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Simulating flow behaviour of wet particles within the immersed tumbling process

E. Uhlmann[1,2], J. Polte[1], Y. Kuche[1], F. Landua[1]

[1]*Fraunhofer Institute for Production Systems and Design Technology IPK, Germany*
[2]*Institute for Machine Tools and Factory Management IWF, Technische Universität Berlin, Germany*

yves.kuche@ipk.fraunhofer.de

Abstract
For many production chains, it is mandatory to involve special finishing of the manufactured parts for the chipping of the edges as well as the polishing of surfaces. One commonly used method is the immersed tumbling process, where any workpiece is dragged through a particle filled container. In many cases, the immersed tumbling process operates in environments with added liquids, leading to changes in particle-tool interaction and general flow behaviour of the used particles. Whilst the discrete element method for simulating particles is mainly limited to dry particles, the used software ROCKY DEM from ESSS, Florianópolis, Brasil, comes with a built-in liquid-bridge model to simulate water-covered particles and granulate and furthermore an extension for system couplings with Ansys Fluent of the company ANSYS, INC., Canonsburg, Pennsylvania. The latter can be used to create from both software one three-phase-model with higher amounts of actually simulated water. In this study, small amounts of water were added to differently shaped particles using the build-in liquid-bridge model, to analyse and compare the particles flow characteristics in both, wet and dry environments. To gather significant information leading towards precise comparisons, the particles trajectories, velocities and resulting forces against the workpieces can be specifically observed and analysed, whilst this kind of process knowledge could previously never been taken into account without simulation.

Immersed tumbling, discrete element method, liquid-bridge, three-phase-simulation

1. Introduction

There are a variety of applications for the immersed tumbling process as a mandatory part of various finishing operations, many of which operate in wet particle environments. Here, a liquid circulates within the container to obtain a moisture distribution as homogenous as possible. This not only improves the particles flow behaviour but is also needed to wash out dust and chips from the circuit. To simulate this kind of process the common discrete element method (DEM) needs to be extended by a module to numerically calculate the fluid behaviour. As shown in previous work, the software ROCKY DEM from the company ESSS, Florianópolis, Brasil was successfully used to describe the movement of spherical and non-spherical particles within the immersed tumbling process [1]. The software also allows system coupling with Ansys Fluent from the company ANSYS, INC., Canonsburg, Pennsylvania to calculate particles and liquid separately to then merge the results or allows the simulation of small amounts of moisture via a built-in "liquid-bridge"-module. For the wet immersed tumbling process the particles are usually moistened and not really floating. So, for investigations with a low liquid content, the use of the built-in liquid-bridge module is advisable and therefore chosen in this study. With this module a liquid film can be added on each particles surface. Close-by particles then build bridges between these liquid films [2] that add additional attractive forces F_A [3].

In this study the changes to the flow behaviour are investigated and quantified by analysing resulting forces F_{res} on a homogenous cylinder being dragged through a particle filled container.

2. Simulation environment

The simulations done for this study were executed with the software version 4.4.2 of ROCKY DEM. Contacts are modelled with hysteretic linear springs for normal forces and linear coulomb springs for tangential forces. The rectangular basin has dimensions of $l = 0.25$ m, $w = 0.1$ m and $h = 0.22$ m and the used particle geometries are spheres with radii of $r = 10$ mm (B10), cones with height of $h_c = 10$ mm (KM10) and triangular prisms with edge lengths of $l_e = 11$ mm (D11), as shown in Figure 1.

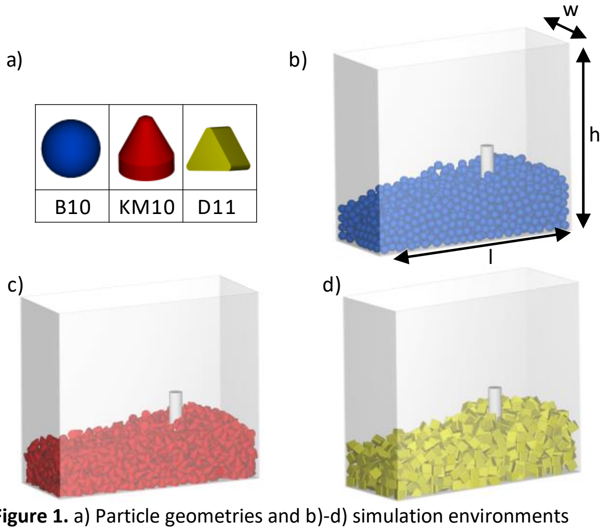

Figure 1. a) Particle geometries and b)-d) simulation environments

The non-spherical geometries were meshed with 300 cells for KM10 and 104 cells for D11. To reach equivalent filling heights of $h_f \approx 0.07$ m, the basins were filled with $n_P = 1{,}600$ particles for B10, $n_P = 1{,}710$ particles for KM10 and $n_P = 997$ particles for D11.

For the wet experiments a homogenous moisture distribution is chosen with physical parameters of water and mass of m_w = 10 mg per particle. The physical parameters for all particles are selected as of the material of polyvinylidene fluoride.

3. Results and discussion

For the first set of experiments the cylinder with mass m_c = 1 kg has a constant velocity of v_c = 0.2 m/s and moves through each basin filled with the different particle sets and dry and wet particles, respectively. The effective normal forces F on the rod are then plotted and compared as shown in Figure 2.

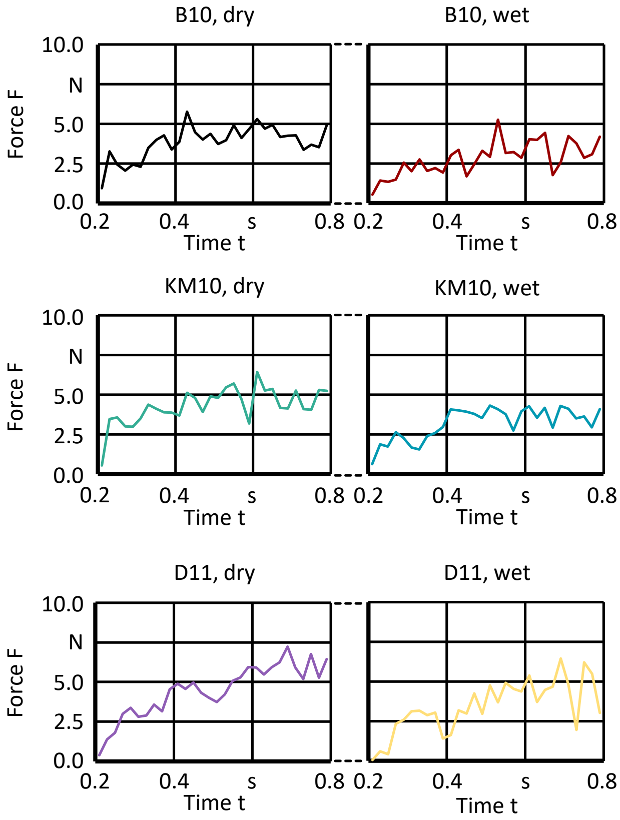

Figure 2. Effective resistance forces F over time for constant cylinder velocities v_c

The plots clearly display the influence of even such small amounts of added liquids and the results all point to a tendency for lower forces F to be required to run through wet media environments. At the same time the resulting tangential stresses were slightly higher in the dry environments. With B10 for instance the averages were around τ_{dry} = 140 Pa for the dry and τ_{wet} = 100 Pa for the wet use case. Both values indicate a changed flow behaviour, whereby the moist particles seem to provide less resistance to the rod movement, possibly favoured by an almost resistance-free breaking of the liquid bridges due to the fixed velocity value.

Given, that in real experiments one could never expect geometry movements to be as unrelenting as in the shown numerical experiments, some additional experiments were done where the rod is being pushed by a constant directional force F = 5 N. The rods movability is then analysed by observing its velocity over time as shown in Figure 3.

Despite the previous findings of lower needed forces F in wet environments, the second investigations point towards a faster and therefore easier movement of the rod through dry media environments, which could be explained by a looser composition of the dry media. The tangential stresses τ, on the other hand, generally remain higher in the dry applications.

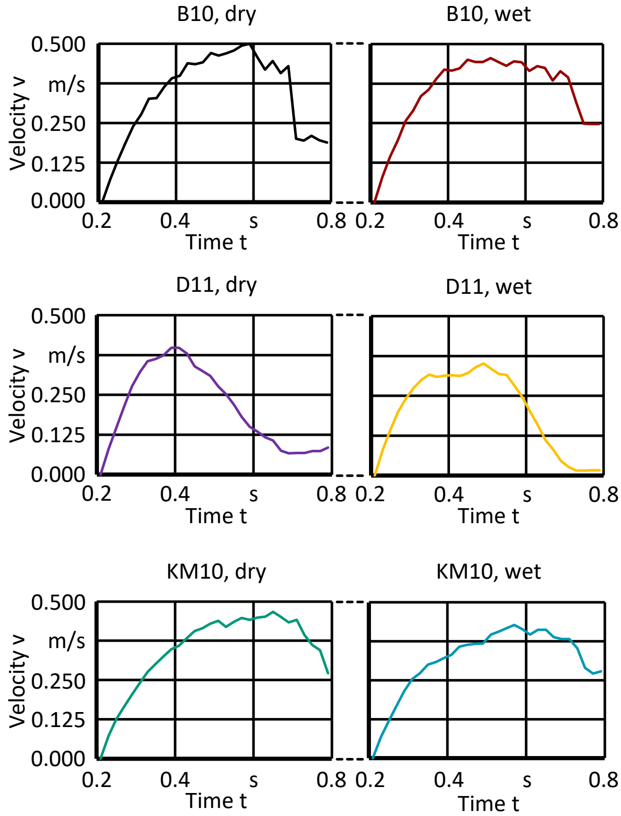

Figure 3. Resulting translational velocity v over time under constant directional forces F = 5 N

4. Conclusion

The given study provides a numerical modelling of grinding media with wet particles and shows how even small amounts of added moisture directly influence fundamental process parameters. A simple structure is chosen to show general trends and minimise further influences. This creates the opportunity for more complex applications of the immersed tumbling process to be simulated and thereby quantify additional process parameters for wet media environments. If the simulation provides reliable results, this additional knowledge can be used in questions of optimizations and general process design. For improved accuracy of the model additional validation of the undertaken investigations needs to be done by comparison with like-wise real life experiments. Therefore, some of the input parameters need to be closer reviewed as for example in dry environments additional adhesive forces arise, which are hard to quantify and hence usually ignored in numerical modulations. Furthermore, different additional parameter studies need to be done in order to better understand the wet particles behaviour, like variation of the velocity v_w of the workpiece or amount and distribution of the added liquid.

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