Cutting edge preparation of PCBN inserts

DENKENA B. 1,a, KOHLER J. 1,b and VENTURA C. E. H. 1,c

1Institute of Production Engineering and Machine Tools – Leibniz Universität Hannover
An der Universität 2 – 30823 Garbsen, Germany

denkena@ifw.uni-hannover.de, koehler@ifw.uni-hannover.de, ventura@ifw-uni-hannover.de

Keywords: PCBN, grinding, cutting edge preparation.

Abstract. In order to increase tool life and workpiece surface quality, cutting processes with geometrically defined cutting edges demand inserts with a targeted prepared edge. For example, chamfers are largely used in many processes to provide edge strengthening without damaging the chip flow. In order to achieve a stable and reliable cutting process, small and uniform chamfers are necessary. In this context, the influence of grinding parameters on the edge quality and on the chamfer width deviations is investigated. It was found that larger abrasive grains increase edge chipping and that elastic deformation during chamfer grinding at insert corner radius is the main responsible for chamfer width deviation.

Introduction

Usually sharp edges are not applied in cutting processes, since they lead to low tool life. Therefore, different kinds of edge micro geometries are prepared by tool manufacturers, like chamfers, roundings, chamfers with roundings and asymmetric roundings [1]. Chamfers are often manufactured in PCBN and ceramic inserts, while roundings are prepared in PCD and cemented carbide tools [2]. Commercial inserts have chamfer angles in the range of 10-35° and chamfer widths varying from 100 to 200 μm. Roundings use to be symmetric and range from 30 to 125 μm.

By machining of hardened steels chamfers are commonly applied, aiming to optimize chip formation and to increase tool life [3]. In this process the edge micro geometry plays an important role, since the cut occurs at the tool tip because of the small depths of cut and feeds used [4]. Zhou et al. [5] demonstrate that the use of chamfered PCBN tools in dry hard turning causes higher cutting forces, but lower flank wear than tools with positive or zero rake angles. Additionally, high temperatures contribute to the plastic softening of the workpiece material [6]. Moreover, during cutting, workpiece material is compressed over the chamfered tool and acts like an edge, increasing the edge strength and reducing tool wear [7].

In hard turning of 42CrMoS4 steel with PCBN cutting tools, Kress [8] notes that a minimum chamfer angle of 20° must be applied in order to achieve higher tool lives. Such an angle reinforces the cutting wedge and helps avoiding edge chipping at the beginning of the cutting process. A further increase of the chamfer angle brings no advantage, since the crater formation is favored and the cutting forces increase [8]. Therefore, the choice of the chamfer parameters plays an important role in the process design. Furthermore, the preparation process must also be considered. Differences of the target edge geometry to the produced one affect cutting forces [9] and, consequently, tool life as well. As a result, a regular micro geometry of the cutting edge is important to achieve a reliable and reproducible process.
Manufacturing process of chamfers in cutting inserts. Chamfers in cutting inserts are produced by plunge-face grinding. This process offers a proper kinematics and enables the manufacturing of the insert flank faces, corner radii and edge in only one clamping. After sintering, the insert flank and rake faces must be ground to improve surface quality. Face grinding (Fig. 1a) is used to prepare the rake faces, while plunge-face grinding (Fig. 1b) is often used to grind flank faces. The sharp edges of the insert are formed from the intersection of these both surfaces and its quality depends on the grinding process design. The level of edge chipping will determine the minimum possible size of the micro geometry (Fig. 1c).

![Fig. 1 Minimum micro geometry in relation to obtained edge chipping [10, 11]](image)

It is known that in hard turning an adequate edge preparation with chamfer or rounding avoids tool failure and consequently increases tool life [1]. However, large micro geometries contribute to higher cutting forces and temperatures [12]. In this way, small chamfers have the potential to reinforce the edge without injuring the process. Therefore a proper process design to reduce edge chipping is of great importance. Cutting insert materials are brittle and their grinding is dominated by the formation of micro-cracks and the resultant breaking out of fragments [13]. As a consequence high edge chipping values result. Friemuth [10] affirms that the improvement of edge quality can be achieved with reduced abrasive grain sizes. Small grain sizes lead to a significant increase of active cutting edges, decrease of the single grain chip thickness and accordingly, to the decrease of the load in each grain.

Considering the growing importance of PCBN cutting inserts and the lack of knowledge about their manufacturing methods, the edge preparation of this cutting material will be treated in this study. Taking into account the challenge of achieving high edge qualities in PCBN cutting inserts due to their high brittleness, the influence of the abrasive grain size on the insert edge quality will be investigated. Furthermore, aiming to reach uniform chamfer geometries at the insert corner radius, the influence of the insert rotational speed on the chamfer geometry deviation during chamfer grinding will also be analyzed.

**Material and Methods**
Experimental tests are carried out in a five-axes grinding machine Wendt WAC 715 Centro. This machine allows a maximum rotational speed of 1,625 min\(^{-1}\) and a maximum power of 3 kW. Two of the axes are linked with the grinding wheel: the X axis is responsible for the axial feed movement and the W axis enables the oscillation of the wheel and a complete utilization of the grinding layer. The remaining three axes move the insert: The A axis determines the grinding direction in relation to the grinding wheel; the B axis allows an inclination of the insert, in order to grind chamfers; and the C axis rotates the insert, enabling the grinding of the entire insert and corner radii. Additionally the L axis is responsible for the feed movement of the dressing roll. The grinding machine and a schema of the grinding region are showed in Fig. 2.

![Fig. 2 Five-axes grinding machine WAC 715 Centro](image)

Vitrified grinding wheels with different diamond grain sizes are tested: D10, D15, D36 and D46. An additional grinding wheel with grain size D36 and resinoid bonding is also applied. All grinding wheels have the concentration C120. Grinding wheels with different grain sizes must be dressed with dressing rolls of different grain sizes in order to provide wheel flatness, sharpness and to avoid high wear rates of wheel and roll. In this way, the variation of the wheel grain size implies at the same time a variation of the dressing roll grain size. All dressing rolls are made of Al\(_2\)O\(_3\). The combinations “grinding wheel grain size – dressing roll grain size” follow the recommendation of the grinding wheel manufacturer and are: D10 – 320 Mesh, D15 – 320 Mesh, D36 – 220 Mesh, D46 – 180 Mesh. A continuous dressing with the dressing feed \(v_{fad} = 1 \mu\text{m/s}\) is performed in all tests.

For grinding flank faces and chamfers, insert rotational speeds from 695 to 10417°/min, an axial feed speed \(v_{fa} = 4 \text{ mm/min}\) and two cutting speeds \(v_c = 20\) and 35 m/s are used. The grinding wheel oscillates with the frequency \(f_{osc.} = 1 \text{ Hz}\) and mineral oil is applied as coolant in all tests.

PCBN cutting inserts with specification SNMA 120408 are ground. The insert has eight corners brazed on a cemented carbide substrate grade K10-20. The PCBN part is composed of 90% PCBN, and TiCN and Co as bond materials. Its Vickers hardness is \(36.4 \pm 0.48 \text{ GPa}\). Insert cutting edges are prepared with the chamfers width \(b = 50 \mu\text{m}\) and angle \(\gamma = 20^\circ\).

By investigating the influence of grinding wheel on edge quality, only the insert flank faces are ground. Rake faces were ground by the manufacturer and have a uniform surface quality with \(Ra = 0.32 \pm 0.01 \mu\text{m}\).
The measurement of the edge chipping after the grinding process has been quantified by the optical 3D measurement device Mikrocad GFM. Twenty measurements per insert were performed in different positions of different edges. A Mahr Perhometer has been used for obtaining the chamfer profiles. The calculated standard deviations correspond to the measurements obtained from two inserts in twenty different positions, i.e. forty measurements.

Results and Discussion

The abrasive grain size has the greatest influence on the edge quality in comparison with feed and cutting speeds, as a result of the influence on the number of active edges in the grinding wheel layer and the single grain chip thickness. Fig. 3 shows that small diamond grains lead to a reduced edge chipping, i.e. a better edge quality of the PCBN insert, due to a decrease of the single grain chip thickness and, accordingly, the forces per grain. Although grinding with small grain sizes results in better edge qualities, the larger quantity of active edges can cause higher total grinding forces. Particularly in plunge-face grinding high normal forces can lead to dimensional deviations and this situation must be taken into account by choosing an adequate grinding tool.

![Fig. 3 Edge chipping under variation of grinding wheel grain size and bonding](image)

Aiming to investigate the influence of the wheel bonding on the insert edge quality and the possibility of reaching lower values of Rk by using larger grain sizes, a resinoid bonded wheel with grain size D36 was applied and compared with a vitrified bonded wheel with the same grain size and concentration. However, a resinoid bonding did not improve the edge quality. Moreover, the higher elastic deformation of a resinoid bonding can still contribute to insert dimension deviations. After investigating the main influential factor on edge chipping, the manufacturing of the edge chamfer was considered.

If the proper chamfer width or chamfer angle is not reached in a first grinding, the NC-path must be corrected in order to compensate the error. This process must be repeated until the chamfer dimensions are within a predefined tolerance range. With this procedure, systematic errors can be resolved. Though there are still random errors, which can lead to unpredictable deviations, it can be said that they play a minor role during chamfer grinding. In this way, the manufacturing of a precise micro geometry is possible by reducing the deviation of the micro geometry in each insert corner.
Deviations occur due to axes positioning errors, irregular material removal and elastic deformations.

In Fig. 4 left, it can be noted that the chamfer in the central region of the corner radius does not demonstrate any significant deviation. However, larger chamfer widths can occur outside of this region. Two reasons can be given: system relaxation or positioning error of the X axis at the end of the insert rotation. This latter problem occurs randomly within a determined range, according to the machine precision.

During the grinding of a chamfer in an insert corner, the system becomes tense in the central region of the corner radius due to the continuous rotation of the insert and the high contact pressure between grinding wheel and workpiece. As a consequence, a localized elastic deflection takes place and a system relaxation is expected at the end of the insert rotation.

Rotational speed $v_R$ and cutting speed $v_c$ can influence this relaxation effect, as shown in Fig. 4 right. During grinding with the cutting speed $v_c = 20 \text{ m/s}$, small rotational speeds reduce the elastic deflection in the corner radius, but enable a larger elastic recovery in the straight edges. Higher rotational speeds reduce the elastic recovery in the straight edges, but increase the elastic deflection in the corner radius. In these both extreme situations higher chamfer widths in the straight edges are obtained. Thus, a compromise between elastic recovery in the straight edges and elastic deflection in the corner radius is necessary.

Since higher cutting speeds contribute to the reduction of the mechanical load, an increase of the cutting speed to $v_c = 35 \text{ m/s}$ moves the curve to the right and smaller deviations are also possible even with higher rotational speeds. Thereby a reduction of the process time becomes possible, without increasing the micro geometry deviation.

**Conclusions**

Based on the obtained results, it can be concluded that in grinding of PCBN inserts, the use of grinding wheels with small abrasive grains leads to a decrease of edge chipping, since the mechanical load per abrasive edge is reduced. With this knowledge, the manufacturing of smaller edge micro geometries becomes possible.
In relation to the chamfer grinding, a compromise between elastic recovery in the straight edges and elastic deflection in the corner radius must be taken into account by choosing grinding parameters, in order to reduce chamfer width deviations at the insert corner radius.

References


Corresponding author: C. E. H. Ventura
Institute of Production Engineering and Machine Tools – Leibniz Universität Hannover
An der Universität 2 – 30823 Garbsen, Germany
Phone: +49 5117625207, Fax: +49 5117625115
E-mail: ventura@ifw.uni-hannover.de