Cutting Edge Preparation by Means of Abrasive Brushing

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Abstract. The need for new cutting tool technologies is driven by the constantly increasing performance of machine tools and the rising market competition. Current research results show that an improved combination of the cutting edge macro- and microgeometry, together with an appropriate substrate and coating, leads to a significant enhancement of cutting tool performance. Furthermore, inappropriate cutting edge microgeometries cause, in addition to the higher production costs, a reduction of the tool life. Hence, it is essential to produce tailored cutting edge microgeometries with high precision and process reliability. This paper presents the influence of brushing process parameters on the size and the form of produced cutting edges of indexable inserts. This leads to a better understanding and higher quality of the cutting edge preparation process by means of abrasive brushes. Furthermore, the process reliability of 5-axes brushing is analyzed. An example of a tool life map presents the significantly enhanced tool performance through cutting edge preparation and its sensitivity towards varying the cutting edge microgeometry.

Introduction

Cutting edge microgeometries, which are commonly realized in form of a rounding on the sharp cutting edge, influence the tool wear behavior significantly [1]. Current research shows that a honed cutting edge is able to increase as well as decrease the tool life [2]. This depends on the adapted rounding of the cutting edge geometry in relation to the load collective applied on it. Therefore, it is essential to use tailored cutting edge microgeometries in order to improve the wear behavior of the cutting tool and extend its tool life significantly. Furthermore, the productivity of a cutting process can be increased using prepared cutting tools [3]. The microgeometry can even affect the surface residual stress status of the workpiece [4]. Different forms of cutting edge microgeometries can be produced by means of microblasting, brushing, magnet- or drag-finishing as well as using laser techniques. Every technique has its field of application depending on its productivity, accuracy and the intended form of the microgeometry.

The characterization of the cutting tool microgeometry is a fundamental requirement in order to investigate its influence on machining processes systematically. The radius of the rounded cutting edge $r_\beta$ is not sufficient to characterize different forms of the cutting edge microgeometry. Hence, the parameters $\Delta r$, $S_\gamma$, $S_\alpha$ and the form factor $K$ (as shown in Figure 1) have been defined in order to describe such cutting edge geometries [1]. By means of abrasive brushing various forms of the cutting edge microgeometry depending on the tool macrogeometry and substrate as well as on the applied brushing process kinematics and the type of the applied abrasive brush can be produced. Furthermore, chipping of the cutting edge, which greatly affects the cutting tool performance, is reduced significantly through the cutting edge preparation. Hereby, the application of fine-grained, e.g. SiC-brushes SiC#500, leads to a much lower chipping of the cutting edge [5].
A better understanding of the influence of brushing process parameters on the achieved rounding and topography of the cutting edge enables the production engineer the preparation of cutting edges with a higher quality. The interrelation between the brushing process parameters and the achieved cutting edge rounding will be presented in the following chapters.

**Cutting Edge Preparation through Brushing**

Abrasive brushing tools are widely used for cutting edge preparation in form of wheel or disc brushes. Figure 2 shows an example of abrasive wheel brushes and their filaments. These filaments are made of extruded polymer fibers and contain dispersed abrasive material such as SiC or PCD particles, which usually make 30-40% of the total volume. The wear of the filaments is mainly affected by blunting and dissolving of the abrasive particles, which primarily depends on the cutting speed. Due to the wear of the filaments, there is a decrease in the material removal rate [6].

The brush interface pressure, depending on the process parameters, impacts the material removal rate significantly [7, 8]. The influence of the applied brush on residual stress and surface roughness of the prepared cutting edge has been presented in [5]. It has been shown that using fine-grained SiC-brushes leads to smaller mean roughness depth $R_z$ and higher residual stress in the substrate at the cutting edge. Moreover, the material properties of the substrates influenced the produced cutting edge geometry. These differ through carbide grain size and the mixture ratios of carbide and cobalt matrix. Additional carbides of materials such titanium (Ti), tantalum (Ta), vanadium (V) and niobium (Nb) build mixed carbides, which increase the hardness and abrasion resistance of the sintered substrate at high temperatures [9, 10].

The experimental setup is presented in Figure 3. Thereby, indexable inserts with a tool included angle of $\epsilon_r = 90^\circ$ (SNMG-160616-NM9) are prepared with a preconditioned SiC#240 brush and systematically varied values of cutting speed $v_c$, brushing time $t$ and infeed $a_z$. The setting angle is
constant and has been set to \( \phi_B = 0^\circ \). Brushing direction is also kept constant and defined from the rake to the flank face of the insert. All produced cutting edge microgeometries are measured after the preparation with a contact stylus (Pertho meter Concept – Mahr GmbH) and characterized consistently using \( S_\gamma, S_\alpha \) and \( K \) via the software “Determine K”. This software has been developed at IFW for evaluating measured microgeometries.

Figure 3: Experimental setup of the preparation process by means of abrasive SiC#240 brush

**Influence of the Brushing Process Parameters on the Size of the Honed Cutting Edge**

In this chapter the cutting speed \( v_c \), the infeed \( a_z \) and the brushing time \( t \) will be systematically varied in order to investigate their influence on the achieved cutting edge rounding. Figure 4 – left presents the influence of the cutting speed \( v_c \) and the infeed \( a_z \) on the size of the cutting edge rounding represented by the parameters \( S_\gamma \) and \( S_\alpha \). An increase of the cutting speed leads to an overproportional increase of \( S_\gamma \) and \( S_\alpha \). Raising the infeed from \( a_z = 0.5 \) mm to \( a_z = 1.5 \) mm in addition to the cutting speed enhances the influence of the cutting speed on the size of the cutting edge rounding. This is caused due to the increasing kinetic energy and the impact frequency of the filaments on the cutting edge at a constant time of brushing.

Nevertheless the kinetic energy and the impact frequency of the filaments influence the achieved size of the cutting edge differently. These differences are shown in Figure 4 – right. Hereby, three inserts have been prepared at a constant impact frequency of the filaments on the cutting edge as well as an increasing kinetic energy (bar diagrams – left). This has been carried out by applying \( v_{c1} = 15 \) m/s and \( v_{c2} = 30 \) m/s at a brushing time of \( t_1 = 28 \) s and \( t_2 = 14 \) s respectively. Further three inserts have been prepared with a constant kinetic energy of the filaments at a different impact frequency (bar diagrams – right). This has been carried out by applying \( v_{c1} = v_{c2} = 15 \) m/s at brushing time \( t_1 = 28 \) s and \( t_2 = 14 \) s respectively. The results show that the size of the achieved rounding of the cutting edge can be influenced more sufficiently through the cutting speed \( v_c \) than through the brushing time \( t \). Furthermore, a longer brushing time leads to lower process productivity, which is an important criteria for choosing and evaluating a cutting edge preparation process.

<table>
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<tr>
<th>( v_c ) = cutting speed</th>
<th>( a_z ) = infeed</th>
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<td>( v_p ) = oscillation speed</td>
<td>( \varphi_B ) = setting angle</td>
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The form of the cutting edge can be described using the parameter $\Delta r$ and the form factor $K$, which describe the flattening and the tilt of the honed cutting edge, respectively. The influence of the cutting speed and the infeed on the form factor $K$ is presented in Figure 4 - left. Neither of these process parameters shows a significant influence on the form factor at a constant setting angle $\varphi_B$. Both of $S_\gamma$ and $S_\alpha$ increase almost equally. This leads to minor changes in the form factor $K = S_\gamma / S_\alpha$.

Nevertheless, with an increase of the cutting speed, there is marginal tendency of the form factor in the direction of the rake face ($K > 1$). Furthermore, raising the cutting speed and the infeed in a brushing process leads to an increasing flattening of the honed cutting edge $\Delta r$. This indicates a higher material removal (Figure 5).

Figure 5: Influence of the infeed $a_z$ and cutting speed $v_c$ on the flattening of the honed cutting edge.
In order to produce tailored cutting edge geometries, it is essential to be able to adapt the size as well as the form of cutting edge roundings efficiently. This happens by additionally adapting the process kinematics, which will be presented in the following chapter.

**Influence of the Brushing Process Kinematics on the Form of the Honed Cutting Edge**

The results of the experiments show that different forms of honed cutting edges cannot be produced by only varying brushing process parameters. The form factor $K$ is independent of applied infeed and cutting speed respectively. Therefore, a 5-axes brushing process has been developed in order to produce tailored cutting edge microgeometries on several macrogeometries of indexable inserts and cemented carbide end mills. Through the high process flexibility and adjustable setting angle $\phi_B$, it is possible to achieve a symmetrical ($K = 1$) as well as a nonsymmetrical ($K > 1$, $K < 1$) rounding of the cutting edge. Figure 6 presents the developed process schematically [5].

![Figure 6: 5-axes brushing process](image)

The process reliability of 5-axes brushing is presented in Figure 7. It shows scatter diagrams of prepared CNGG-inserts made of an ultrafine cemented carbide grade K30. Three different sizes of symmetrical cutting edge roundings have been prepared via 5-axes brushing with the same preconditioned SiC#240 brush. For each size of these cutting edge geometries 40 inserts have been produced. The resulting cutting edge geometries have been measured with an optical measurement system “GFM MikroCAD” and characterized consistently using $S_p$, $S_\alpha$ via the software “Determine K”. By calculating the mean value and standard deviation of all produced microgeometries, it is possible to evaluate the repeatability of this process for different sizes of the honed cutting edge.

The results show that the scatter of the produced cutting edges increases with the growing size of the cutting edge rounding. At the cutting edge microgeometry with $S_\gamma = S_\alpha = 60 \, \mu m$ the standard deviation from the mean value is 12 %. Experimental tool life tests have shown that all of the prepared cutting tools, which are located within this tolerance bandwidth, have a comparable wear behavior and tool life.
Figure 7: Scatter diagram of 5-axes brushing

**Tool Life Enhancement by Means of Quality-Oriented Cutting Edge Preparation**

This chapter presents an example of tool life enhancement due to tailored cutting edge preparation in cylindrical turning of spheroidal cast iron EN-GJS 600-3 (ISO 1083). For this purpose, a tool life map has been set up (Figure 8). This map presents all the achieved tool life times of prepared cutting tools in dependence of the different forms and sizes of their cutting edge microgeometries. These are marked numerical from 1 to 8 in the map. The colored scale presents the enhancement or the reduction of the cutting tool life due to the cutting edge microgeometry. This mapping method shows that the tool life maximum is not located on the symmetrically honed cutting edge, but underneath the diagonal at $K < 1$. With such cutting edge geometry it is possible to achieve a percentage tool life increase up to 100 $\%$ in comparison to the tool life achieved with the cutting tool without cutting edge preparation. Furthermore, a reduction of tool life occurs at cutting tools with the microgeometries 1, 5 and 6 ($K > 1$).

Figure 8: Tool life increase due to the tailored cutting edge preparation
Summary

The microgeometry of the cutting edge can enhance the performance of cutting tools and expand its tool life significantly. It is therefore essential to produce tailored cutting edge microgeometries, which are adapted to the loads applied on the cutting edge, at high quality and process reliability. Such cutting edge geometries can be produced by means of abrasive brushing. The brushing process parameters and kinematics influences the chipping, the size as well as the form of the produced cutting edge rounding. Hereby, the size of the cutting edge rounding can be increased significantly by adapting the cutting speed \( v_c \) and infeed \( a_z \). The form of the cutting edge rounding can be adapted via 5-axes brushing process. Using this process, it is possible to prepare different forms of cutting edge microgeometries on various cutting tools at high process reliability and precision. Tool life experiments show that a quality-oriented cutting tool preparation enhances the tool performance significantly, increases the productivity of the machining process and, therefore, helps reducing process costs.

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References


