Assessment of grindability in slag sands by using a laboratory disc mill: Comparison to the Zeisel test

Abstract

We have previously shown that a vibrating disc mill can be used to determine the grindability of clinker. In this application note, we aimed at assessing the grindability of various slag sands which are used for production of blast furnace cements. For this purpose, we compared the grindability of four different slag sands as measured in a vibrating disc mill of (type HP-MP) to the results of the Zeisel test used as a standard protocol in the cement industry. We found that both the HP-MP and the Zeisel test revealed the same results for slag sand grindability. Minor differences were observed in the gradients of grindability curves which might be due to the different input grain sizes. The outcome of this study confirms that a vibrating disc mill can be used for the easy, quick, and cost-effective determination of grindability in different cement materials.

Key words

• **Grindability** • **Slag sand** • **Vibrating disc mill** • **Zeisel test** • **Cement**

Introduction

Slag sands are combined with Portland cement clinker to form so-called blast furnace cements. Blast furnace cements have various favorable technical properties like, e.g., a high post-hardening potential and increased resistance to chemical attacks, sulphate-containing water, or alkali-silica reaction [1, 2]. Furthermore, a blast furnace cement with 75 wt% slag sand requires less than half the primary energy of a Portland cement and causes only about one third of the CO_2 emissions [2]. However, the slag sands added usually have to be ground very finely to counteract certain shortcomings of blast furnace cements, such as lower early strength [3]. Consequently, increasing the specific surface area of the slag sands results in significantly higher energy consumption and production costs.

It is therefore helpful to assess the grindability of the different slag sands already in the laboratory to predict the expected grinding energy and associated costs. In general, grindability is understood as the change in dispersity of a material in relation to the specific energy input required. For input materials in the cement industry, the grindability test according to Zeisel has become the standard procedure [4]. The test apparatus used for the Zeisel test is a modification of Hardgrove's ball ring mill with a grinding track on which the grinding balls run combined with a rotating grinding bowl. The torque transferred from the balls to the grinding track through the sample material (30 g) corresponds to the energy introduced into the material to be ground. The energy input can be recorded by means of the deflection of the grinding bowl using a spring dynamometer.

Whilst the Zeisel test is a standard procedure, it also entails some disadvantages: It is time-consuming, cost-intensive and can usually only be carried out by a few specialized laboratories. Furthermore, the results are often only available with a latency of several days and cannot be used for immediate production control. Finally, the feed grain size has a major influence on the result of the Zeisel test. The acceptable grain of the Zeisel test is between 0.75 mm and 1.0 mm. However, for most slag sands, only approx. 20 % of the grain size fractions lie within this range and the remaining particles are equally distributed above or below.

We have previously described a new approach to measure the grindability of clinker using a laboratory vibrating disc mill [5, 6]. This has the advantage that any laboratory can carry out a grindability measurement and the results are available very quickly, virtually online. In this application note, we apply the method to determine the grindability of four different slag sands and compare the test results with the findings obtained during the Zeisel test.

Methods

We ground four different slag sands (Figure 1) from various steel plants using the combined 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.

Five aliquots of each of the four slag sand samples were ground for 20, 55, 90, 130 and 170 s, respectively. Each sample was ground at the same rotation speed of 800 rpm and a constant grinding vessel temperature of 35 °C. For the test we used pre-dried sample material without any grinding aid. 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).

Figure 1: *Photographs of the four different slag sand types examined in this study.*

During each grinding trial, the grinding power of the HP-MP was 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 was determined. In the 170 s trial we also plotted the grinding power over time (Figure 2).

A representative sample of each of the four slag sands was sent to a specialized laboratory that carried out the Zeisel test.

Results

Grinding power over time

For all four slag sands, there was a characteristic course of the power curve with initially higher values, which then declined within the first 50 seconds and subsequently stabilized at a constant level (Figure 2).

Slag sand #4 showed the fastest drop to 0.148 kW and then increased to values of 0.155 kW. This was the highest value of all four sands. The other three sands showed varying degrees of decline to values between 0.145 and 0.150 kW. All three power curves then stabilized at values around 0.150 kW.

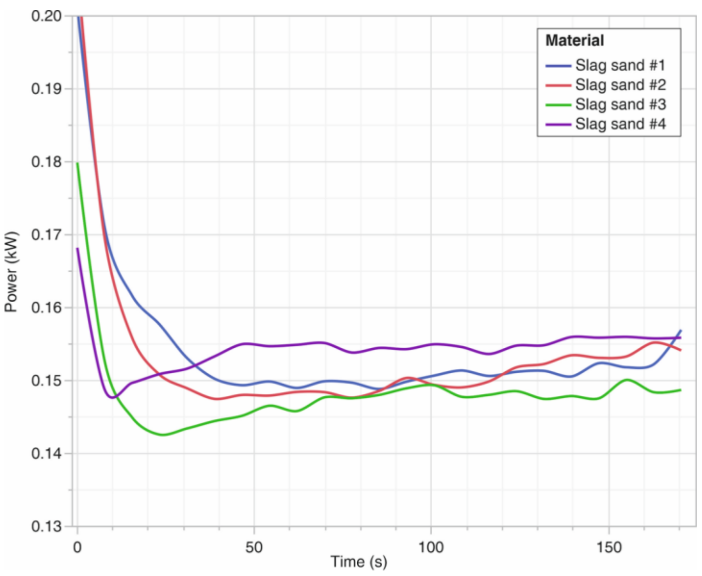

Figure 2: *Plot of the grinding power (kW) over time for each of the four slag sand samples.*

Grindability as determined by the HP-MP

In Figure 3, the specific surface of the ground material (cm²/g) was plotted against the specific energy demand (kWh/t) at the different measurement times from 20 to 170 s. The four curves showed a typical progression with an almost linear increase at the beginning and subsequently transition to an exponential progression. The accelerated increase in specific energy at later stages of grinding typically characterizes the formation of agglomerates as well as increasingly elastic properties of fragmented particles.

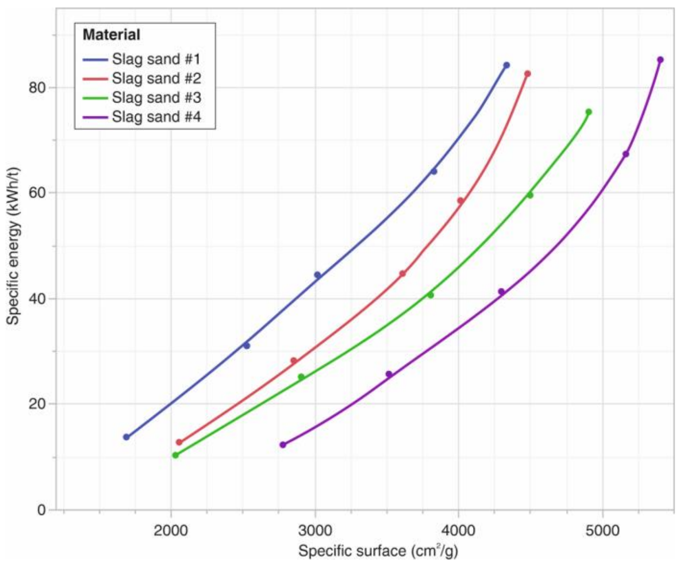

Figure 3: *Graphical display of the grindability of each of the four tested slag sand shown by plotting specific energy (kWh/t) over specific surface (cm²/g).*

The graph revealed clear differences between the four slag sands. Blast furnace slag #4 showed the highest fineness, which developed from a specific surface of initially 2800 cm²/g to 5300 cm²/g. In contrast, slag sand #1 had the lowest fineness with values of 1800 cm²/g to 4200 cm²/g. Blast furnace slags #2 and #3 were between these two curves.

Grindability as determined by the Zeisel test

The Zeisel test curves (Figure 4) were comparable to those obtained using the HP-MP. Here again, an initially linear, then exponential increase could be observed. Overall, the curve gradient was lower in the Zeisel test than in the HP-MP trials, particularly in the exponential section of the curve. The smaller exponential increase is possibly due to the lower maximum fineness achieved in the Zeisel test. This was 4500 cm²/g in the Zeisel test compared to 5500 cm²/g in the HP-MP. As with the HP-MP, the measured values for the specific energy were in the range between 10 kWh/t and 90 kWh/t.

The order of the curves in the Zeisel test was identical to the measurement in the HP-MP. Slag sand #1 produced the top curve, i.e., required the highest energy. Slag sand #4 had the lowest specific energy requirement, while slag sands #2 and #3 were in between.

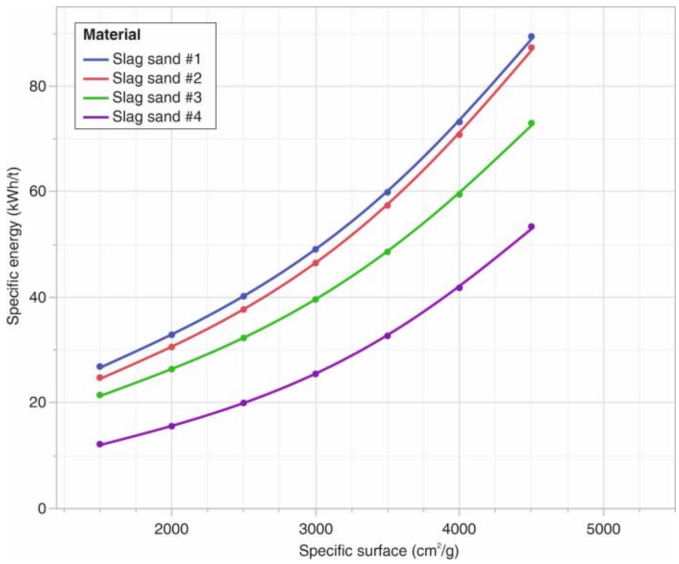

Figure 4: *Graphical display of the grindability of the four different slag sand samples as revealed by the Zeisel test.*

Discussion

The results of this study confirm the previous clinker studies [5, 6] and demonstrate that the HP-MP can be used to determine the grindability of cement materials like, e.g., slag sands. As for clinker, the values of grindability obtained in the HP-MP were in the same order of magnitude as in the Zeisel test. In addition, the measurement in the HP-MP and the Zeisel test resulted in the same assessment of the grindability for the four slag sands. These findings indicate that the determination of the specific energy demand in the vibrating disc mill provides a good analogy to the existing Zeisel standard procedure.

Differences were found in the gradient of the grindability curves, with the curves in the HP-MP method being steeper than in the Zeisel test. This difference can be attributed to various causes. One possible explanation might be the different input particle size. While the Zeisel test only accepts samples with grain sizes between 0.75 and 1.0 mm, the HP-MP can process grain sizes up to 5.0 mm. The comminution of the larger grain sizes in the HP-MP may explain the steeper increase in the specific energy and the overall higher energy demand across all four materials. Future measurements in the HP-MP with a selected grain size fraction could show whether a better match of the curves can be achieved.

The main advantage of determining the grindability in a vibrating disc mill is that the analysis results are instantaneously available. In an automated laboratory, the assessment of grindability can be completed within approximately one hour. Consequently, adjustments could still be made to the production process if necessary. Further advantages are the permanent access of the laboratory to this easy-to-perform method and the low costs. Fully automated data recording and evaluation of grindability is included in the TCM Module for grinding performance of the PrepMaster Analytics software from Herzog.

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