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# DEM-simulation of particle behaviour during cutting edge preparation of micro-milling tools by immersed tumbling

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**Abstract**
The micro-milling process is widely used in industry for the manufacturing of complex geometries for a wide range of materials. To increase the tool life and cutting length the cutting edge preparation could be successfully established. Within preliminary investigations the immersed tumbling process was identified as the most promising process for cutting edge preparation of micro-milling tools. The process enables a reproducible cutting edge preparation with constant cutting edge radii as well as low chipping of the cutting edges. 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. Therefore, the process simulation using discrete element methods (DEM) offers the possibility of an improved understanding of the process behaviour. In this investigation simulation studies about the cutting edge preparation of micro-milling tools using the immersed tumbling process will be presented. The DEM with the software ROCKY DEM from the company ESSS, Florianópolis, Brasil, was used and a process model was derived. The investigations show that the software can be successfully used for the visualisation of the immersed tumbling process and the flow mechanisms can be examined more closely.

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

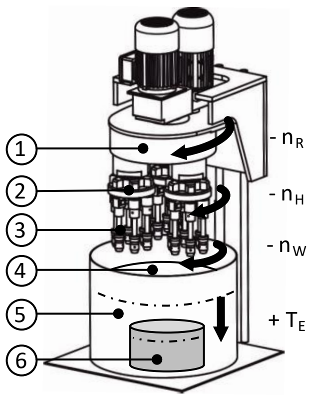
## 1 Introduction

The micro-milling technology is used in different fields of biomedicine, aerospace, automotive, electronics industry and die and mould fabrication [1, 2]. For improved tool wear behaviour during the cutting process as well as the preparative of subsequent tool coating the cutting edge preparation with the immersed tumbling process is used [3, 4, 5]. The immersed tumbling process is characterised by a uniform comprehensive preparation of the workpiece for parts of the medicine technology, polishing of jewellery or cutting tools. The workpieces are fixed in tool holders and immersed in an abrasive medium. Due to the use of a planetary gear two drives cause a relative movement of the workpieces in the media. The cutting process is mainly described by ploughing and furrowing of the abrasive grains on the workpiece [4]. Within the process, no particle flow can be observed at the workpiece due to the complete flow around the workpiece in the container. By DEM the particle flow can be visualised and the particle pressure can be determined. Nevertheless, the simulation of discrete complex and dry particles with software like ANSYS CFX from ANSYS, Inc. or the open source software YADE is time intensive and limited. A new approach is the software ROCKY DEM, which enables a fast implementation of the machine kinematics, particles and boundary conditions [6].

During the following investigation, a model made by the software ROCKY DEM is presented for the simulation of the particle-interaction with a micro-milling tool during the immersed tumbling process. In consequence of the particle-particle, particle-wall and particle-workpiece interactions a pressure profile of the tool is derived and discussed.

## 2 Experimental setup and input parameters

For the immersed tumbling process a machine tool DF-3 tools from OTEC PRÄZISIONSFINISH GMBH, Straubenhardt, Germany, was taken into account. A working container with reduced size with a diameter $D_C = 30$ mm and a height of $h_C = 17$ mm was designed for the reduction of the process media and particle number $n_P$, shown in figure 1 in comparison to the real container. The kinematic of the planetary gear system was implemented with a rotational speed of the workpiece of $n_H = 5$ 1/min, a rotational speed of the workpiece holder $n_H = 3$ 1/min and a rotational speed of the rotor $n_R = 2$ 1/min. A micro-milling tool made of cemented carbide with a diameter of D = 0.5 mm was used.




1. Rotor
2. Holder of the workpiece holders
3. Workpiece holders
4. Lapping media
5. Working container
6. Modeled working container

$n_R$ rotational speed of the rotor
$n_H$ rotational speed of the workpiece holder
$n_W$ rotational speed of the workpiece
$T_E$ Depth of immersion

**Figure 1.** Machine tool DF-3 tools with the machine kinematic and visualisation of the container sizes for the simulation model

For the preparation a lapping medium of the type H 4/400 consisting of a mixture of walnut shell granulate with a grain diameter of $0.4\ mm \le d_G \le 0.8\ mm$ and a polishing paste containing diamond particles was applied. The distribution of the particles and particle size $S_P$ was proofed corresponding to the DIN 66165 [7]. Therefore, a particle measurement system of the type EML 200 from HAVER & BOECKER OHG, Oelde, Germany, was used. Three charges of the medium were extracted and analysed by sieves. The mass of particles $m_P$ was measured with a precision scale of the type Kern PLS 12000-3a from KERN & SOHN GMBH, Balingen, Germany. The measurement results are given in table 1.

**Table 1.** Particle distribution according to the size of the sieves $S_P$ and mass of particle $m_P$

| 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 |

The model was designed with ROCKY DEM version 4.3.1. The particle geometry was designed as rectangular polyhedron with 14 corners and the particle size $S_P$ as well as the amount of particles $n_P$ was implemented according to the measurement results. The particle geometry was implemented according to optical measurement results of the particles. For contact modelling a hysteretic linear spring normal force model and a linear spring coulomb tangential force model were used. The workpiece was latticed with a triangle size $S_T = 25$ µm and the container was filled with $n_P = 60{,}527$ particles. The material parameters were chosen according to a comparative material for walnut shell.

## 3 Discrete element model and results

Figure 2 shows the model with the micro-milling tool inside of the container filled with lapping medium in the section view. Furthermore, the particle flow is visualized with the particle velocity $v_P$ as a result of the particle-workpiece, particle-particle and particle-wall interaction. Thereby, the gear kinematic can easily traced. In consequence of the three rotational speed parameters highest particle velocities $v_P$ can be reached due to the superimposed feed velocities $v_f$ from each rotational movement.

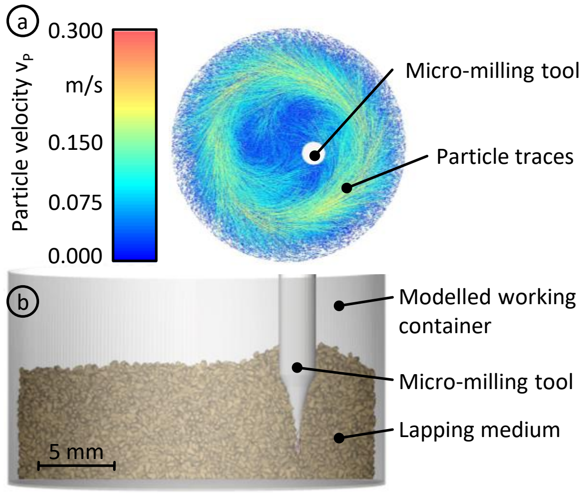



**Figure 2.** a) simulated particle velocity $v_P$ in consequence of the relative movement of the workpiece; b) simulated preparation model in the section view

The effects of the interaction between the workpiece, presented by the micro-milling tool, as well as the lapping particles were evaluated by the pressure P on the workpiece. In difference to the simulation with ANSYS CFX only segments resulting from the used lattice of the workpiece can be analysed and the transition can be displayed less finely. The simulation results are presented in figure 3. The tool is shown in comparison with a unprepared and prepared micro-milling tool. Increased pressure P representative for the material removal due to particle interactions is shown at the corner and in the transition between the main cutting edge S and the minor cutting edge S'. The results correspond to experimental results of LÖWENSTEIN [8] and show that the simulation is able to reproduce the real process.

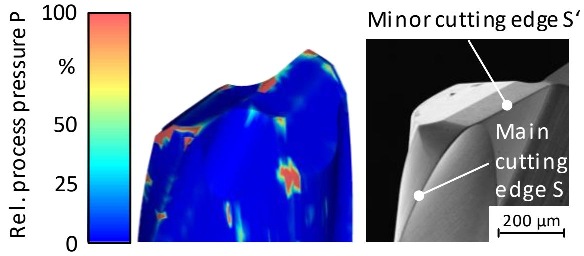



**Figure 3.** Simulated relative process pressure P on the cutting part of a micro-milling tool

## 4 Conclusion

For a better understanding of the cutting edge preparation of micro-milling tools using the immersed tumbling process further knowledge in the process simulation is needed. Within the presented investigation the software ROCKY DEM was successfully used and realistic particle behaviour as well as first results of the pressure profile of a micro-milling tool could be shown.

In further investigations the model will be extended and the pressure profile will be improved. The results will be validated with further experimental results and the influences of the lapping media as well as the cutting tool macro-geometry will be analysed.

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