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Impact of the powder flow behavior on continuous fine grinding in dry operated stirred media mills

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ABSTRACT

Due to the rising demand for minerals with high product fineness, new and innovative mill types are needed, which enable the energy efficient production of fine materials within the lower micron range. As fine grinding processes require mills with high energy densities as well as high production capacities, there is currently a great interest in research and development of dry operated stirred media mills. These mills are a promising option for energy efficient dry fine grinding especially due to their high stress energies and frequencies. While present studies on these mills mainly focus on the investigation of machine-related parameters, the impacts of product-related characteristics on the grinding process are still mainly unknown. Especially in continuous grinding mode, product properties are normally of high importance. Therefore, this study focusses on the investigation of the product flow behavior regarding the grinding performance in continuously and dry operated stirred media mills. This study revealed that the grinding performance is strongly determined by both, machine-related values like the choice of process parameters as well as product-related characteristics like the powder flowability. It was further shown that the flow behavior of the product influences the grinding process on different levels simultaneously. Thereby, both too high and too low powder flowabilities lead to inefficient grinding. Also, an overlapping retention mechanism of the grinding media deflector wheel was identified, which may lead to further crucial impacts especially at high powder flowabilities.

1. Introduction

The energy efficiency of dry fine grinding processes can mainly be increased by either (1) further development of mills and mill equipment, (2) improving classifiers as well as grinding-classifying-circuits or (3) enhancing the process behavior of the ground material (Scheibe et al., 1978). Since the demand on fine and ultra-fine materials is still increasing, conventional ball mills are steadily being replaced by alternative mill types which enable more efficient grinding processes especially in the range of high product finenesses.

As dry operated stirred media mills provide high stress energies and high stress frequencies, they have recently come to the fore in the field of research and development. It was already shown in different studies that these mills can lead to higher energy efficiencies compared to grinding in conventional tumbling ball mills (Jankovic et al., 2004; Shi et al., 2009). However, even though they are already established in wet fine and wet ultra-fine grinding, the dry operation of stirred media mills is still in an early to intermediate stage.

Within the last two decades, first research groups started to study dry stirred milling in either vertical (e.g. Toraman et al., 2016; Toraman, 2012; Cayirli and Gokcen, 2017; Prziwara et al., 2018a) or horizontal (e.g. Cayirli and Gokcen, 2017; Rácz and Csőke, 2016; Mucsi et al., 2013) designs, mostly in batch-wise operated laboratory applications. Recently, even more studies focusing on continuously operated mills can be found in literature (Pilevneli et al., 2004; Wang et al., 2004; Gerl and Sachweh, 2007; Altun et al., 2013a, 2013b, 2014; Altun, 2015; Rácz et al., 2017; Sander et al., 2017; Droop and Stein, 2013). All these works underline that dry stirred media milling is significantly different compared to wet stirred milling, i.e. as comparably moderate stirrer tip speeds in combination with bead sizes in the millimeter range (Wang et al., 2004; Altun et al., 2013a) and lower bead filling ratios (Rácz and Csőke, 2016; Altun et al., 2013a) are favorable for a high energy utilization.

In comparison to these machine-related parameters, the impacts of product-related characteristics on the grinding performance – such as the flow behavior of the product powder or the ball-to-powder-ratio within the mill – are still not understood sufficiently. Since these values may have a strong influence on the stressing mechanism between colliding grinding beads, as it was already shown for dry and batch-wise operated stirred media mills (Prziwara et al., 2018a), this lack of

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understanding may become a crucial issue regarding the realization of high grinding efficiencies. As one of the few relevant studies regarding continuously operated stirred mills, Altun et al. showed that different grinding aids change the grinding performance, which they assumed to be a consequence of the different flow behavior depending on the used grinding aid (Altun, 2015). In dry fine grinding processes, those additives are often added to the product in order to control re-agglomeration phenomena as well as the product bulk behavior, and thus, increase the grinding efficiency (Prziwara et al., 2018b; Sverak et al., 2013). Other influences of grinding aids on the transport behavior as well as mill retention times are known for the operation of conventional tumbling ball mills (Dombrowe et al., 1982; Sottili and Padovani, 2000) and may be explained by similar powder-flow-related effects. As these studies indicate, a comprehensive understanding of the relation between product behavior and grinding conditions inside the mill is essential for efficient fine grinding in any kind of dry operated mills. Besides the choice and concentration of grinding aids, those product-related properties depend on a variety of parameters like the nature of the ground material itself, the target fineness or material moisture. Unfortunately, this variety of influencing parameters in turn makes the development of a comprehensive understanding very complex.

Within this study, the impact of the product flow behavior on dry fine grinding in a continuously operated horizontal stirred mill was investigated. Thereby, the product powder flowability was specifically adjusted by different grinding aids and grinding aid concentrations. In addition, the most important machine-related parameters were varied to identify their influence on the grinding result, and especially, their interaction with the product flow behavior. The grinding experiments were evaluated in terms of product particle size, energy efficiency as well as material hold-up inside the mill.

2. Experimental

2.1. Dry operated horizontal stirred media mill

A dry operated horizontal stirred media mill with a net grinding chamber volume of 6.6 L was used for the grinding experiments. The mill was originally constructed for wet stirred milling by the former company Draiswerke GmbH, Germany. Within this project, the mill was modified in order to enable continuous dry fine grinding.

The shaft of the modified mill is equipped with a number of 32 pins as stirring unit and a deflector wheel at the outlet side of the mill to hold back the grinding beads inside the grinding chamber (see Fig. 1). All of these parts are made of stainless steel. During the grinding operation, the raw material is continuously fed into the mill via a screw conveyor at the drive side of the milling chamber. A minimum air volume flow of 6 m^3/h is introduced around the stirrer shaft for flushing the shaft bearings. As this air flow is also introduced at the drive side whilst being removed at the mill outlet, it slightly supports the axial material transport through the mill simultaneously. A further air volume flow of 18 m^3/h is introduced into the mill in the sector of the internal deflector wheel in order to improve product material transportation through the wheel and to prevent an excessive material accumulation around the deflector wheel. After leaving the mill through the deflector wheel and subsequent mill outlet, the ground material is transported to a filter unit via a third air flow. Here, the fine product is removed from the total air flow. The air leaves the system via a side channel blower.

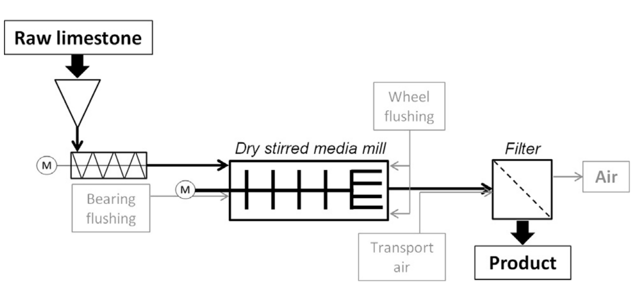

Fig. 1. Setup of the horizontal stirred media mill for continuous dry fine grinding applications.

During the mill operation, the power draw of the mill was measured. Consequently, the specific energy input E_m of the grinding process was determined by the power draw of the mill P, the no load power draw P_0 as well as the product throughput $\dot{m}_p$ (see Eq. (1)).

$$E_m = \frac{P-P_0}{\dot{m}_p} \quad (1)$$

According to Eq. (1), higher throughputs lead to lower specific energy consumptions for a constant net power input. Within this study, three different feed rates were investigated for each combination of process parameters in order to obtain three different product throughputs, and thus, different residence times as well as specific energy inputs. Unfortunately, it was hard to adjust identical throughputs for each parameter setting because the material feed rate does not only depend on the rotational speed of the screw conveyor, but also on parameters like the feed filling level within the feed material silo, the flowability of the feed material as well as the (negative) pressure inside the grinding plant. Thus, the feed rates deviated in the range of 4.2–5.7 kg/h (low feed rate setting), 7–9 kg/h (medium feed rate setting) and 13.7–14.5 kg/h (high feed rate setting). For each of the three throughput settings, the product masses and product particle size distributions were determined for three successive time intervals of 15 min at steady state conditions of the mill. The average value of these three samples was then chosen for calculating the product mass flow rate and by that, the specific energy input. Samples for the particle size analysis were taken from the total amount of the filter product stream for each of the three intervals in order to identify process fluctuations. Since these fluctuations were negligible, only the particle size distributions obtained from the last interval are illustrated in the manuscript.

Furthermore, the temperature was measured at the mill outlet. Since it was nearly constant for all experiment (approx. 25–30 °C), temperature effects are neglected within the following discussion. The reason for the constant temperature is the double shell cooling of the mill in combination with air streams and continuous material throughput, which help to maintain comparatively low internal mill temperatures.

In the case of selected parameter combinations, the mill was also crash-stopped afterwards and emptied for determining the material hold-up inside the milling chamber. After crash-stopping, the entire mill filling was removed from the mill and sieved to separate the hold-up material from the grinding media. Afterwards, a sample was taken from the entity of the limestone hold-up in order to analyze both the particle size distribution and the powder flowability.

2.2. Grinding parameter

The impact of the product powder flow behavior on the continuous dry grinding in stirred mills was investigated in dependence of the stressing conditions inside the mill. Therefore, the stressing energy of the grinding beads was specifically changed by varying the stirrer tip speed and bead size according to Table 1. Furthermore, the bead filling

Table 1
Grinding parameters.

Parameter	
Stirrer tip speed [m/s]	2/3/4
Bitossi alumina bead diameter [mm]	3.6/2.6/2.0
Steel bead diameter [mm]	2.0
Bead filling ratio [%]	50/60/70