A novel and easy approach to determine the specific energy demand of clinker grinding

Abstract

Using the tool condition monitoring (TCM) module within the laboratory milling and pelletizing machine HP-MP we automatically determined the specific energy demand for grinding of OPC clinker. Additionally, we investigated the influence of various solid grinding aids (GAs) on the specific energy demand and the temporal pattern of power and grinding vessel acceleration. Based on these parameters, the combination of microcellulose and Lipowax C was found to be the most efficient GA leading to a significant reduction of the specific energy demand and increase of material fineness. This study shows that the TCM module within the HP-MP allows the easy assessment of clinker grindability parameters which can be used for development of laboratory applications and production control.

Key words

• **Clinker** • **Specific energy demand** • **HP-MP** • **Grinding aid** • **Agglomeration**

Introduction

Grinding aids (GAs) are used for clinker processing to reduce electrostatic forces and agglomeration of cement grains [1]. GAs lead to an increase in the fineness and specific surface of the cement and reduction in electrical energy used for comminution of the clinker [2, 3]. Although GAs are mainly applied in continuously operated industrial mills, they are also essential for the operation of batch laboratory mills. The use of suitable GAs in the laboratory ensures, among other things, the optimal grain size distribution to carry out reliable and reproducible analyses, e.g., by XRF spectroscopy or other methods.

On a molecular level, it has been shown that the surface energy of particles is reduced by the absorption of the surface-active compounds contained in the GA. The polar parts of the additive molecule absorb on the particle surface while the non-polar compounds further shield the particles [4, 5, 6]. For GAs like triisopropanolamine and other agents it has been demonstrated that adsorption onto cement surfaces happens by coordination of Ca+ ions, hydrogen bonds and other polar interactions [5]. Usually, the surface energy of particles decreases with an increasing amount of GA, as a more complete adsorption layer on the particles is achieved with sufficiently high GA concentrations [7]. However, the adsorption energy also depends on the molecule- solid interactions. Therefore, various material with different surfaces properties react differently to the different GA compounds.

It is hardly possible to draw universal rules on solid-specific GA effects since even small changes in the properties of the solid or the grinding environment may cause significant consequences on the GA efficiency. Therefore, the application of GAs is still mainly based on empirical knowledge.

Here we describe a novel approach for automatic determination of the specific energy demand of clinker using the tool condition monitoring (TCM) of a laboratory vibrating disc mill. The specific energy demand is defined as the amount of energy that is needed per product mass to obtain a specific fineness. It is an important parameter to describe the grindability of a specific material and the beneficial effects of GAs. The correlation between specific energy demand and product fineness can be displayed graphically by means of characteristic curves. This makes it easy to compare and quantify the effects of the different GAs in an objective manner. The TCM tools from Herzog enable the real-time acquisition of grindability parameters using laboratory standard equipment. By contrast, methods according to Zeisel, Bond or Hardgrove can only be carried out offline and require a significant effort of personnel and time.

In this application note we investigate the effect of various GAs on the specific energy demand of clinker. In addition, we examine the impact of GAs on the dynamic course of power and acceleration during a grinding period of 300 s. The temporal evolution of these parameters will provide further insights into timing and extent of particle comminution, material flow behavior, and agglomeration formation.

Methods

We ground ordinary Portland cement (OPC) clinker from a German cement producer using the milling and pelletizing machine of the type HP-MP (Herzog, Germany). The HP-MP was equipped with the standard TCM module for the evaluation of grinding performance.

We conducted a total of four test series, with eight samples of 30 g clinker material being ground in each test series. While all tests were performed at the same speed of 1500 rpm, the grinding time for each of the eight samples was different at 5, 10, 20, 30, 40, 50, 60 and 300 s. Apart from the 300 s trial, after each trial the ground sample was discharged into a cup and the particle size distribution as well as the specific surface were determined by granulometry (Mastersizer 3000, Malvern, UK).

During each grinding trial, the grinding power of the HP-MP and the acceleration of the grinding vessel were automatically recorded at a sampling frequency of 100 Hz. Using the integral of the grinding power as well as the specific surface measured at the different grinding times, the characteristic curve of the specific energy demand for each test series was determined. In the 300 s trial we only plotted the grinding power and acceleration over time without calculation of the specific energy demand.

The test series were carried out using a compact linear automatic system. All eight samples of a test series were loaded into the input magazine of the HP-MP. After completion of grinding, the ground sample was transported to the granulometry device for measurement of the specific surface. All data of acceleration, specific grinding power and granulometry were automatically recorded and processed by using the PrepMaster Analytics software (Herzog, Germany).

The clinker was ground either without any GA (test series A) or together with solid grinding aids in tablet form. For this purpose, six tablets of PE 190 (series B), HMPA 20 (series C) or HMPA 40 (series D) were added to each sample of 30 g clinker.

All investigated solid GAs are standard products frequently used in the sample preparation of various materials. The PE 190 grinding aid is a macromolecular linear polyethylene wax with a high density. The HMPA grinding aids contain microcellulose with a grain size of around 100 µm and a density between 0.28 and 0.33 g/cm3.

In HMPA 20, microcellulose is the only active ingredient mixed with a binder. HMPA 40 mainly consists of microcellulose and contains a small amount of Licowax C in a mixing ratio of 1:9.

Results

Assessment of the specific energy demand

In Figure 1, the specific surface of the ground material (cm^2/g) is plotted against the specific energy demand (kWh/t) at the different measurement times from 5 to 60 s.

In test series A (no GA), the specific surface continuously increases up to approx. 3200 cm^2/g. During this initial period, the applied energy increases linearly and is similar to the energy demand of HMPA 20 and HMPA 40. In the subsequent 40 seconds, however, there is a sharp rise in the specific energy to a maximum of approx. 170 kWh/t. Simultaneously, the specific surface area increases by only about 1400 cm^2/g to a maximum value of 4600 cm^2/g.

Test series B (PE 190) exhibits a rise of the specific energy to approx. 190 kWh/t. At the same time, only an insignificant growth of the specific surface area from 880 cm^2/g to 1070 cm^2/g is observed. From 20 seconds on, after a temporary increase, the specific surface area decreases indicating the formation of agglomerations.

Test series C (HMPA 20) shows a continuous increase in the specific surface area from approx. 1300 cm^2/g to 5500 cm^2/g. At the same time, the specific energy increases up to approx. 130 kWh/t. From 40 seconds, the energy consumption increases more quickly.

In test series D (HMPA 40), the specific surface area increases up to 6000 cm^2/g during 60 seconds of grinding. This is the highest value among all grinding aids investigated in this study. At the same time, the specific energy reaches only 117 kWh/t, which is the lowest value for all GAs evaluated. From 40 seconds grinding time, only a slight acceleration in energy consumption is observed.

The grey area drawn in Figure 1 represents the typical range of specific energy consumption for grinding of various clinker types as measured by the Zeisel grindability test (according to [8,9]).

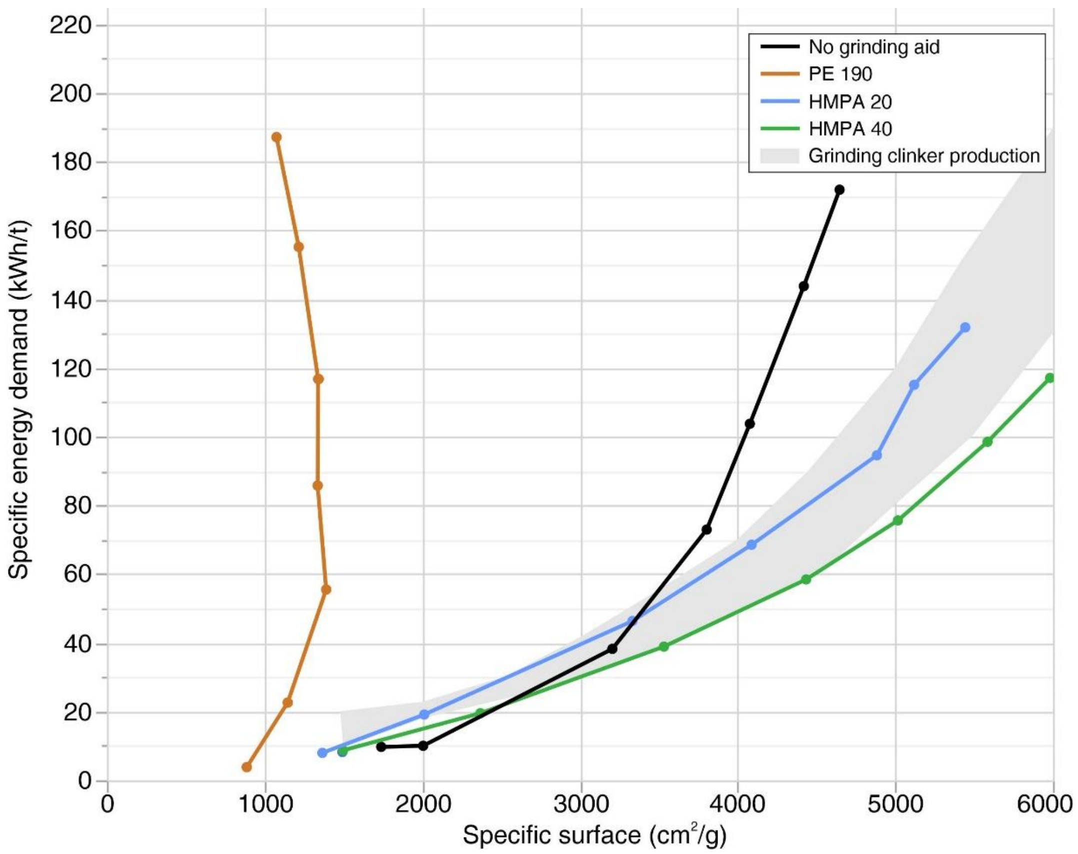

Figure 1: *Graphical display of the specific energy demand for grinding of OPC clinker. To obtain the characteristic curves, the specific energy was plotted over the specific surface area measured at different times.*

This graph contains the specific energy demand for clinker grinding without any grinding aids as well as for grinding with various grinding aids (PE 190, HMPA 20 and HMPA 40).

The gray area within the graph represents the range of the specific energy demand of clinker grinding as obtained by the Zeisel test (according to [8, 9]).

Temporal pattern of grinding power and acceleration within the 300 s trials

For test series A- D we plotted and evaluated the course of power and acceleration of each 300 s trial. Figure 2 shows the acceleration and power curves for grinding without GA (A), PE 190 (B), HMPA 20 (C) and HMPA 40 (D).

During grinding without GA, a continuous increase in power can be observed until about 190 s. From approx. 120 s, the steepness of the power rises markedly.

From 190 s, the power drops from 0.55 kW to values between 0.45 and 0.50 kW. Parallel to the increase in power, the acceleration shows a continuous decline. The drop in power at 190 s is accompanied by a simultaneous drop in acceleration and subsequent plateau formation.

Grinding with PE 190 (test series B) is characterized by a continuous increase of power and decrease of acceleration. Otherwise, no special incidents can be observed in the dynamic course of power and acceleration.

Grinding with HMPA 20 initially shows an increase in power, which peaks at about 15 s. This is followed by a drop in power until approx. 60 s and then a slight increase in power until 120 s. Acceleration shows a peak at approx. 15 s and then a significant drop until approx. 30 s when acceleration increases again. From approx. 60 s, the increase of acceleration steadily diminishes until 120 s when there is a sudden upturn in power and a drop in acceleration (asterixis in Figure 2 C). Subsequently, the power slowly increases to values of approx. 0.30 kW. At the same time, the acceleration slowly decreases to values around 62.5 m/s^2.

Grinding with HMPA 40 follows a similar pattern as the power and acceleration curve of HMPA 20. Two significant differences can be identified: First, the power and acceleration values are generally lower than for grinding with HMPA 20. Second, the sudden power upturn and acceleration decrease occurs about 40 s later than with HMPA 20, i.e. at 160 s (asterixis).

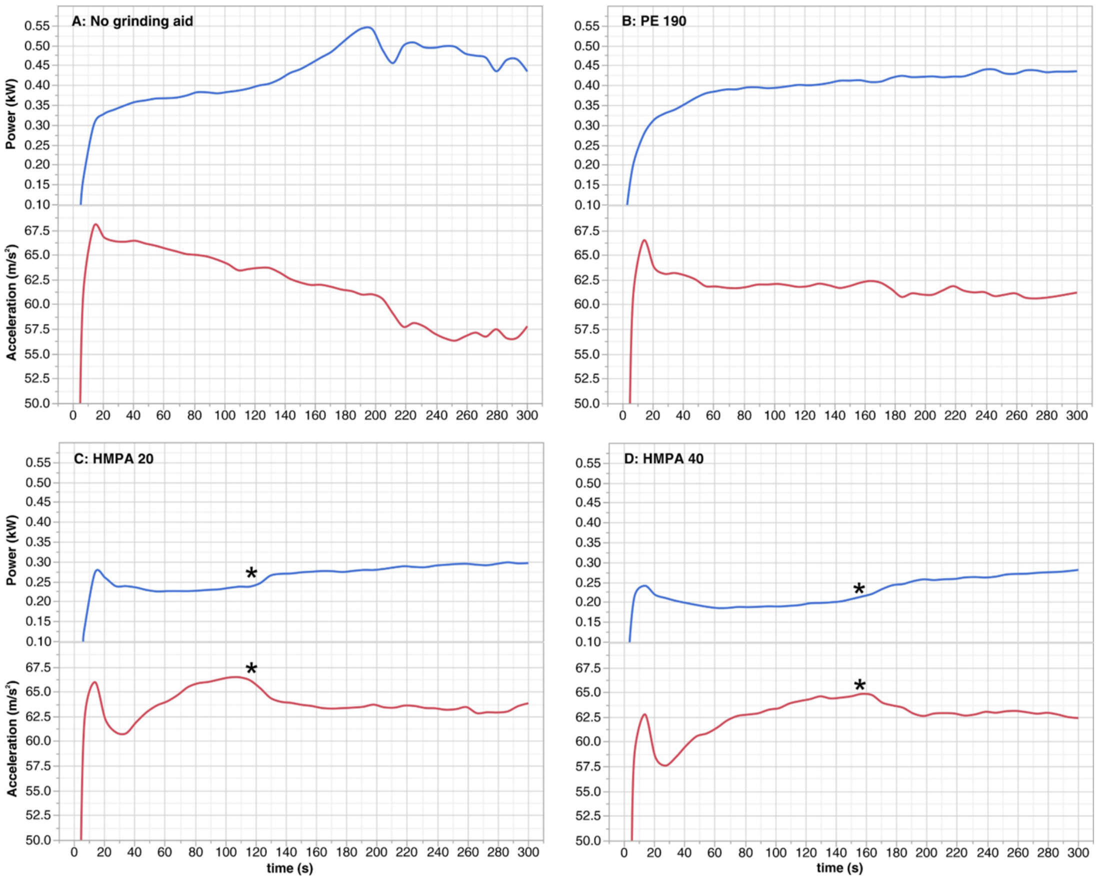

Figure 2: *Display of the time course of grinding power and acceleration of the grinding vessel during the 300 s grinding trials.*

In each test series a 300 s grinding trial was performed to examine development of power and acceleration without any grinding aids (A), with PE 190 (B), with HMPA 20 (C) and HMPA 40 (D).

The power and acceleration pattern allows the monitoring of the grinding performance. In A and B, the continuous increase of power and decrease of acceleration indicates inefficient grinding. In C and D, the initial grinding is efficient. At a certain potin of time (*) agglomerates are formed despite grinding aids.

Discussion

This study shows that the TCM module implemented in the HP-MP allows the easy determination of the specific energy demand for grinding of clinker. The TCM module provides parameters to evaluate the grinding efficiency in an objective manner. The information facilitates the development of the most appropriate sample preparation method for an optimal analysis, e.g., by means of X-ray fluorescence spectroscopy. Moreover, the influence of different GA types can be quantified for comparison and benchmarking with each other.

For the clinker investigated in the present application note, the most effective GA can be easily identified from the curve presented in Figure 1. PE 190 leads to a deterioration of the grinding efficiency compared to grinding without GA. For fineness below 3000 cm^2/g, HMPA 20 and 40 reveal no significant differences to grinding without GA. Beyond 3000 cm^2/g, however, the HMPA tablets exert a considerable effect and cause a higher fineness with lower energy consumption. The direct comparison of the HMPA grinding aids shows that HMPA 40 is more efficient than HMPA 20 due to its lower energy requirement and larger gain in surface area.

The analysis of the temporal pattern of power and acceleration (Figure 2) provides further insight into the grinding behavior of the material and the GA influence. When the clinker is ground without GA, the continuous increase in grinding power and the constant decline in acceleration suggest an insufficient comminution of the clinker. The rise in power from 120 to 190 s demonstrates an enhanced agglomeration and clogging of the material on the grinding vessel wall. At 190 s, the power drops while the acceleration exhibits a low-level plateauing. This is a characteristic indicator that the clinker partially adheres to the grinding vessel wall and a major portion of the material no longer participate in the grinding process.

For PE 190, the continuous increase in power and decrease in acceleration reveal inefficient grinding. The absence of major changes in power and acceleration shows that there is no stronger agglomeration or clogging of the material.

HMPA 20 and HMPA 40 demonstrate a completely different course of power and acceleration compared to grinding without GA or with PE 190. After a transient power peak at approx. 15 s, the subsequent drop in power indicates that an effective particle size reduction has been achieved and subsequently less energy is employed in surface enlargement. Initially, HMPA results in a highly effective reduction of electrostatic forces thus promoting particle breakage and preventing agglomeration. However, from about 60 seconds onwards, a slight increase in power can be observed. This suggests that as the surface of the material grows, increasing amounts of energy are put into redissolving of agglomerates. At a particular point, agglomeration occurs nevertheless, which is reflected in a sudden increase in power and decrease in acceleration. This point is earlier for HMPA 20 (120 s) than for HMPA 40 (160 s).

The overall applied grinding power is lower for HMPA 40 than for HMPA 20. While HMPA 20 contains only microcellulose, HMPA 40 also includes small amount of Licowax C. Apparently, the wax leads to more effective grinding, which may be due to the additional reduction of adhesive forces or improvement of the dispersion and flow behavior of the material within the grinding vessel.

The results of this study show that assessment of the specific energy demand, power and acceleration can be used as a supporting technology in the development of laboratory application. Interestingly, the value of the specific energy demand obtained in this study were comparable to those measured in real-scale production mills. As an example, in Figure 1, we have plotted the specific energy demand which was determined by using the Zeisel test [8, 9]. Also, other methods of power determination, e.g., by means of laboratory ball mills yielded values of a similar order of magnitude [10].

This may create an opportunity to apply the values gathered in the laboratory mill to clinker grinding on an industrial scale. However, the significant differences between industrial and laboratory grinding must be taken into account. One major difference is that in industrial mills grinding is continuous whereby the grinding forces are directed at the coarser particles and the fine particles are discharged once they have reached the necessary fineness. All particles that are larger than the cut size are sent to a reject stream, therefore creating a circulating load. By contrast, the laboratory disc mill is a batch mill without discharging fine particles from the grinding process. Further studies will have to investigate whether the values acquired in the HP-MP can be transferred to the plant's large-scale clinker grinding and used for process control optimization.

References

[1] Assaad J. J. (2015). Industrial versus Laboratory Clinker Processing Using Grinding Aids (Scale Effect). Advances in Material Science and Engineering, http://dx.doi.org/10.1155/2015/938176

[2] Teoreanu I. and Guslicov G (1999). Mechanisms and effects of additives from the dihydroxy-compound class on Portland cement grinding. Cement and Concrete Research, 29 (1), 9-15

[3] Assaad J. (2015). Quantifying the effect of clinker grinding aids under laboratory conditions. Minerals Engineering, 81, 40-51

[4] Prziwara P. and Kwade A (2020). Grinding aids for dry grinding processes- Part I: Mechanism of action and lab-scale grinding. Power Technology, http://doi.org/10.1016/j.powtec.2020.07.038

[5] Mishra R.K., Flatt R.J., Heinz H. (2013). Force field for tricalcium silicate and insight into nanoscale properties; cleavage, initial hydration, and adsorption of organic molecules. J. Phys. Chem. C117, 10417-10432.

[6] Weibel M, Mishra R.K. (2014). Comprehensive understanding of grindin aids, Zement- Kalk- Gips, 6, 28-39.

[7] Prziwara P., Breitung-Faes S., Kwade A. (2018). Impact of grind aids on dry grinding performance, bulk properties and surface energy. Adv. Powder Technol. 29, 416-425.

[8] Ehrenberg A. (2006). Hüttensand- Ein leistungsfähiger Baustoff mit Tradition und Zukunft. Beton- Informationen 5, 67- 95.

[9] Zeisel H.G. (1952). Entwicklung eines Verfahrens zur Bestimmung der Mahlbarkeit. Schriftenreihe der Zementindustrie. 14.

[10] Assaad J.J., Asseily S.E., Harb J. (2009). Effect of specific energy consumption in fineness of Portland cement incorporating amine or glycol-based grinding aids. Materials and Structures, 42, 1077-1087.

Germany

HERZOG Maschinenfabrik GmbH & Co.KG
Auf dem Gehren 1
49086 Osnabrück
Germany
Phone +49 541 93320
info@herzog-maschinenfabrik.de
www.herzog-maschinenfabrik.de

USA

HERZOG Automation Corp.
16600 Sprague Road, Suite 400
Cleveland, Ohio 44130
USA
Phone +1 440 891 9777
info@herzogautomation.com
www.herzogautomation.com

Japan

HERZOG Japan Co., Ltd.
3-7, Komagome 2-chome
Toshima-ku
Tokio 170-0003
Japan
Phone +81 3 5907 1771
info@herzog.co.jp
www.herzog.co.jp

China

HERZOG (Shanghai) Automation Equipment Co., Ltd.
Section A2, 2/F, Building 6
No. 473, West Fute 1st Road,
Waigaoqiao F.T.Z., Shagnhai, 200131
P.R.China
Phone +86 21 50375915
info@herzog-automation.com.cn
www.herzog-automation.com.cn