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Particle contact conditions for cutting edge preparation of micro-milling tools by the immersed tumbling process

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Abstract
For increasing tool life and cutting length of micro-milling tools the cutting edge preparation was successfully established. Using the immersed tumbling process, a reproducible cutting edge preparation with constant cutting edge radii as well as low chipping of the cutting edges can be realised. For a profound understanding of the preparation process and the process mechanisms further knowledge about the particle interactions with cutting tools as well as the particle flow mechanisms needs to be obtained.
In this investigation the preparation process of micro-milling tools was analysed and the contact-mechanisms as well as the resulting pressures were investigated by simulation studies. Using the discrete element method (DEM) with the software ROCKY DEM from the company ESSS, Florianópolis, Brasil, the immersed tumbling process could be modelled and particle contacts, particle traces as well as particle interactions with the micro-milling tool can be visualized. Especially the particle-tool interactions were more accurately investigated by analysing the stresses and particles shear work as well as correlations between these parameters to prove the comparability between the process simulation and the real preparation process.

immersed tumbling, micro-milling tools, discrete element method, cutting edge radius

1. Introduction

The immersed tumbling process is an appropriate technology for the cutting edge preparation of milling tools made of cemented carbide [1, 2]. After their manufacturing by grinding processes the sharp cutting edges usually indicate grain-outbreaks and in consequence an increased chipping of the cutting edges R_s. The high chipping of the cutting edges R_s lead to higher tool wear in the cutting process as well as higher fluctuations in tool performance [3]. During the preparation process the cutting edges were rounded and the chipping of the cutting edges R_s decrease, shown in Figure 1. Compared to other technologies like abrasive brushing or abrasive jet machining the immersed tumbling process enables the preparation of micro-milling tools with diameter D ≤ 0.5 mm [4].

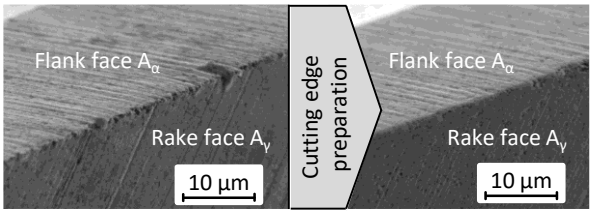

Figure 1. SEM images cutting edges of micro-milling tools; a) unprepared, b) prepared

During the process the milling-tools are fixed in tool holders and immersed in an abrasive medium. The tools are completely surrounded by the lapping medium and the material removal takes place by ploughing and furrowing of the abrasive grains on the micro-milling tools [5]. Within the process, no particle flow can be observed. In initial investigations the simulation of the immersed tumbling process with the software ROCKY DEM from the company ESSS, Florianópolis, Brasil, could be realized [6].

In the following, simulation results of the flow of an abrasive lapping medium onto a micro-milling tool are shown and the particle influence is investigated. The pressure profiles are analysed and the comparability between results of a linear inflow and a complex flow caused by the planetary motion of a drag finishing machine tool is discussed.

2. Discrete element modelling

The software ROCKY DEM version 4.4.2 was used for the process simulation. A rectangular basin with a side length of l = 40 mm, a width of w = 21 mm and a height of h = 17 mm was created as the container for the lapping medium, shown in Figure 2.

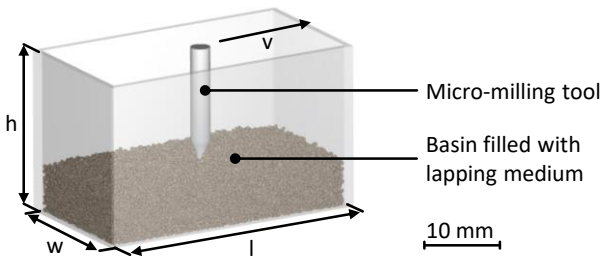

Figure 2. Test environment and boundary conditions

In the simulation, particles were generated in accordance with a medium of the type H 4/400. They consist of a mixture of walnut shell granulate with grain diameters in the range of 0.4 mm ≤ d_G ≤ 0.8 mm and a polishing paste containing diamond particles. The abrasive particles of the lapping medium were designed as rectangular polyhedron with 14 corners and the particle size S_P as well as the amount of particles n_P were implemented according to the measurement results, shown in

Table 1 [6]. Within the simulation, the basin was filled with n_P = 47,835 particles and the micro-milling tool with diameter D = 0.5 mm was moved in one direction with the velocity of v = 35 mm/s. Three tests were carried out. Thereby, the flow angle and tool orientation were changed by α = 45 ° for each attempt. The path length was l_p = 30 mm. For contact modelling a hysteretic linear spring normal force model and a linear spring coulomb tangential force model were used.

Table 1. Particle distribution according to the size of the sieves S_P and mass of particle m_P [6]

Size of the sieve S_S	Mass of particle m_P	Size of the sieve S_S	Mass of particle m_P
1,000 µm	0.00 g	500 µm	30.86 g
900 µm	0.31 g	400 µm	17.49 g
800 µm	0.13 g	300 µm	1.37 g
710 µm	5.58 g	200 µm	0.00 g
600 µm	44.09 g	< 200 µm	0.00 g

3. Results and discussion

Figure 3 shows the calculated material displacement d_m of the micro-milling tool resulting from the particle interactions with the tool in dependence of the flow direction by varied flow angle α. During the simulated preparation process an average of stress in the range of 0 Pa ≤ σ ≤ 10,000 Pa was determined. The average stress σ can be divided into the normal stress σ_n and the tangential stress σ_t. Higher normal stresses σ_n than tangential stresses σ_t were found in all three cases with varied flow direction. The flow angle of α = 0 ° shows the highest loads onto the cutting corner. Compared to the first setting, shadowing effects on the cutting corner were observed with the second setting and a flow angle of α = 45 °, which reduces the pressure P on the cutting corner and thus the intensity of the machining. With a flow angle of α = 90 ° the intensity of the process pressure P increases on the major cutting edge S. A higher material displacement d_m of the major cutting edge S in comparison with other flow directions α could be determined which leads to higher cutting edge radii r_β. In further investigations with rotating tool during machining with planetary motion a superposition of all pressure ranges could be determined. Since a direct pressure measurement during the cutting edge preparation could not be realized so far, a direct statement about the accuracy of the simulated pressures is not possible. However, a comparison of prepared micro-milling tools and the manufactured cutting edge radii r_β along the major cutting edge S and the minor cutting edge S' showed a good qualitative agreement with the simulation results.

4. Conclusion

For the improved understanding of the immersed tumbling process during the cutting edge preparation of micro-milling tools the software Rocky DEM could be selected and different machining scenarios could be presented. The results show good correlations in the pressure distribution depending on the flow direction α. Particularly at the cutting corners, an increased intensity of the machining was observed, which is associated with increased cutting edge preparation, increased material removal and thus higher cutting edge rounding.

Further development potentials are given in the validation of the material removal d_m and the analysis of the input parameters for a better quantification of the results.

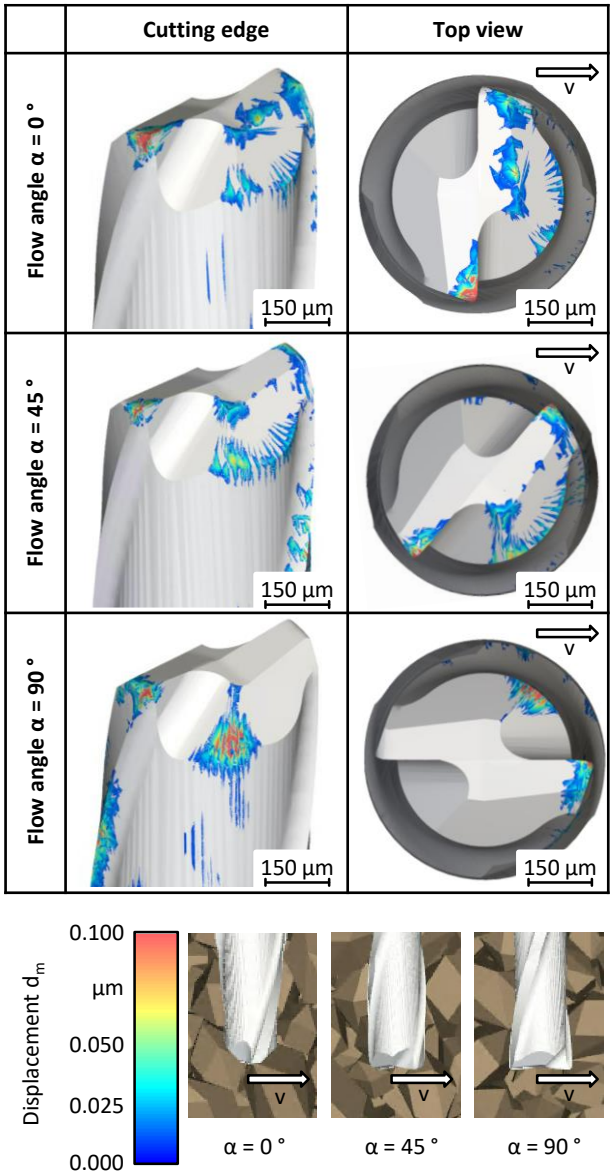

Figure 3. Material displacement d_m of the cutting part of the micro-milling tool after the simulated preparation with different flow directions of the abrasive medium

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