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The influence of methanol on efficiency and performance of a disc mill during grinding of clinker

Abstract

Liquid grinding aids (GA) are frequently used agents to enhance the grinding efficiency of clinker, limestone and other components of the cement production process. In the present study we investigated the effect of methanol on the grinding of clinker using a disc mill. Application of 400 µl methanol resulted in a greater fineness of the material with an increase of the grain size fraction smaller than 45 µm by 10 to 20 %. Simultaneously, we monitored the acceleration of the grinding vessel revealing a significant impact of methanol both on comminution and agglomeration of clinker particles. The study results highlight the ability of acceleration monitoring to track the influence of, e.g., liquid GA and predict their effect on the grinding efficiency of disc mills.

Key words

• **Liquid grinding aids** • **Real time monitoring** • **Grinding** • **Methanol** • **Disc mill**

Introduction

We have previously shown that measurement of the grinding vessel acceleration is an efficient real-time method to monitor the grinding process in a disc mill (1). The approach makes it possible to clearly identify different grinding phases and correlate them with parameters such as the particle size distribution.

During grinding of, e.g., clinker three different phases can be distinguished, namely the breakage phase, plateau phase and agglomeration phase. The initial breakage phase is characterized by a transient drop of the acceleration curve which is followed by a rise in acceleration again. In this phase majority of inserted particles are broken down to a grain size below 45 µm. The underlying mechanism is impact breakage leading to particle cracking and fragmentation along lattice lacks. The subsequent plateau phase takes between 60 and 90 s and shows constant or slightly sloping acceleration values. In this phase, particle size reduction is mainly based on attrition producing particles in the range of 10 µm and less. At the same time, a small percentage of the ultrafine particles are already converted into agglomerates. In the final agglomeration phase, the specific surface of the ground material exceeds a critical value promoting the substantial increase of agglomeration formation due to enhanced interparticle interactions and other mechanisms. The agglomeration formation is clearly reflected by a rapid and sharp decline in the acceleration curve.

Liquid chemical additives are mainly used in the cement industry for increasing product fineness and throughput while decreasing energy consumption. A wide variety of organic and inorganic grinding aids (GA) are used to improve the efficiency in grinding of limestone, clinker, cement and other components used in the cement production process. Other industrial applications for, e.g., mineral beneficiation, mainly make use of wet grinding. However, due to the general water scarcity, alternatives are being researched and the suitability of dry grinding together with GA is increasingly being tested.

In the present application note we aim at investigating the influence of a liquid GA (methanol) on the grinding of clinker using a disc mill. For that purpose, we compared the grain size distribution after grinding with and without methanol. Additionally, we recorded the acceleration curve to monitor the impact of methanol on the different phases of the grinding process.

Method

For all trials of this study, we used the combined mill and press HP-MP (Herzog, Germany) equipped with a 100 ccm tungsten grinding vessel. The test material was clinker from two different German cement plants (clinker I and clinker II). In each trial we ground 30 g of the clinker material for 120 s. During each grinding cycle eight wax tablets were automatically added to the grinding vessel via the integrated bowl feeder of the HP-MP.

For clinker I, we performed 10 trials without methanol and 10 trials with methanol at a rotation speed of both 1300 rpm and 1400 rpm resulting in a total of 40 trials. For clinker II, we performed 10 trials each with and without methanol at a rotation speed of 1300 rpm resulting in a total of 20 trials.

The sample material was introduced into the HP-MP via a standard sample cup. In trials with methanol, we previously added 400 µml methanol to the sample material by using a piston-stroke micropipette. After completion of each grinding trial the pelletizing process was skipped and the ground material was discharged into the sample cup. Subsequently, the grain size distribution was determined by using an air jet sieve with a mesh width of 45 µm. Out of the 10 trials of each experimental condition we calculated the mean percentage fraction of particles below 45 µm (d_{45} fraction).

In each trial we monitored the acceleration of the grinding vessel by a sensor mounted on the lower half of the swinging aggregate. The sensory signal was acquired by the PLC of the HP-MP and forwarded to the PrepMaster Analytics software for further data computation, graphical display and statistical analysis. Based on the acceleration values in x- and y- direction the root mean square (RMS) of acceleration was computed for each point of time resulting in an acceleration curve for each trial. Out of the 10 trials of each experimental condition we calculated an average acceleration curve.

Results

<u>Influence of methanol on grain size distribution</u>

In all trials, the addition of 400 µl methanol led to an increase of the d_{45} fraction (Table 1).

	1300 rpm		1400 rpm	
	with methanol	without methanol	with methanol	without methanol
Clinker I	92.1 ± 1.1 %	81.4 ± 1.5 %	87.8 ± 1.3 %	68.0 ± 1.7 %
Clinker II	91.3 ± 4.3 %	82.9 ± 1.4 %	n.a.	n.a.

Table 1: *Grinding efficiency as measured by the fraction of particles smaller than 45 µm (d_{45} fraction). The table displays the mean (± standard deviation) of ten trials assessed in each experimental condition.*

After grinding of clinker I at 1300 rpm, the mean d_{45} fraction was 81.4 ± 1.5 % without methanol and 92.1 ± 1.5 % with methanol. After grinding of clinker II without methanol, the d_{45} fraction was 82.9 ± 1.4 % and increased to 91.3 ± 4.3 % after adding methanol. In clinker I, increase of the rotation speed to 1400 rpm resulted in a reduction of the d_{45} fraction to 68.0 ± 6.7 % (without methanol) and 87.8 ± 1.3 % (with methanol).

Influence of methanol on the acceleration curve

Addition of methanol had a significant influence on the acceleration curve recorded during the grinding cycle. In all experimental conditions, the addition of methanol led to a shift of the average acceleration curve to higher values (Figure 1) which could be observed in all grinding phases. In the initial breakage phase, the maximum acceleration value around 8 s was slightly higher with methanol than without methanol. Furthermore, the drop of the acceleration value at 15 s was diminished by methanol. For a rotation speed of 1300 rpm, methanol reduced the amplitude between the maximum and the local minimum at 15 s by approx. 34 % (clinker I) and 20 % (clinker II). For the rotation speed of 1400 rpm, the amplitude reduction in the breakage phase was also in the range of approx. 34 %.

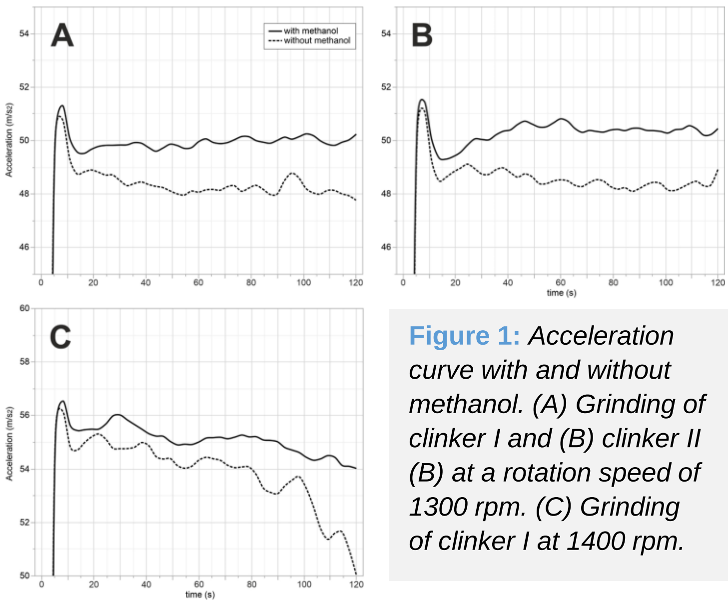

Figure 1: *Acceleration curve with and without methanol. (A) Grinding of clinker I and (B) clinker II (B) at a rotation speed of 1300 rpm. (C) Grinding of clinker I at 1400 rpm.*

In the plateau phase, the acceleration values were consistently higher after addition of methanol. For 1300 rpm, methanol resulted in a slight incline of the average acceleration curve throughout the plateau phase (clinker I, Figure 1 A) or a mainly constant course (clinker II, Figure 1 B). By contrast, the absence of methanol led to a slight acceleration decline both in clinker I and clinker II. For 1400 rpm, there was a decline throughout the plateau phase, regardless of whether or not methanol was added. However, the decline was smaller after addition of methanol (Figure 1 C).

A clear agglomeration phase could only be observed for grinding of clinker without methanol at a rotation speed of 1400 rpm. Here, a bending of the acceleration curve could be detected from about 100 s (Figure 1 C). For grinding of clinker with methanol there was only a continuous slope of the acceleration values without a clear bending.

Correlation between grain size distribution and acceleration curve

For clinker II ground with methanol, the standard deviation of the mean d_{45} fraction was 4.3 % which was higher than in the other experimental settings. Accordingly, the d_{45} of the individual trials showed a relatively wide spread between 83.1 % and 95.8 %. We therefore investigated whether there was a relationship between the grain size distribution and the course of the acceleration curve. For this purpose, we classified all trials into three groups: Trials with d_{45} fraction > 95 % (trials 1, 4, 8), >85 % (trials 2, 3, 5, 6, 7, 9) and <85 % (trial 10). The d_{45} fractions in the three groups were 96.0 ± 0.6 %, 88.7 ± 0.6 % and 83.1 %, respectively.

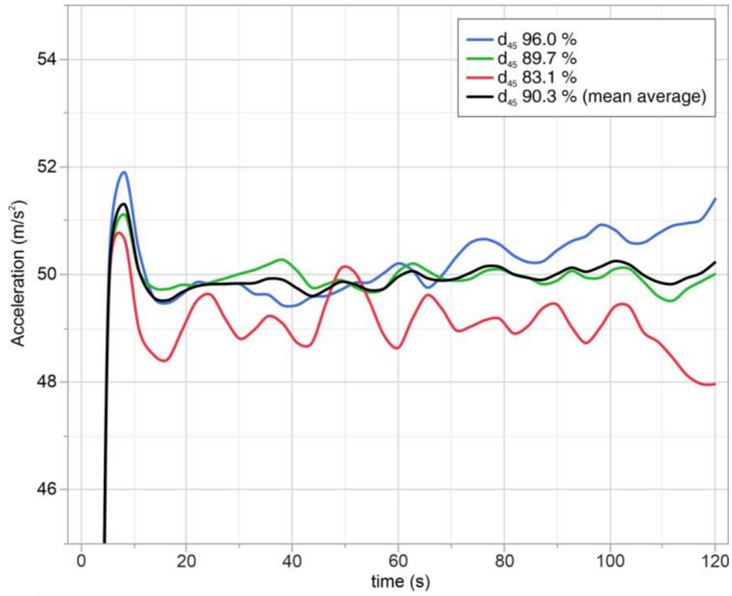

Figure 2: *Average acceleration curves of trials with a d_{45} value < 95 % (mean 96.0 %, blue), > 85 % (mean 89.7 %, green) and < 85 % (83.1 %, red). They are plotted against the average curve of all trials (mean 83.1 %, black).*

We then calculated the mean average acceleration curves of all three groups and plotted them together with the mean average curve of all trials (Figure 2).

The acceleration curve for trials with the d_{45} value of 96.0 % showed an ascending slope throughout the whole grinding cycle. In the second part of the milling cycle, it intersected the mean average curve and then was above it. By contrast, the curve with the d_{45} value of 83.1 % was constantly below the average curve and showed a significant decrease in the final stage of the grinding cycle. The grinding trial with the d_{45} of 89.7 % showed an almost identical course to the mean average curve of all trials.

Discussion

The results of this study clearly show that methanol significantly influences the performance of a disc milling during grinding of clinker. This is demonstrated by differences in the grain size distribution of samples ground with and without methanol. Methanol results in an increase of the d_{45} fraction of approx. 10 % at a rotation speed of 1300 rpm and approx. 20 % at a rotation speed of 1400 rpm.

The differences in the grain size distribution are paralleled by significant alterations in the acceleration curve. In general, methanol causes an increase of the acceleration values throughout the complete grinding cycle. This effect is evident in the breakage, attrition and agglomeration phase. We therefore assume that methanol has both a promoting effect on the comminution of particles and a preventive effect on the formation of agglomerates. The exact contribution of both effects to the final particle size distribution cannot be determined with certainty on the basis of this study. In order to answer this question it would be necessary to conduct a time series studies in conjunction with a laser granulometric analysis of the ground material.

The hypothesis of an influence of methanol both on comminution and agglomeration is supported by data from the previous studies. Liquid GA have been reported to reduce the surface energy of particles (2, 3) thus facilitating the crack propagation and successful fracturing within the granular material. At the same time, it has been shown that liquid GA neutralize particle charges (4). This again causes less particle- particle interactions and leads to improved flowability and reduced agglomeration formation. As a consequence of these molecular effects several studies reported a significant reduction of the energy consumption of the grinding process after application of different types of liquid GA (5). In accordance with this we observed an acceleration reduction for samples with methanol compared to samples without methanol. Therefore, it can be assumed that less acceleration energy has to be applied to the size reduction of the sample after addition of methanol.

Another remarkable aspect of this study is that the method of acceleration monitoring is capable of detecting even subtle changes of the sample preparation conditions. For clinker II, we found varying grain size distributions among subsequent trials which were accompanied by significant changes in the acceleration curves. The variation in the grain size distribution is most probably due to differences in the effective methanol concentration in each sample. These differences might be caused by, e.g., an inconsistent methanol application or varying methanol evaporation due to changing environmental conditions. The real-time monitoring of the grinding vessel allowed us to estimate the effective methanol concentration in each sample. Accordingly, trials with higher methanol concentrations (leading to a high d_{45} fraction) showed higher acceleration values. By contrast the acceleration values of the trial with low methanol concentration (leading to a smaller d_{45} fraction) were significantly lower. The trials with an average size reduction were in between these two extremes.

In summary, this study underlines that the disc mill monitoring is a highly efficient and accurate method for tracking the grinding process and ensuring reproducible analytical conditions. The approach has great potential to assist laboratories both in application development and routine operation.

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