IFPRI Project Abstract

A System Engineering Approach to Dry-Milling with Grinding Aid Additives

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Project Objective:

1. Develop a system engineering approach for optimizing and scaling industrial dry fine grinding processes.

2. Obtain numerical relations about effect of grinding aid (GA) additives on material behavior, process aspects and energy requirements.

Approach:

In its second phase, the project will continue the work started during the first phase to build a digital twin for dry ball mill and air classifier systems with special focus of predicting the effect of grinding aids. The first phase focused on identifying the impacts of grinding or flow aids on macroscopic aspects of such processes. It was identified which mechanisms on both milling and classification are directly affected by GA and where the current models should be improved.

The second phase focuses on bridging the gap between dynamical changes on product microscopic properties (particle size and surface) and powder bulk behavior. Moreover, the findings are to be implemented into the current flow sheet model structure to dynamically account for flowability changes. The second phase was divided in the following steps:

❖ Determine a proper powder macroscopic property to represent the combination of material and GA type and dosage

❖ Relate measurable microscopic particle properties with powder bulk behavior

❖ Design a characterization procedure to obtain the model parameters required for axial transport simulation

❖ Model powder internal axial transport during milling

❖ Validate all developed models and flowsheet simulation with industrial data

Recent Results:

In a dry grinding process, bulk powder properties affect key process parameters such as material hold-up, residence time, and stress conditions (especially the capturing of powder between colliding balls) within the mill, which in turn influence the fineness of the final product. In order to account for the impact of GA on these process parameters and thus on the grinding results, macroscopic powder properties that correctly represent the influence of both, material (on particle-level) as well as the type and dosage of GAs are investigated. In open-circuit tumbling ball milling experiments, samples were collected from the grinding chamber after reaching steady-state operation to characterize the powder properties. Since the particle size distributions obtained from the ball milling tests were within a narrow range, additional grinding tests were conducted using planetary ball mills to cover a broader range of particle sizes. It was found that the flowability index (ff_c) measured using the Schulze Ring Shear Tester represents a proper property that can be used to quantify this impact for cases, in which the effect of powder aeration is small. Moreover, between the flowability index (ff_c) and the specific surface area measured via BET technique a correlation was found that can be fitted with a power function as illustrated in Figure 1. This correlation can be used in a flowsheet simulation of a dry grinding process to track the flowability change during grinding progresses.
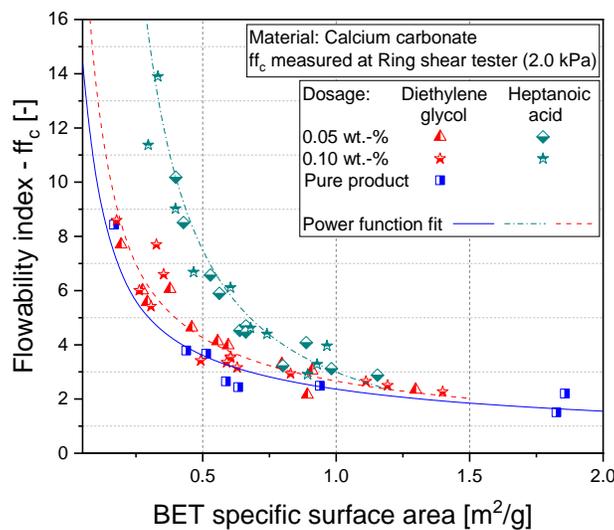

Figure 1: Powder flowability as function of specific surface area and grinding aid

Regarding the influence of GA on the material hold-up, continuous ball milling experiments with the three different GAs, Heptanoic acid, Diethylene glycol, and Hexanol are carried out. Figure 2 shows the hold-up in term of powder-to-void ratio (left) and the flowability indices of samples taken from the grinding chamber after steady-state operation (right). The figure reveals that a steady-state operation within the desired range of powder-to-void ratio of 1 was possible for materials with a flowability index of 3 to 4, so that the type and dosage of a GA should be chosen to achieve this criteria in relation to the achieved particle size. This can be realized by using the relationship between flowability index and specific surface area of the powder as depicted in Figure 1.
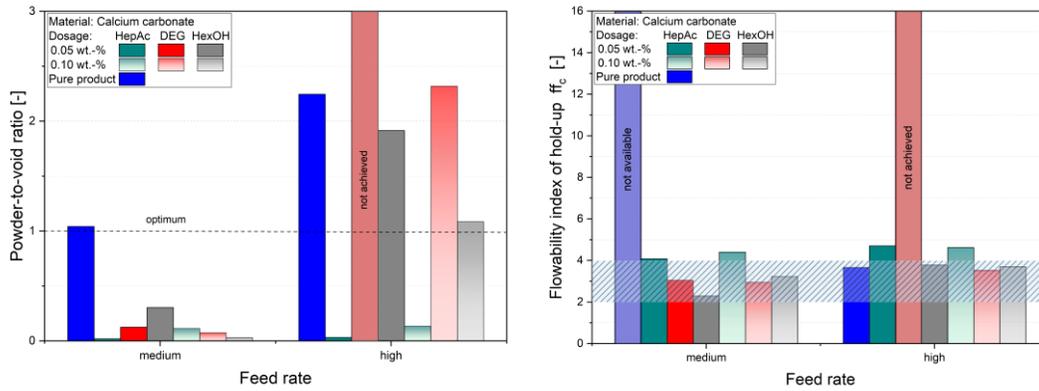
Figure 2: Material hold-up in grinding chamber in term of powder-to-void ratio (left) and flowability indices of corresponding hold-up materials (right)

A further factor that affects the process is the fluidization behavior of powders with different GAs which is not described by the flowability index. Therefore, measurements of cohesion strength with and without aeration using the Anton Paar powder rheometer have been carried out for the original powder with a fineness of $x_{50} = 110$ µm and its variations using the three different GAs. The results show that GAs which induce better powder flowability (Heptanoic acid and Hexanol) resulted in a higher cohesion strength in comparison to the material with DEG or the one without GA, measured without aeration of the powder as illustrated in Figure 3 (left). The reason for this result being opposite to the flowability measurements using the ring shear tester is thought to be the effect of the powder density which is significantly higher for Heptanoic acid and Hexanol as illustrated in Figure 4 (left). A higher powder density means a higher densification and by that a higher cohesion (also regarding typical yield loci). Against that, if the powder are aerated a totally different behavior can be found. Comparing the results of material hold-up and residence time distributions (see Figure 4 (right)) with different GAs show that the material properties obtained with the powder bed aeration can better estimate the impact of GAs on the material hold-up and residence time. As a consequence, for the simulation of ball milling processes both, flowability index ffc and cohesion strength under aeration, have to be considered for the further model development.
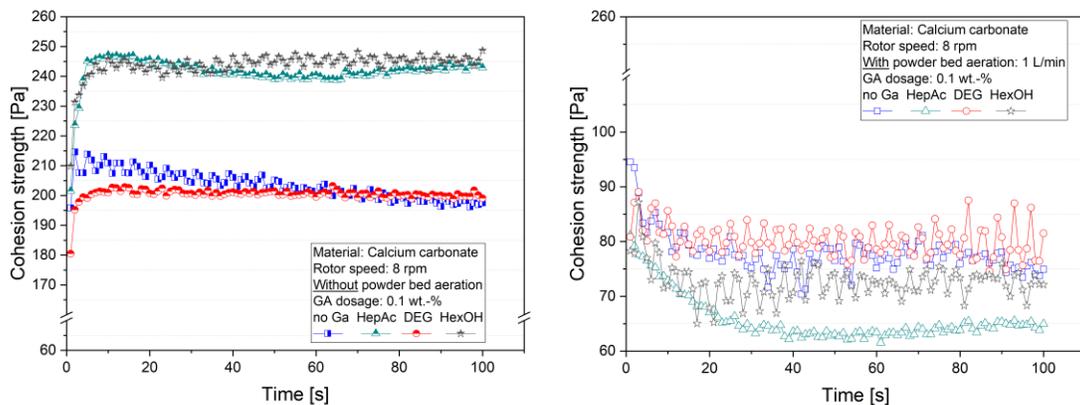

Figure 3: Measuring the cohesion strength with Anton Paar powder rheometer without powder bed aeration (left) and with powder bed aeration (right)
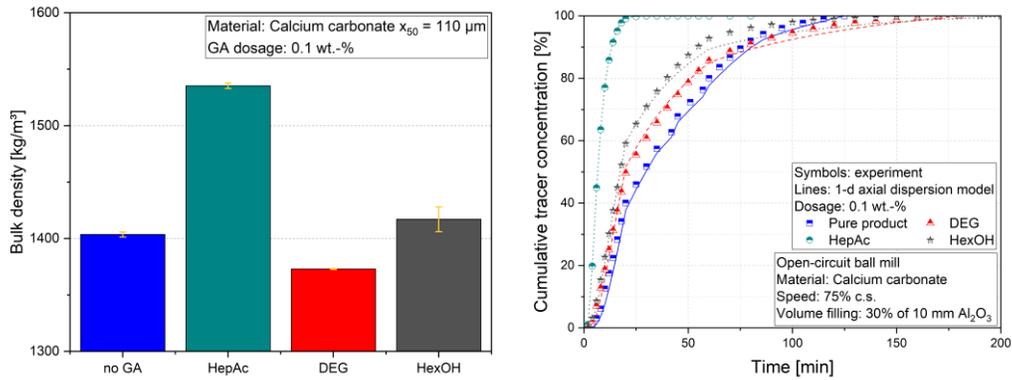
Figure 4: Bulk densities of feed materials (left) Cumulative residence time distribution of pure material and materials with three types of grinding aids (right)

Next Steps:

Further measurements with the powder rheometer and other powder configurations as well as with a rotating drum (to characterize the dynamic angle of repose) are carried out to complete the data to describe the macroscopic powder behavior, which will be related to the specific surface area and eventually other particle size determined parameters. Based on these parameters, the grinding efficiency (especially capturing of powder between the balls) and the powder transport through the mill and resulting hold-up shall be calculated within the flow sheet simulations.