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Cutting edge preparation of monolithic ceramic milling tools

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Abstract
Due to international competition, continuous increases in productivity, product quality and reduction of production costs are required. Especially, the development of milling tools made of innovative cutting materials and application-specific tool geometries for the machining of brittle materials are in focus to overcome these challenges. One approach to improve the performance and the tool behaviour concerning milling of graphite is the use of monolithic ceramic milling tools. Unfortunately, the high brittleness of the ceramic leads to breakouts on the cutting edge during the grinding process. This results in an increased maximum chipping of the cutting edge, which has a significant influence on the milling process. To improve the breakout behaviour, a cutting edge preparation with the immersed tumbling process was applied. To enable a process reliable cutting edge preparation, a suitable lapping medium, the influence of the processing time as well as the depth of immersion were investigated. Besides the maximum chipping of the cutting edge, the rounded cutting edge radius was also analysed. The results show that a process reliable cutting edge preparation of monolithic ceramic milling tools with a maximum chipping of the cutting edge $R_{S,max} \leq 3$ µm and a rounded cutting edge radius of $r_\beta \leq 7$ µm could be realised. In future investigations, the experimental applicability of monolithic ceramic milling tools will be proved.

immersed tumbling process, ceramic, milling tools, cutting edge preparation

1. Introduction

The milling process is a key technology for the manufacturing of forming tools in the field of tool and mould making for a wide range of materials. Especially, for the manufacturing of electrodes for die-sinking electrical discharge machining graphite represents a suitable material [1, 2]. At the state of the art the machining of graphite will be carried out with uncoated carbide as well as diamond coated carbide tools, which leads to a considerable tool wear and reduced tool life times T_{St}. Using these tools results in an early elution of the binder phase and a fast chipping of the coating. Furthermore, the coating of the carbide tools leads to high process costs c_p and a reduced economic efficiency [3].

In order to overcome the current challenges, dedicated cutting tools made of an oxide ceramic type AZ25PPr represent a promising approach due to the specific properties. Previously performed scientific studies show the great potential of this ceramic as a cutting material [4]. The oxide ceramic type AZ25PPr is characterised by covalent binding forces f_b, no binder phase as well as a high hardness H, which enables great advantages compared to uncoated and cost-intensive diamond coated carbide tools. Unfortunalety, the oxide ceramic shows a considerable breakout behaviour on the cutting edge during the grinding process. This can be related to the high brittleness of the ceramic. To improve the breakout behaviour, experimental investigations for cutting edge preparation with the immersed tumbling process were carried out. Therefore, the immersed tumbling process presents an important process technology and needs to be evaluated for a defined cutting edge preparation of the monolithic ceramic milling tools [5, 6].

2. Experimental Setup

2.1. Cutting material and tool geometry

For the investigations, cutting tools made of a zirconium dioxide-reinforced aluminium oxide caramic type AZ25PPr were used. The oxide ceramic was provided by the company OxiMaTec GmbH, Hochdorf, Germany, and the cutting tools were ground by the company HOPPE Präzisionstechnik GmbH, Hoyerswerda, Germany. The used cutting tools were eqquiped with a parabolic radius transition to the cutting part. This enables optimised process conditions and allow improved process parameters. The cutting tools were ground with state of the art process technologies.

2.2. Testing methods and devices

For the experimental investigations, the immersed tumbling process was carried out with the machine tool DF-3 Tools of Otec Präzisionsfinish GmbH, Straubenhardt, Germany. The measurement of the cutting edge micro-geometries rounded cutting edge radius r_β and maximum chipping of the cutting edge $R_{s,max}$ were realised with the optical measurement device InfiniteFocus from the company Alicona Imaging GmbH, Graz, Austria. To enable a suitable visualisation of the experimental results, the scanning electron microscope (SEM) JCM-5000 of the company Joel Neoscope, Akishima, Präfektur Tokio, Japan, was used.

3. Experimental investigations

Within the investigations, experiments for the evaluation of three different lapping media, H4/400 (diamond paste with walnut shell granulate), M4/300 (corn granulate) as well as HSC 1/500 (silicon carbide with walnut shell granulate) regarding the machining results were carried out (Figure 1). Figure 1 shows the influence of the lapping media on the rounded cutting edge radius r_β and the maximum chipping of the cutting edge $R_{s,max}$ as a function of the machining time t_m. As a result of the investigations the lapping medium H4/400 leads to a change of the rounded cutting edge radius in the range of 4.7 µm $\leq r_\beta \leq$ 5.3 µm and a maximum chipping of the cutting edge in the range of 4.5 µm $\leq R_{s,max} \leq$ 6.9 µm. For the lapping medium M4/300 a rounded cutting edge radius in a range of 4.8 µm $\leq r_\beta \leq$ 7.1 µm as well as a maximum chipping of the cutting edge of 3.5 µm $\leq R_{s,max} \leq$ 6.6 µm could be obtained.

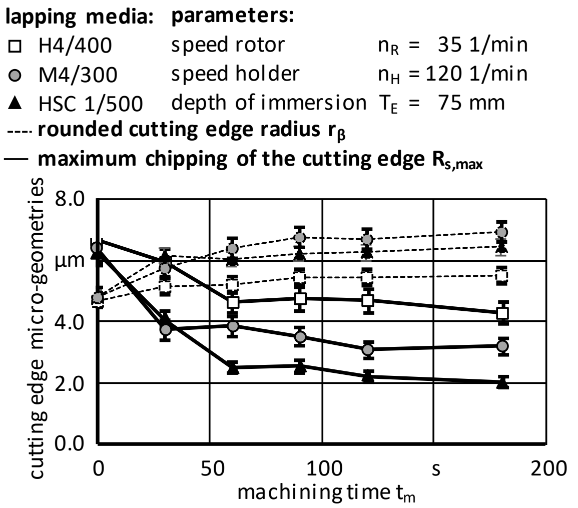

Figure 1. Influence of lapping media on cutting edge micro-geometries

A rounded cutting edge radius between $4.7\ \mu m \leq r_\beta \leq 6.3\ \mu m$ and a maximum chipping of the cutting edge between $2.4\ \mu m \leq R_{s,max} \leq 6.4\ \mu m$ result for the application of the lapping medium HSC 1/500. In general, the findings show for all lapping media an asymptotic course of the rounded cutting edge radius r_β up to a machining time of $t_m = 30$ s to a non linear function in the further course. Beyond that, the application of all three lapping media leads to a considerable reduction of the maximum chipping of the cutting edge $R_{s,max}$ up to a machining time of $t_m = 60$ s, followed by a flatter progression. The lapping medium HSC 1/500 shows the lowest maximum chipping of the cutting edge $R_{s,max}$ and a moderate rounded cutting edge radius r_β. Furthermore, the consideration of the standard deviations shows that the immersed tumbling could be identified as a precise and reliable process technology for the cutting edge preparation of monolithic ceramic milling tools. According to the results, the lapping medium HSC 1/500 will be used for further investigations and experiments were carried out to identify the influences of the process parameters for the cutting edge preparation of ceramic ball end mills. For the investigations a statistical test plan based on the Design of Experiments (DoE) was applied. Each test series was repeated three times for statistical validation. The selected process parameters are the depth of immersion in a range of $50\ mm \leq a_I \leq 100\ mm$, the rotor speed $20\ 1/min \leq n_R \leq 50\ 1/min$ as well as the holder speed $120\ 1/min \leq n_H \leq 200\ 1/min$. Figure 2 illustrates the findings of the investigations.

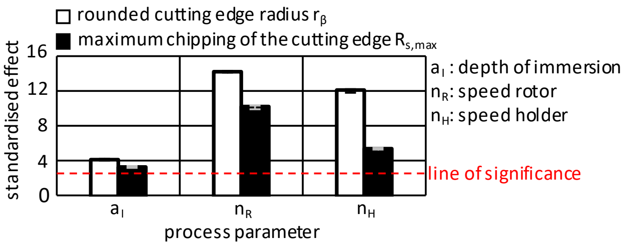

Figure 2. Visualisation of the significance analysis

Fundamentally, all process parameters show a significant influence on the cutting edge preparation. The red line in Figure 2 symbolises the significance of the investigated process parameters. The micro-geometries are strongly affected by the rotor speed n_R and the holder speed n_H. The increasing of these parameters results in an increased rounded cutting edge radius r_β and in a decreased maximum chipping of the cutting edge $R_{s,max}$, due to a growing machining speed v_m and higher removal rates $\dot{V}_W$. Furthermore, the depth of immersion a_I also shows a significance. Due to a growing lapping pressure p_L the removal rate $\dot{V}_W$ increases, which affects the preparation of the micro-geometries. To visualise the results of the defined cutting edge preparation, Figure 3 illustrates scanning electron microscope (SEM) images before and after the immersed tumbling process of an exemplary ceramic tool. Correllating to Figure 3 all process results are shown as averaged values. Figure 3 shows that the rounded cutting edge radius r_β increases, while the maximum chipping of the cutting edge $R_{s,max}$ decreases during the immersed tumbling process. This effect needs to be considered for the cutting process. The process results during the cutting are strongly affected by the micro-geometries of the used milling tools [7].

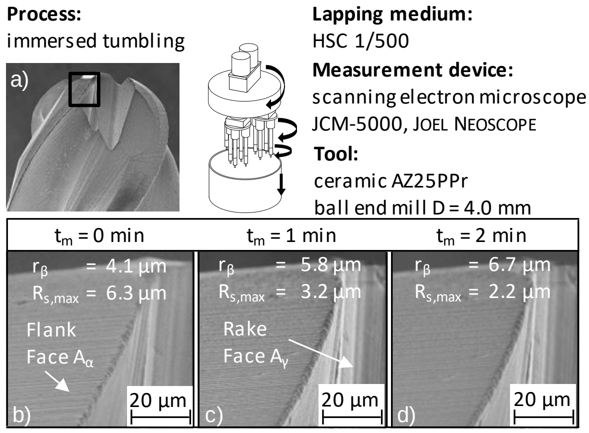

Figure 3. SEM images of one exemplary ceramic tool

a) reference; b) initial state; c) after t_m = 1 min; d) after t_m = 2 min

4. Conclusion and further investigations

The aim of the investigation was the identification of a suitable lapping medium and process parameters for a reliable cutting edge preparation of monolithic ceramic ball end mills. The findings show that the lapping medium HSC 1/500 is suitable for the preparation of monolithic ceramic milling tools made of a zirconium dioxide-reinforced aluminium oxide caramic type AZ25PPr. Furthermore, all investigated process parameters show a significant influence. The results for the investigation of the immersed tumbling show a great applicability for the cutting edge preparation of monolithic ceramic milling tools. Based on this, a defined preparation of the rounded cutting edge radius $r_\beta \leq 7\ \mu m$ as well as the maximum chipping of the cutting edge $R_{s,max} \leq 3\ \mu m$ could be proven. Further investigations will address the suitability concerning the tool wear and tool life times T_{St} of the monolithic ceramic milling tools during the cutting process. In addition, the correlations of the micro-geometries and the tool wear will be analysed. This work is supported by the funding program Zentrales Innovations-programm Mittelstand (ZIM) by the FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY (BMWI).

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