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Innovative method for cutting edge preparation with flexible diamond tools

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Abstract

The micro geometry of the cutting edge is of central importance for the performance of cutting tools. It influences all essential parameters in the machining process: chip formation, thermal and mechanical load on the tool and the workpiece, tool wear and the resulting workpiece quality. The effect depends on the size and shape of the cutting edge rounding. Depending on the machining process, asymmetrical roundings often show the greatest potential. In addition to increasing tool life, the quality of the surfaces produced can be improved by a specifically designed asymmetrical rounding. For edge preparation, blasting, brushing and drag finishing are used in industrial applications. However, an economic production of asymmetrical cutting edge geometries on cutting tools with complicated cutting edge geometry, such as solid carbide tools with helical cutting edge, cannot be achieved with these methods. Therefore, a novel method for preparation of the cutting edge rounding using flexible bond diamond polishing tools is introduced. Hence, the conducted research in this study analyzes the basic mechanisms and influencing factors using the new preparation method. For this purpose, polishing tests are carried out on carbide indexable inserts. The results show that the polishing tools can be used to create both asymmetrical and symmetrical roundings in an industrially relevant dimension.

Keywords: Cutting edge rounding; asymmetrical rounding; polishing; diamond tool

1. Introduction

The cutting edge preparation is a process step in tool manufacture. Cutting edge preparation is usually carried out after tool grinding and before coating [1, 2]. The most widespread industrial processes are the mechanical processes of blasting, drag finishing and brushing [3, 4, 5]. This process step pursues two basic objectives. On the one hand, microdefects originating from the tool grinding process and causing a high chipping are to be reduced and on the other hand defined cutting edge shapes are to be generated [6]. Irrespective of the considered cutting process, several studies have shown an increase in the performance of cutting tools with a defined cutting edge shape compared to the ground or sintered initial shape [1, 2, 7, 8, 9]. The increase in performance was attributed to the higher stability of the cutting edge compared to sharp cutting edges [1]. For instance, when machining C45E in the interrupted cut, it was shown that a tool life increase of 80 % could be achieved with an asymmetrical cutting edge rounding tilted to the rake face, K = 2. The form factor K is the quotient of S_γ and S_α [5]. In this context, the cutting edge sections on the rake face S_γ and on the flank face S_α are defined as the distance from the cutting edge of an ideally sharp cutting edge to the detachment point on the rake or flank face [5]. Symmetrically rounded tools, K = 1, were used as a reference [10]. In his work on milling 42CrMo4-QT, Rehe was also able to demonstrate a 70 % reduction in wear on the flank face with a rounding inclined to the rake face of K = 1.7 [5]. The rounding results in a shift of the thermo-mechanical load from the cutting edge to the rake and flank face.

The preparation of complicated tool geometries, such as complex end mills, poses a particular challenge. For this purpose, processes based on the flow of an abrasive medium

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around the tools are particularly suitable. Thus, due to its many degrees of freedom in the movement of the component and the blasting nozzle, blasting offers a high degree of flexibility and is therefore also suitable for the production of asymmetrical cutting edge geometries. The associated complexity of the process, however, leads to fluctuations in the preparation result. For example, irregularities can occur in the flow of the cutting medium and lead to deviations from the nominal geometry [9]. Hence, a reproducible production of prepared tools is difficult to realize with blasting [1, 6, 9]. Further methods for the preparation of tools with complicated geometries are magnetic finishing, drag finishing and flow grinding. These processes are characterized by high productivity. They can only be carried out on separate machines and not in the grinding machine tool itself. In addition, a complex run-in of the processes is necessary for each new cutting edge microgeometry or each new tool type. As a result, a reliable production of asymmetrical cutting edge geometries on complicated cutting tools is not possible today. For this reason, a novel method for preparation of the cutting edge rounding using flexible bond diamond polishing tools is introduced in this paper. It will be analysed regarding the achievable cutting edge rounding as well as the wear of the polishing tools.

Nomenclature

A	Trial number
a_p	Depth of cut
A_v	Wear surface
K	Form factor
$\bar{S}$	Mean size of the honed cutting edge
S_α	Cutting edge section on the flank face
S_γ	Cutting edge section on the rake face
v_c	Cutting speed
v_f	Feed velocity
β	Wedge angle
ζ	Tilt angle
η	Pitch angle

2. Experimental approach

All investigations were carried out on a 5-axis CNC milling centre of type Ultrasonic 10 by DMG Mori. The polishing tools used are provided by EVE GmbH, type DT-DCP14m (Fig. 1). They have a diameter of 14 mm and consist of flexible plastic lamellas with embedded diamond grains. The grain size is approx. 20 µm. A pair of lamellas has a width of approx. 1.9 mm. The polishing tools are generally used in medical technology for processing ceramic dental implants. Uncoated carbide indexable inserts type SNMA120412-RK5 with a wedge angle of $\beta = 90°$ were used to analyse the effect of process parameters on the cutting edge rounding and to quantify tool wear. Because of the simple geometry, errors due to possible machine or CAM inaccuracies are avoided. In the initial condition, the inserts have a sharp cutting edge with a cutting edge rounding $\bar{S} < 5$ µm. The corresponding test setup for the investigations is shown in Fig. 1. The cutting edge rounding as well as the roughness were carried out with the optical roughness measuring device Alicona Infinite Focus G5.

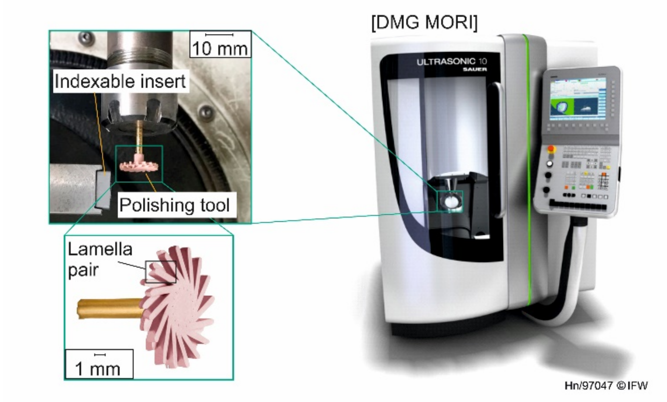

Fig. 1. Experimental setup

3. 5-axis polishing

This paper focuses on the parallel polishing. In parallel polishing, the lamella pairs are perpendicular to the cutting edge and the contact surface on the tool is at the polisher tips.

3.1. Parallel polishing

During the investigations on parallel polishing, five process parameters were partially varied in at least three stages in order to identify the influence on the cutting edge rounding. In addition, two repetitions were carried out per parameter set. The cutting speed v_c, the feed velocity v_f, the tilt angle ζ, the pitch angle η and the depth of cut a_p were investigated (Fig. 2). Table 1 shows the varied process parameters. The target parameters for both processes are the achievable rounding on the flank and rake face, described by the cutting edge sections S_α and S_γ as well as the form factor K.

Table 1. Process parameters

Parameter set	Set 1	Set 2	Set 3
Cutting speed v_c [m/min]	44	440	880
Feed velocity v_f [mm/min]	10	60	150
Depth of cut a_p [mm]	0,1	0,3	0,6
Tilt angle ζ [°]	5	30	45
Pitch angle η [°]	5	30	45

The tilt angle ζ describes the inclination of the polishing tool to the flank or rake face during parallel polishing. Using a tilt angle of 0°, the flank and rake face are machined equally. At a tilt angle of $\zeta > 0°$, the machined surface is enlarged on the flank face and reduced on the rake face. The opposite is true for a tilt angle $\zeta < 0°$. However, due to a possible collision between the workpiece and the collet chuck of the tool, only a tilt angle $\zeta > 0°$ could be investigated with the described test setup. The pitch angle η defines the inclination of the polishing tool in relation to the horizontal alignment of the tool shank. Due to a possible collision between collet chuck and workpiece, only a positive pitch angle η could be considered in the investigations. The depth of cut a_p describes the ideal geometric maximum overlap of the workpiece and the polishing tool without elastic effects. The kinematics of 5-axis parallel polishing are illustrated in Fig. 2.

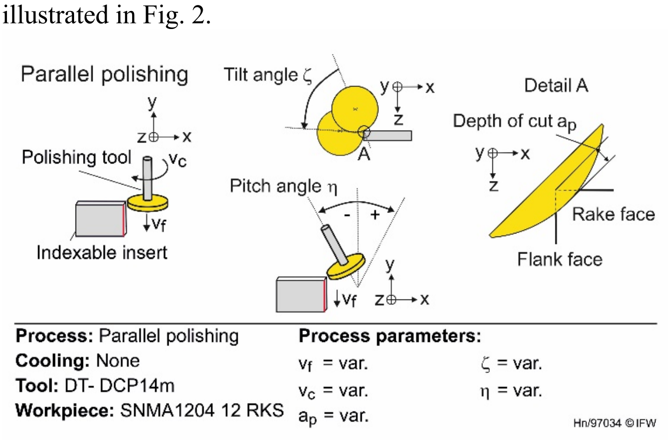

Fig. 2. Kinematics of 5-axis parallel polishing

Initially, a cutting speed of $v_c = 440$ m/min, a feed velocity of $v_f = 60$ mm/min, a depth of cut of $a_p = 0.3$ mm, a tilt angle of $\zeta = 0°$ and a pitch angle of $\eta = 0°$ were selected as process parameters.
For the initial values, a rounding with $S_\alpha/S_\gamma = 60/120$ µm could be created during parallel polishing (Fig. 3). This results in an asymmetrical rounding with a tilt to the rake face and a form factor of K = 2. Due to the direction of rotation of the polishing tool, the lamella pairs first hit the rake face of the indexable insert, polish it on the rake face side and then hit the flank face, where the polishing time is shorter. This generates more material removal on the rake face and the cutting edge section S_γ is larger. Thus, an asymmetrical rounding with a form factor of K = 2 with a high repeatability, as shown in Fig. 3, can be created. The machining time for a cutting edge of 12 mm length is approx. twelve seconds. The results demonstrate the high potential of the novel method. The running-in behaviour of the polishing tools is discussed in the wear section of this paper.

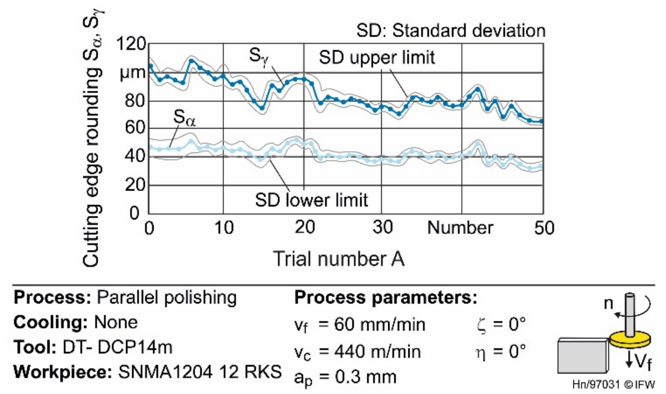

Fig. 3. Achievable cutting edge rounding with diamond tools during parallel polishing

In order to be able to produce an advanced polishing tool for cutting edge preparation, the basic influences of conventional polishing tools must first be investigated. The effects of the parameters are explained as follows. The investigations on the influence of the feed velocity on the cutting edge rounding during parallel polishing show that at a higher feed velocity, the produced rounding and thus both cutting edge sections S_α and S_γ are reduced and the form factor increases. The increase in the form factor results from a more pronounced decrease in removal on the flank face than on the rake face. If the feed velocity is reduced, the rounding increases and the form factor decreases slightly (Fig. 4). According to the conventional removal hypothesis, material removal during polishing is achieved in the form of an abrasive process in which the usually harder abrasive polishing grain penetrates into the softer workpiece surface and removes material similar to a machining process [11]. At a lower feed velocity, the degree of overlap of the individual polishing transitions and the cutting edge increases. In addition, the removal achieved increases. The opposite is true at a higher feed rate.
The depth of cut a_p has the following influence on the resulting cutting edge rounding: Increasing the depth of cut results in a larger rounding and decreasing the depth of cut results in a smaller cutting edge rounding (Fig. 4). An increase of the depth of cut results in a larger area of the lamella pairs being in contact with the workpiece surface and, as a result, more diamond grains can generate an ablation. The form factor remains almost constant with a slightly decreasing tendency with an increased depth of cut.

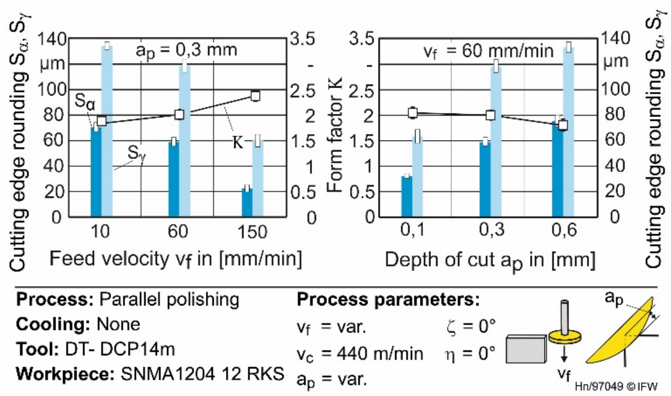

Fig. 4. Effects of the process settings feed velocity and depth of cut on the rounding result

For the pitch angle η and the tilt angle ζ, similar influences could be identified as shown in Fig. 5. When the angles are increased, the two cutting edge sections decrease to a certain point. Subsequently, the cutting edge section S_α rises and S_γ falls slightly. The contact surface between the lamella pairs and the workpiece is first reduced in size on both cutting edge sections. Afterwards, the increase in angle shifts the contact surface of the lamella pairs to the side of the flank face, whereby the cutting edge section S_α rises again. The form factor decreases when the angles are increased and approaches the value 1. The investigations show that a symmetrical cutting edge rounding can be created with a pitch angle of $\eta = 45°$ or a tilt angle of $\zeta = 45°$.

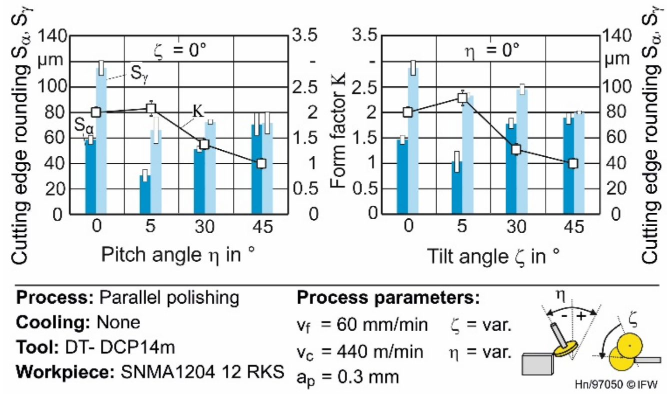

Fig. 5. Effects of the process settings pitch angle and tilt angle on the rounding result

Finally, the influence of the cutting speed v_c was investigated (Fig. 6). With increasing cutting speed, the cutting edge section S_γ is enlarged and the cutting edge section S_α is reduced. The form factor decreases with increasing cutting speed. In addition, a change in the direction of rotation was investigated. It was found that the change in the direction of rotation causes the asymmetrical rounding to tilt towards the flank face. The cutting edge sections change approximately their size, resulting in a form factor of K = 0.5. The change in the direction of rotation causes the lamella pairs to first hit the flank face of the indexable insert, polish it on the flank face and then hit the rake face. The polishing time on the rake face is shorter and the removal rate decreases.

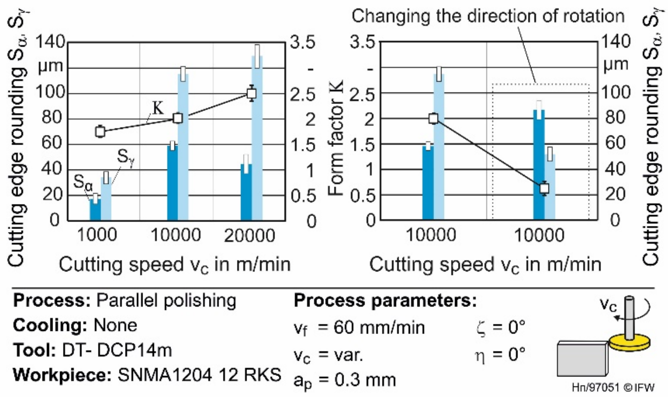

Fig. 6. Effects of the process setting cutting speed on the rounding result

In summary it becomes clear that all examined process setting parameters have an influence on the cutting edge rounding during parallel polishing and that the cutting edge rounding can be adjusted within a wide range of K = 0.5 - 2.

In addition, the influence of the process parameters on the edge quality was investigated. The edge quality was determined by the roughness value Ra. It was found that the process parameters have no significant influence on the edge quality. The result is a roughness value of Ra = 0.2 +/- 0.05 determined in the investigations carried out.

Further images of two prepared cutting edges were taken using a scanning electron microscope (SEM) to show the quality of the preparation process. The preparation was carried out on the one hand with a brushing process and on the other hand with the diamond polishing tools presented here during parallel polishing. With both processes, a cutting edge rounding of S_α/S_γ = 60/60 µm was created. It becomes clear that the shape of the prepared cutting edge with the polishing tools corresponds to a circular shape. On the other hand, the brushing process with the used process parameter produces a cutting edge shape that resembles a mixture between rounding and chamfer. The resulting edge quality determined by the roughness value Ra is higher with the diamond polishing tools in comparison with the brushing process (Fig. 7). The presented results are analogous to [12].

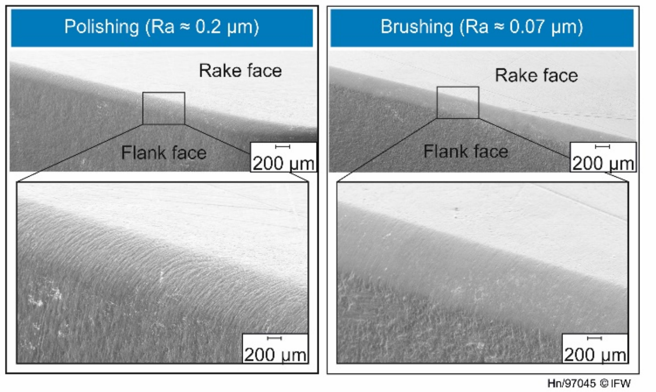

Fig. 7. Comparison of polishing and brushing processes

3.2. Wear behavior of the polishing tools

In order to determine the productivity of the diamond tools, the tool life of the polishing tools was investigated. The process parameters were kept constant and the wear behavior of the tools was analyzed. In total, the examination covered 50 runs and thus a cutting edge length of 250 millimetre. During this trial, the achieved cutting edge roundings were also measured as shown in Fig. 3. A light microscope was used to record the condition of the diamond tools. Dark discolorations are visible on the polisher tips as shown in the Fig. 8. These become more pronounced during longer periods of use. During polishing, the smallest carbide particles are abrasively removed from the indexable insert and are deposited on the polisher tips in the form of carbide dust. At the beginning of the investigations, fibers and material detachments can also be seen on the polishing tips. If the diamond tools are used for a longer period of time, the polisher tips will also show a wear surface A_v (Fig. 8). The surface increases with further trials. Due to wear of the polishing tool, the cutting edge sections S_α and S_γ decrease slightly with increasing operating time as shown in Fig. 3. At the beginning of the trail, the cutting edge rounding produced vary considerably. With a larger wear surface A_v and less material detachment, the values for the cutting edge sections become more constant.

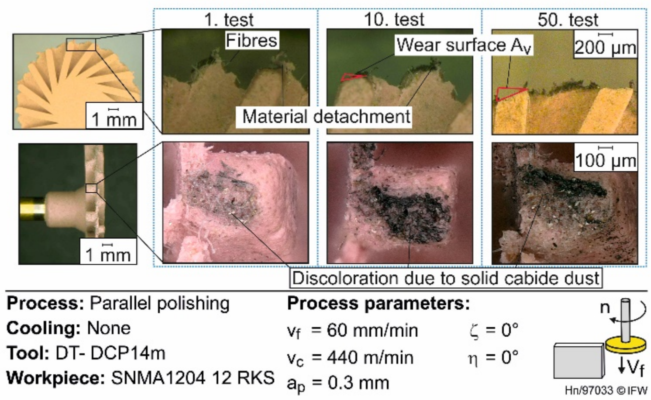

Fig. 8. Wear characterization of the polishing tools

During the tool life tests, the tool diameter and the mass after each operation were also documented (Fig 9). The diameter was determined directly by the machine tool and an integrated laser sensor. The weight of the polishing tools was measured with a precision scale. The diameter of the polishing tools was subject to strong fluctuations at the beginning of the investigations. The diameter of the basic body of the polishing tools is increased by the occurrence of material detachments, which are still connected to the polishing tool. If the detachments are separated from the polishing tool, the diameter decreases again. At the beginning, the mass of the polishing tools decreases sharply. Over the tool life, it remains almost constant. Only a slight material loss is visible. This can be explained by the detachment of polishing material at the beginning of the tool life tests. In so far a remarkable tool life for the polishing tools could be shown, which is a requirement of industrial preparation processes.

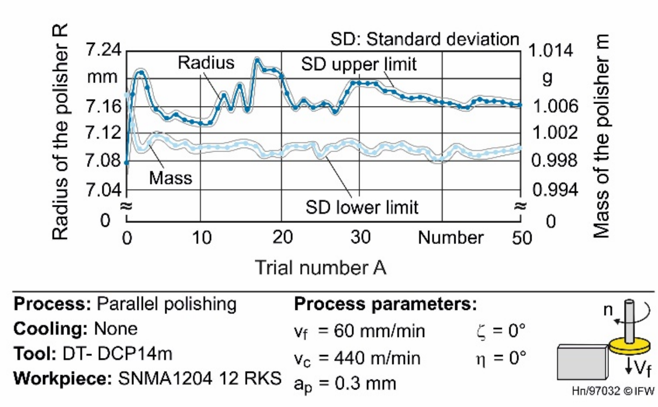

Fig. 9. Mass and radius of the polisher

4. Conclusion and outlook

First, the influence of the process setting variables on the cutting edge rounding during parallel polishing was investigated. With parallel polishing, it is possible to produce both asymmetrical and symmetrical cutting edge roundings with a high repeatability. Further investigations showed that during parallel polishing, all examined process parameters have a strong influence on the cutting edge rounding. This allows the process to be configured specifically and targeted cutting edge rounding to be created.

In addition, the wear of the polishing tools can be characterized by the wear surface A_v at the polisher tips. Further the wear behaviour of the polishing tools proofed that a cutting edge length of 250 millimetre can be rounded with the same diamond tool without any major change in the preparation result. In addition, it could be shown that the wear of the polishing tools has no significant influence on the cutting edge quality. The roughness value remains almost constant at a value of Ra = 0.2 +/- 0.05. For the preparation of a cutting edge with a length of twelve millimetres, the polishing tool takes twelve seconds, which indicates high productivity.

In the near future, a regression model is set up for the modelling of the achievable removal on flank and rake face as a function of the process setting variables.

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