CEMENTS GROUND IN THE VERTICAL ROLLER MILL
FULFIL THE QUALITY REQUIREMENTS OF THE MARKET

IN DER VERTIKAL-WÄLZMÜHLE GEMAHLEN E ZEMENTE
ERFÜLLEN DIE QUALITÄTSANFORDERUNGEN DES MARKTES
Cement production typically requires the grinding of three separate types of material during the process: the raw materials and coal before the kiln, and the final cement product once firing is complete and the clinker cooled. Looking back on a century or more, ball mill systems were used for all three grinding stages, but the development of more energy-efficient vertical roller mills (VRMs) led to their replacement. Initially, this focused on grinding coal and the cement raw materials, with the adoption of vertical roller mills for cement product grinding – with its finer grinding requirements – coming more recently, in the late 1990s. The main reason for the delay in uptake of VRM technology for cement grinding was the concerns of producers that their product qualities would not meet market requirements, specifically in three key areas: water demand, strength development and setting times. Over the past 15 years, however, it could be demonstrated that these concerns are unfounded, and that the quality of cement obtained from VRM grinding is as good as, or in some cases better than, that produced in a ball mill. In consequence, most of the world’s major cement producers now use vertical roller mills for cement grinding with no hesitation.

(English text supplied by the author)
Cements ground in the vertical roller mill fulfil the quality requirements of the market

In der Vertikal-Wälzmühle gemahlene Zemente erfüllen die Qualitätsanforderungen des Marktes

1 Introduction

There is no question that vertical roller mills like the Loesche Mill offer significant advantages over ball mills in terms of their energy efficiency. As noted in a current publication (1) the specific power consumption of a ball mill is higher than that of a vertical roller mill (VRM) carrying out the same operations by a factor of between 1.5 and 2, depending on the degree of optimisation of the ball mill. Fig. 1 illustrates this connexion, as well as showing the increasing energy benefit that can be obtained with a vertical roller mill as the specific Blaine surface area rises.

![Figure 1: Specific power consumption of ball mill system v/s vertical roller mill system for OPC grinding](image)

Fundamentally, ball mills use proportionately more energy to produce a finer ground product than do VRMs, and while the energy consumption in a VRM obviously does increase with product fineness, it does so much less rapidly. Indeed, while the difference in energy efficiency is significant when a VRM is used for grinding OPC, the energy benefit is even greater in the case of blastfurnace slag which is hard to grind, as can be seen in Fig. 2.

Having demonstrated the energy advantage of the VRM concept over ball milling, the remainder of this paper focuses on various aspects of cement quality, with the aim of putting to rest once and for all the outdated, disproven ideas that cements produced in a VRM differ markedly from those produced in traditional ball mill systems. The article looks first at the various grinding systems that are available for cement producers today, then takes each of the purported product quality issues in turn to show that these are neither justified nor valid.

2 Grinding system options

Today, cement producers have the option for using a range of different systems for cement grinding. A comprehensive list of all the available options would certainly include traditional ball-mill systems, high-pressure grinding rolls in every kind of design types and their various combinations with ball mills and, of course, VRMs vertical roller mills. All of these systems treat the material to be ground differently, in that the actual grinding needed to achieve the desired characteristics varies from one to the other. Fig. 3 illustrates schematically some possible alternative flowsheets using VRMs and ball mills.

With the focus here being on ball mills and VRMs, Table 1 shows some comparative performance parameters for the two systems when used for grinding cement. It has to be remembered that there are major differences in the mechanism of grinding between VRMs and ball mills, in terms of how grinding occurs, the residence time, the level of repeat grinding and recirculation factors, among others.

In a VRM, comminution occurs by pressure and shear forces that are introduced via the grinding rollers. In ball mills, comminution is mainly done by impact, with the grinding balls being lifted up by the rotating shell, then dropped back onto the charge and other balls. There is some attrition as well.

There is also a major difference in terms of the average residence time – the time the material particles remain in the mill system before they leave the classifier as product. Including both grinding in the mill body and a circulation factor, the residence time for a VRM is less than one minute, while particles can remain within a ball mill system for 20 to 30 minutes. Individual cement particles will be ground from one to three times in a VRM before being offered to the classifier, whereas repeat grinding in a ball mill is virtually uncountable because of the grinding mechanism. Finally, while a ball mill will have a recirculation factor of 2 to 3, this increases between 6 to 20 for a VRM, depending on the pressure height, the grinding tools configuration, the grindability of the material and the required product fineness. The differences in all of these parameters are shown in Table 1.

3 Outlining the issues

The first modern Loesche Mill for cement and slag grinding, a mill with the designation LM 46.2+2, was sold to Taiwan’s Lucky Cement Corp. in 1993 and commissioned in 1994, for grinding cement at its Pu Shin plant. While producers were initially concerned that the quality of the cement produced...
would not meet their clients’ specifications, results from the first installations showed that the cement qualities are indeed acceptable to the market. From the late 1990s, the majority of cement producers changed their preference towards the vertical roller mill system.

The producers’ concerns were centred on three specific areas: that cement produced in a VRM would have a higher water demand when mixed to a workable paste; that the setting times would differ drastically; and that the compressive strength would be lower when compared to the same cement produced in a ball mill system. The supposed reasons for these concerns were, respectively: a steeper particle size distribution, the different particle shape produced by a VRM, and a lower gypsum dehydration. In point of fact, operating experiences since then have shown conclusively that none of these concerns is justified, and that the cements produced by grinding in a VRM meet market requirements in all respects.

4 Particle size distribution

The particle size distribution of a cement is usually plotted on the well known RRSB-diagram. Fig. 4 shows size distribution curves for cements produced by grinding in VRMs and in ball mills. The inclination of each curve, the slope ‘n’, is measured at the positioning parameter that represents the particle diameter at which the residue, in terms of mass, is 36.8 %. A higher ‘n’-value produces a steeper curve, whereas the lower the slope, the more fine and over-ground particles are in the finished product at a constant Blaine value, measured in cm²/g.

In more general terms, a typical particle size distribution for a ball mill system in closed-circuit operation with a high-efficiency, third-generation classifier would be between 0.75 and 0.98. The equivalent would be between 0.82 and 1.05 in a Loesche vertical roller mill system. These ranges may differ when different types of laser sizers are used.

The area of concern in the past was that the steeper particle size distribution for VRM cements would lead, for example, to their having higher water demand and lower early strength development. This could, of course, generate problems, especially in precast concrete manufacturing with its sophisticated production processes regarding cycle and stripping times.

The question then has to be asked as to the reason for the different slopes in the particle size distribution diagrams. Firstly, and as explained above, the different grinding behaviour of the vertical roller and ball mill systems means that particles remain in a ball mill system for about 20 to 30 minutes before they leave the classifier as product. They are impacted repeatedly during that time, with the result that some particles are ground more than necessary. By contrast, the limited amount of grinding for each particle in the VRM system before classification avoids any unnecessary over-grinding.

![Figure 3: Alternative flow sheets using vertical roller mills and ball mills](image)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Ball mill (closed circuit)</th>
<th>Vertical roller mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comminution by</td>
<td>Impact and attrition</td>
<td>Pressure and shear forces</td>
</tr>
<tr>
<td>Residence time [min]</td>
<td>20 to 30</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Crushings before separation</td>
<td>∞</td>
<td>1 to 3</td>
</tr>
<tr>
<td>Circulation factor</td>
<td>2 to 3</td>
<td>6 to 20</td>
</tr>
<tr>
<td>Wear rate [g/t]</td>
<td>~ 50</td>
<td>3 to 6</td>
</tr>
</tbody>
</table>

![Figure 4: Different particle size distributions](image)
A higher grinding pressure will result in more intense grinding, with the development of more fine material, and hence a shallower particle size distribution. The higher the dam ring, the longer the material remains on the grinding table, and the more it is ground in one cycle. This again results in the generation of more fines, and a shallower particle size distribution. In addition, the airflow and the classifier settings can be adjusted in order to produce the desired product characteristics.

If a similar product to one from an existing ball mill system is needed, however, the VRM can be adjusted to achieve this. As shown in Fig. 5, adjustments can be made to the grinding pressure, the dam ring height, the mill airflow, the classifier rotor speed and, for cements with a very high Blaine value, the table speed. Fig. 6 shows the effects on the slope of the particle size distribution curve by adjusting each of these parameters.

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Testwork carried out in 2009 at the Vicat group’s Montalieu plant in France has proved conclusively that these adjustments will deliver the required results. The study involved grinding the same cement once in a closed-circuit ball mill system and once in a grinding plant with a Loesche mill LM 53.3+3. Fig. 7 shows some results from the project, confirming that the positioning parameter, the slope of the particle size distribution and the product fineness of both cements are in exactly the same range. Furthermore, the water demand for both cements needed to create a cement paste with a standard consistency are the same, reflecting the same slope ‘n’, positioning parameter and Blaine values. This testwork proved in a practical way that there is no difference in material properties due to the differing grinding mechanisms.

**5 Particle shape considerations**

Differences in particle shape have been another area in which vertical roller mill systems have been the subject of scrutiny. The suggestion was made that cement particles coming out of a ball mill are always much rounder than those coming out of a VRM, which are more shallow and elongated. This again, together with fewer fine particles, would result in increased water demand for the cement paste.

The roundness or circularity of the particles can be determined by optical methods such as image analyses. Within those measurements, particle shapes are described with values of between 1 and 0. A value of 1 indicates a particle that is perfectly spherical, and as the value approaches 0, it indicates an increasingly elongated, shallow polygon.

Fig. 8 illustrates the particle size distribution of a cement with a product fineness of about 4 100 g/cm² acc. to Blaine. This shows that the size of the smallest particle is about 0.1 µm and the size of the largest particle is about 52 µm for this particular cement. In general, while a wide variety of cements are ground to different finenesses, the largest particles are usually between 45 and 55 µm.

In addition, 95 % of all the cement particles are below 45 µm in size, again depending on the final product fineness and the slope of the particle size distribution curve.

Testwork undertaken by the VDZ in its role as Germany’s Cement Research Institute compared the particle shapes produced in different types of milling systems. Fig. 9 shows a plot of the shapes of cement particles from high-pressure grinding rolls, ball mills and vertical roller mills, with the particle size being shown on the x-axis and the circularity on the y-axis [2].

It is clear from this plot that there is no significant difference in particle shape between the cements produced in all three of these mill types, apart from at a particle size of around 58 µm, where the shapes begin to differ. However, this particle size rarely occurs in most types of cement, and where it does, it only appears in such small proportions that there is no severe influence on the water demand, strength development or other issues.
Therefore, if the same cement recipe is ground in both mills, the retention time in ball mills is 20 to 30 times greater than in vertical roller mills, the cement is exposed to the hot-gas atmosphere for much longer. In addition, ball mills use much more energy than vertical roller mills in order to grind the same amount of cement, with this additional energy heating the material even further. Because of this, the particle temperatures at the exit from ball mills operated without water cooling are usually about 30 °C higher than those experienced with vertical roller mills.

As the retention time in ball mills is 20 to 30 times greater than in vertical roller mills, the cement is exposed to the hot-gas atmosphere for much longer. In addition, ball mills use much more energy than vertical roller mills in order to grind the same amount of cement, with this additional energy heating the material even further. Because of this, the particle temperatures at the exit from ball mills operated without water cooling are usually about 30 °C higher than those experienced with vertical roller mills.

Therefore, if the same cement recipe is ground in both mills, paste from cement ground in a vertical roller mill will exhibit different setting behaviour and strength development during hardening. This is because the gypsum is dried more intensively in a ball mill system, resulting in the formation of more hemihydrate and hence higher sulphate solubility.

Of course, commissioning any new mill requires the system to be optimised, including adjusting the amounts of gypsum and the other additives needed to achieve the required setting and strengthening behaviour. The same applies when changing from a ball mill system to a vertical roller mill system, when the operator needs to increase slightly the amount of gypsum put into the cement, or substitutes the gypsum to increase the solubility by hemihydrate or anhydrite.

Other optimisation measures include increasing the mill exit temperature and/or reducing the moisture content of the mill gas flow, both of which will enhance the drying process of the added gypsum. As summarised in Fig. 10 these are standard process-optimisation procedures that can also be used to ensure that the cements produced in vertical roller mills have comparable setting times and compressive strength development to those from ball mills. Because it is partly true that cement produced in a vertical roller mill has lower gypsum dehydration, this can be adjusted through standard process optimisation.

7 Final remarks

Table 2 presents a summary of the results obtained from the comparative milling tests at the Montalieu plant in France. While key features include the very similar particle size distribution, positioning parameter and the fineness acc. to Blaine, the results show that the setting times for the two cements are the same. Setting begins after about 125 minutes and stops – in both cases – after 175 minutes. In addition, the compressive strength and the strength development measured after 2, 7 and 28 days are basically exactly the same. This proves that cements produced in a ball mill or in a vertical roller mill can have the same characteristics and qualities when required to do so by local markets, particularly in terms of the water demand of the cement paste, the setting times, the compressive strengths and strength developments of mortars.

Today, out of the 260 Loesche mills sold around 185 are used worldwide for grinding cement products. On a regional basis, the largest proportion of the total is in eastern Asia, with significant numbers of the machines in Europe and the Americas as well. It is also significant that around 60 % of these mills are used for grinding more than one grade of product, with around 40 % being used for more than three products. Indeed, the flexibility of this mill system is such that today...
A higher grinding pressure will result in more intense grinding with the development of more fine material, and hence a shallower particle size distribution. The higher the dam ring height, the longer the material remains on the grinding table, and the more it is ground in one cycle. This again results in a shallower particle size distribution curve by adjusting each parameter.

Table 2: Same cements with the same characteristics

<table>
<thead>
<tr>
<th>Designation</th>
<th>Unit</th>
<th>Vertical roller mill</th>
<th>Ball mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separator</td>
<td>LSKS</td>
<td></td>
<td>O-SEPA</td>
</tr>
<tr>
<td>Fineness acc. to Blaine</td>
<td>cm³/g</td>
<td>4 258</td>
<td>4 095</td>
</tr>
<tr>
<td>Standard consistency</td>
<td>%</td>
<td>28</td>
<td>28.5</td>
</tr>
<tr>
<td>Setting time, begin</td>
<td>min</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Setting time, end</td>
<td>min</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>MPa</td>
<td>29.8</td>
<td>29.9</td>
</tr>
<tr>
<td>(w/c = 0.5)</td>
<td></td>
<td>38.9</td>
<td>38.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.1</td>
<td>54.1</td>
</tr>
<tr>
<td>Specific energy consump-</td>
<td>kWh/t</td>
<td>28.6</td>
<td>39.7</td>
</tr>
<tr>
<td>tion (measured at shaft)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There are several mills used to grind five or six cement products. Cement producers worldwide appreciate the higher energy efficiency of the vertical roller mill. In addition, the inherent flexibility of this mill system means that product specifications can be changed quickly and easily in contrast to a ball mill.

**LITERATURE / LITERATUR**


Loesche – worldwide presence

Loesche is an export-oriented company run by the owner, which was established in 1906 in Berlin. Today the company is internationally active with subsidiaries, representatives and agencies worldwide.

Our engineers are constantly developing new ideas and individual concepts for grinding technologies and preparation processes for the benefit of our customers. Their competence is mainly due to our worldwide information management. This ensures that current knowledge and developments can also be used immediately for our own projects.

The services of our subsidiaries and agencies are of key importance for analysis, processing and solving specific project problems for our customers.

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