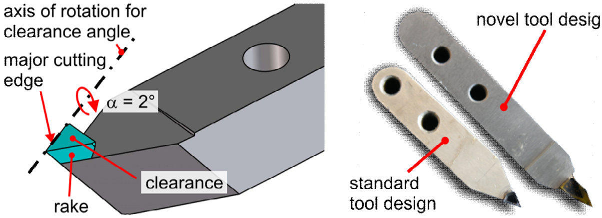

Fig. 3: Cutting edge geometry of DMC tools

3 Machining experiments

For the evaluation of the different tool designs, cutting experiments were conducted using two different substrate materials: oxygen free high conductivity copper (OFHC-Cu) and nickel silver $CuNi_7Zn_{39}Pb_3Mn_2$ (N31). Each material was machined with different process parameters using tools with sharp and rounded cutting edges:

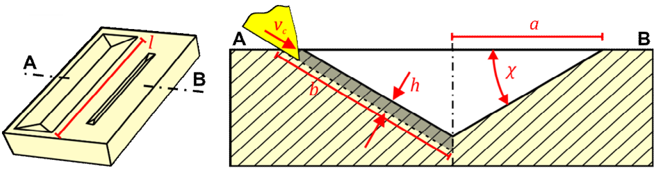

Fig. 4: Parameters for the evaluation of different DMC tools

For each parameter, five V-grooves with a facet-width of $a = 43.3\ \mu m$, a length $l = 2\ mm$ and a slope angle of $\chi = 30°$ were cut and evaluated on both flanks using a Tencor P 15 profilometer. Among the varied parameters are the cutting speed v_c, the undeformed chip thickness h and the width of undeformed chip b (cf. Fig. 4).

The results for the variation of undeformed chip thickness are shown in Fig. 5 and compared to the results acquired with the preceding tool generation.

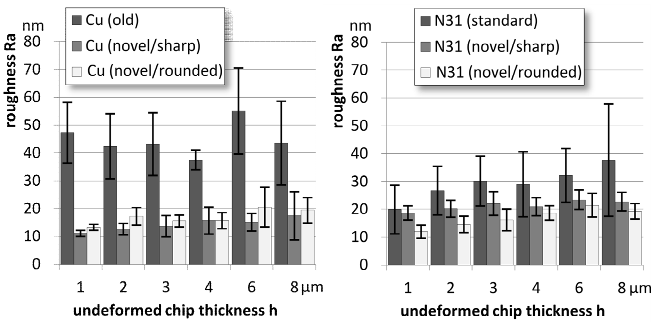

Fig. 5: Surface roughness against undeformed chip thickness
(v_c = 45 mm/min, b =50 µm)

It can be seen, that the novel tool design with a larger synthetic diamond provides superior surface roughness, regardless of the chosen undeformed chip thickness. On OFHC-copper, slightly better results can be achieved with the sharp-edged diamond tools while for nickel silver the tools with a rounded cutting edge generate a lower surface roughness.

A similar improvement of surface quality using the novel tool design can be observed for the variation of cutting speed (Fig. 6). However, the difference between rounded and sharp cutting edge is not as discernible.

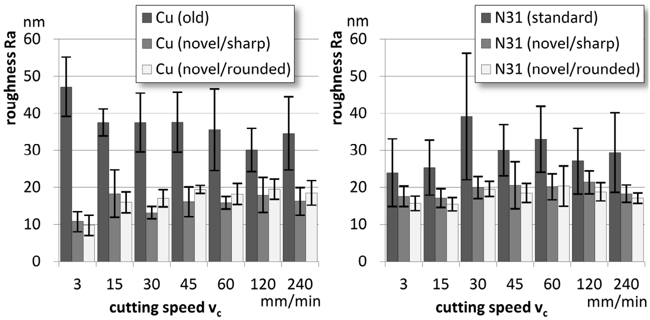

Fig. 6: Surface roughness against cutting speed *(h = 4 µm, b =50 µm)*

4 Conclusion

It was shown that an enhanced tool design considerably improves the surface quality of the structures generated by Diamond Micro Chiseling. By changing the cutting edge geometry and at the same time increasing the size of the diamond, the overall stability of the tool was improved, although the length of the shaft was increased. No chipping or tool failure was observed in the machining experiments. Depending on the type of substrate material, a rounded cutting edge can provide a slightly lower surface roughness as well. In future experiments, the wear behavior of these tools will be in the focus of the investigations.

Acknowledgement

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References:

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[2] Davies, M. A.; Evans, C. J.; Patterson, S. R.; Vohra, R.; Bergner, B. C.: Application of precision diamond machining to the manufacture of micro-photonics components. Proc. of SPIE, Vol. 5183, 2003: pp. 94-108