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DEM simulation of centrifugal disc finishing using smoothed particle hydrodynamics

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Abstract
Centrifugal disc finishing is a widely used technology for serial post-processing of small components made of various materials. During the process, the workpieces are completely surrounded by dry or moist abrasive media, making it difficult to obtain precise information about particle contacts or the movement of the workpieces. Numerical analysis through the discrete element method (DEM) has the potential to improve the understanding of the process, but the accurate representation of moist particles with varying contact conditions remains a challenge. This paper compares different contact models using the ROCKY DEM software, including the liquid-bridge model and the smoothed particle hydrodynamics (SPH) model. The analysis indicates that, compared to other models, SPH demonstrates clear advantages in representing process water flow and is better suited for cases with higher water content in the medium.

Keywords: immersed tumbling, centrifugal disc grinding, discrete element method

1. Introduction

Centrifugal disc finishing belongs to the free abrasive grinding processes and is industrially established for the serial post-processing of small components. In the process, the container is filled with an abrasive medium and the components to be machined. By rotating a disc at the bottom, a toroidal stream is generated inside the stationary process container. The workpieces float as bulk material together with the grinding particles in the container and are completely surrounded by the abrasive medium [1]. Dry lapping media based on diamond, corundum and silicon carbide are used together with walnut shells or corn granulate. In addition, ceramic or plastic-based moisture abrasives are used to increase the material removal rate Q_w. At present, it is only possible to indirectly determine the contact conditions and movement behavior of workpieces and particles through their effects on the workpieces themselves. Various studies were able to show potentials for the analysis of free abrasive grinding processes by the software ROCKY DEM from the company ESSS, Florianópolis, Brasil, and the discrete element method (DEM) [2, 3]. However, the use of DEM for wet media has been relatively unexplored, necessitating further research.

This paper presents the initial findings of using the smoothed particle hydrodynamics (SPH) simulative extension of the ROCKY DEM software. The influences of different simulation models with dry contact conditions, wet contact conditions using the build-in liquid-bridge model as well as the advanced SPH are compared and for the centrifugal disc finishing discussed.

2. Smoothed particle hydrodynamics

ROCKY DEM facilitates the coupling of DEM with SPH, a numerical modelling technique that represents fluids as a collection of individual interacting particles. With SPH, the fluid is represented as a multitude of discrete elements instead of a spatially discretized continuum, and these individual mass particles are in constant mutual dependence as they interact with each other [4]. The velocity of a particle v_p results from a superposition of various attractive and repulsive effects. These consist of the density acceleration a_d, a restoring force F resulting from a spatial compression of the particles, the viscous acceleration a_v and the acceleration a_m resulting from mass inertia. The dynamics of the actual fluid are then mapped by the global consideration of all SPH particles, from which the local densities and velocities in the area result. Unlike SPH, the liquid-bridge model can add a liquid film to each particle surface, and nearby particles can form bridges between these liquid films, generating additional attractive forces F_A [5, 6].

3. Discrete element modelling

The process simulation was carried out using the R22.1.0 version of ROCKY DEM. A CAD model of the centrifugal disc finishing machine tool was designed based on preliminary investigations, and it is depicted in Figure 1 [1]. A moist abrasive medium of the type KM10 with a conical particle geometry and height of $h_c = 10$ mm was used. A homogenous moisture distribution was chosen with physical parameters of water and mass of $m_w = 10$ mg per particle. The particles were meshed with $n_{c,KM10} = 300$ cells and a particle number of $n_{KM10} = 12{,}890$ was selected for the filling volume of $V_M = 9.9$ l. For the SPH simulation, a filling volume of $V_{SPH} = 3$ l with an SPH particle size of $d_{SPH} = 2$ mm and a particle number of $n_{SPH} = 311{,}992$ was employed.

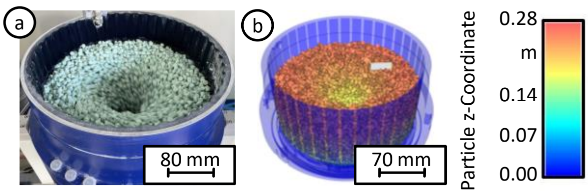

Figure 1. Simulation environment; a) real working container, b) process model with particles and a workpiece [1]

4. Results and discussion

Figure 2 shows SPH particles in the test environment. To better highlight the differences, the abrasive particles are hidden in the view of the working container in a). In this view and the detailed view b), the presence of an additional fluid phase is clearly visible. Moreover, the effect of the centrifugal force F_z is apparent, as the process water pushes against the working container's edge. View c) displays the velocity vectors of the individual SPH particles. The velocity vectors enable the visualization of the fluid flow and the evaluation of changes in particle-particle interaction at varying water concentrations.

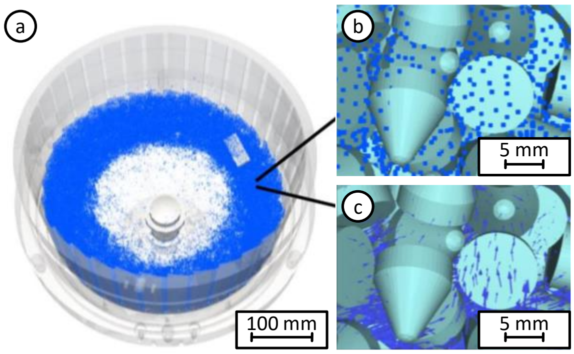

Figure 2. SPH simulation environment; a) SPH content in the working container, b) SPH particles and abrasive particles, c) vector arrows of the SPH particles

Figure 3 below presents the results for the movement of the components in the container, including the rotation velocity v_{rot}, the translation velocity v_t, the normal force F_N and the tangential force F_τ. To consider the influence of the workpiece, a triangular mesh plate with a hole and a mesh with convex bodies were modelled for the liquid-bridge model. By performing a quantitative comparison, it is possible to draw conclusions about the influence of different experimental parameters and assess the quality of the numerical modelling.

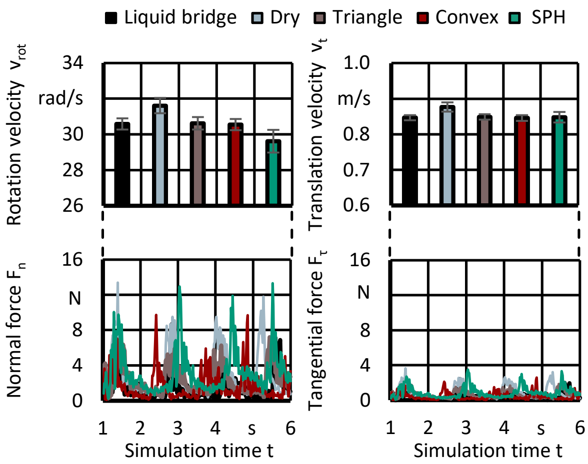

Figure 3. Comparison of macroscopic process variables with SPH

Regarding the translational velocities v_t, the SPH modelling produces results that are comparable to those of the liquid-bridge model. The average translational velocity v_t of the particles is at the level of the wet particle calculations and thus also below that of the purely dry simulation environment. The rotational velocity v_{rot} of the particles, on the other hand, is slightly below the other results and also has a higher standard deviation. In terms of the forces F acting on the workpiece, the curves have a qualitatively similar progression as those of the other quantities. However, the forces F here are generally higher and most comparable with the curves for dry processes.

The velocity distributions in the three simulations with the liquid-bridge wetted particles are almost identical. Differences in comparison to the other two cases appear to be related to moisture modelling. Generally, the higher velocities v of dry particles suggest that the additional moisture envelope affects the viscosity η of the medium. Due to the restoring force F_{wet}, the free movement of the particles is damped. The differences between dry and liquid-bridge particles align with findings from other investigations [7]. The results of the SPH modelling show that the values of translation velocity v_t are similar to those of the liquid-bridge modelling. The general flow behaviour of the particles thus agrees between the two moisture models. However, the temporal force curve analyses exhibit slight differences for the different cases. The maximum occurring forces F_{max} are higher for the SPH modelling than for the simulations with the liquid-bridge model. With the given parameters, a significant portion of the process water appears to be concentrated in the edge area, resulting in a high number of abrasive particles without moisture contact in the container's center. This explains the forces F, which are similar to those in the dry environment. In future investigations, the simulated water's filling quantity can be adjusted more specifically.

5. Conclusion

In conclusion, the coupling of ROCKY DEM with SPH presents several advantages for simulating multiphase systems consisting of air, particles, and fluids. The software enables the independent calculation of particles and fluid, allowing for the simulation of larger amounts of liquid that can interact with the particles. However, this approach comes with an increased computing time t_c compared to other simulation methods. For water contents of more than 10 %, ROCKY DEM and Ansys Fluent coupling is recommended. On the other hand, for low water contents, the liquid-bridge model is still preferable as it offers comparable results with lower computing capacities than SPH. Overall, the selection of the simulation approach should be based on the specific requirements of the system being modelled.

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