Spellbinding grinding improvements

Dr. Caroline Woywadt, Gebr. Pfeiffer, discusses the state of VRM technology in the cement industry, with SCM integration and digitalisation becoming essential features of modern production.

The cement industry is, like every other industry, driven by the best solutions providing efficiency, sustainability, and digitalisation. For the grinding of raw materials, solid fuels, and cements the vertical roller mill (VRM) system is one of the most energy efficient systems available. The combination of three process steps in one system – drying, grinding, separating – makes it very versatile in regard to handling dry and moist feed materials, and grinding these to very high fineness, creating the product properties required by the different market areas.

With the introduction of the MVR mill to the market in 2010 a new concept was available for very high throughput rates. By using a larger diameter, a larger contact area resulting from roller size and/or number of rollers, a faster rotational speed, and higher hydraulic force, the mill capacity can be increased.

Whereas the MPS mills for cement grinding and raw material grinding have been equipped with a power range between 500 kW up to 5400 kW resp. 6400 kW, the MVR mill covers a range of installed power between 60 kW and up to 11 700 kW.

With the MultiDrive® there is sufficient scope to go up to 18 000 kW.

Performance

The performance of a vertical roller mill is defined by a required throughput at a required fineness paired with a low specific thermal and electric energy consumption. For cement grinding, the required product quality is the most important target together with the above-mentioned points. Some areas in general need special attention: feed uniformity, metal detection and extraction, and preventive maintenance to name just a few. The levers to pull for a well performing vertical roller mill are operational parameters such as table speed, gas flow, working pressure, and mechanical adjustments such as dam ring height and covering the nozzle ring.

The success of the VRM in cement grinding was determined by its production of the same or better cement quality. This can be traced back to not only adjusting to the same or similar Particle Size Distribution, but also to the adjustment of feed material properties (clinker C_3A) and especially sulfate agent proportioning.

The sulfate agent needs a balanced proportion of di-hydrate, hemi-hydrate and anhydrite. As a VRM has a significantly higher energy efficiency than a ball mill, much less heat is put into the grinding process. As a result, the dehydration degree of the sulfate agent is lower. The lower hemi-hydrate or plaster content can be compensated for by the addition of more gypsum (within the limit according to relevant standards), by the addition of a more reactive form of gypsum, or by the addition of more heat to the system. By installing the G4C® system with a separate mill and hot gas generator to partially calcine the gypsum, the hemi-hydrate content can be controlled exactly for each clinker that is used. This is made possible by setting the outlet temperature of the mill to adjust the proportion of hemi-hydrate. This system is installed with an MVR 6000 C-6 in Australia and supports a tailor-made sulfate agent for the finished product.

An important factor in the characterisation of cement properties is strength development in combination with setting times. National standards define the procedure for testing. Due to differences in those standards, the results of compressive strength development are not comparable to each other. Gebr. Pfeiffer has its own mortar laboratory and collects samples from the operation of MPS and MVR mills to characterise cement product properties. To ensure the reliability of results, the laboratory participates in annual round robin tests (ATIHL and BE CERT). Concerning the procedure for sample preparation, the proportions of cement, sand, and water are in accordance with EN 196-1. The properties of several cements produced in MPS and MVR mills are listed

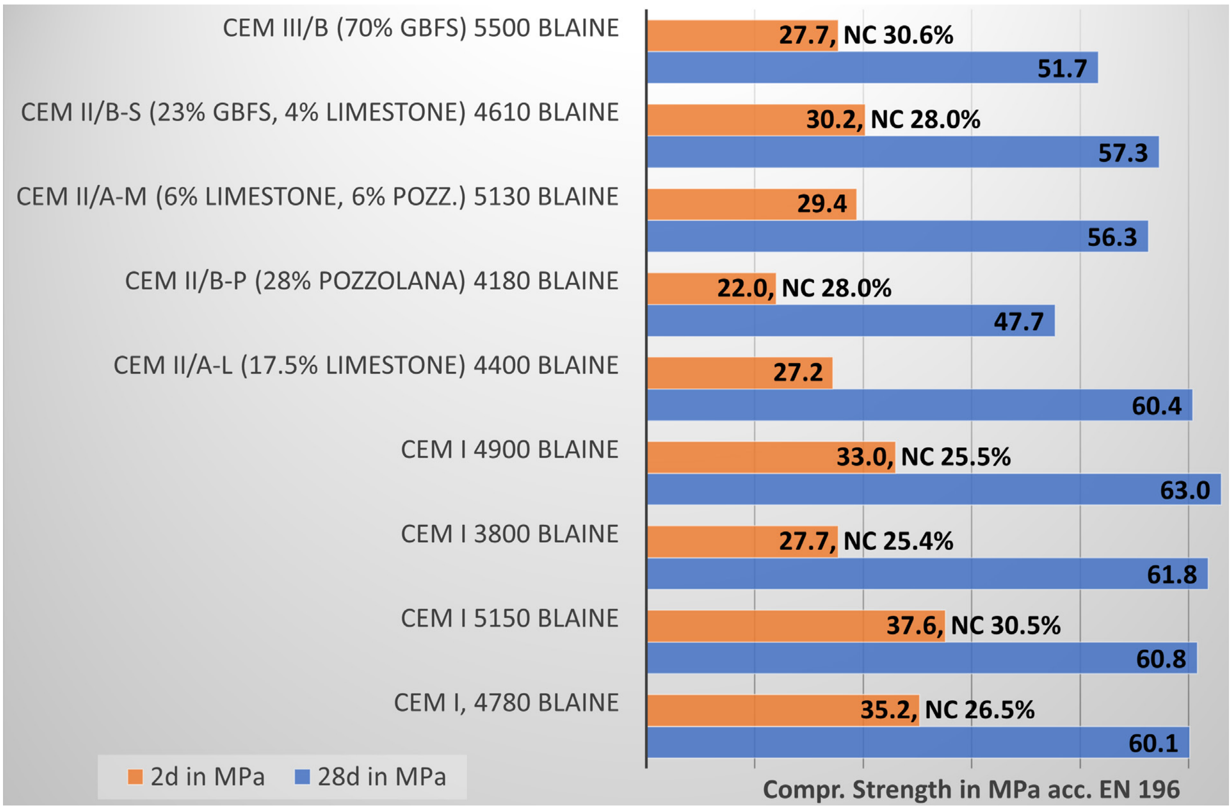

Figure 1. Properties of cements produced in MVR mills.

in Figure 1. Nearly all OPC/CEM I products have developed a 28-day strength of 60 MPa or higher. High 28-day strength figures are achieved as well with a product fineness less than 4000 cm^2/g. Early strength after two days is clearly impacted by clinker quality and, for composite cements, the type of composite is an additional factor.

The composite cements achieve high 28-day strengths. Products need to be ground fine enough to enable composites to reach the required strength level. The given normal consistency (NC) figures have been determined in accordance with EN 196-3 and demonstrate that the workability of products from MVR mills meets the demands of industry. Custom adjustments have been made in many cases during the commissioning of MVR mills, for example: PSD adaptation, sulfate agent selection, or the use of the G4C system to get precise plaster-content. These results show that cements that are ground in vertical roller mills are clearly on the same level as cements ground in ball mills.

Supplementary cementitious materials (SCMs)

Supplementary cementitious materials (SCMs) or clinker replacement materials (CRMs) influence grindability, operational behaviour, and reactivity. SCMs have been used in the industry for many decades, and the amount of composite cements is still increasing considerably. SCMs can be artificial or natural. Artificial SCMs include, for example: fly ash, granulated blast furnace slag (GBFS), and silica fume. Examples of natural SCMs include: limestone, pozzolana, clay, etc.

In many countries, limestone is the most easily available supplemental material. Limestone dilutes the clinker content of the cement and impacts its strength development. The hydraulic properties of natural pozzolana are advantageous for cement products, and so they are preferred if available. The definition of pozzolana includes any volcanic material, but it should be noted that it does not describe the specific origin of the material.[1] Therefore, the term ‘pozzolan’ also includes artificial supplementary materials, such as flyash, bottom ash, etc. The great majority of natural pozzolans is of volcanic origin. The global distribution of volcanic rocks can be compared with the occurrences of natural pozzolan deposits. But not all volcanic rocks are suitable as pozzolanic material. More siliceous magma produces more explosive volcanism with better pozzolanic properties.[2] The activity of some pozzolanas, for example phonolith, can be increased by thermal treatment. By heating the material up to 300 – 500 C, the crystal lattice expands and the surface area increases. Thereby supporting the formation of hydrate-phases.[3] The grindability of natural pozzolana varies widely. For achieving 5000 Blaine, for example, the time of exposure in the laboratory ball mill is between 30 – 80 min. (average 45 min.). This behaviour has to be taken into consideration for rating the industrial mill. Additionally, the reactivity of pozzolanas is very different and has a tremendous impact, in combination with the clinker, on the produced cement. Therefore, a fine adjustment of the feed material properties and the target fineness of the finished product needs to be done.

When it comes to composite cements, the versatility of MVR mills is impressive. These mills are very flexible for the grinding of different materials, such as: clinker, limestone, GBFS, pozzolana, fly ash, bottom ash, calcined clay, etc., with a wide range of properties. When moist materials are included in the feed mix, a heated rotary lock will be installed. When dry and already quite fine materials are included, an additional feeding point is provided at the classifier housing.

When producing composite cements the decision between inter- or separate-grinding is often under discussion. The MVR mill is able to switch from inter-grinding to separate grinding depending on the client’s needs without any changes to the mill’s internals.

Properties of, for example, GBFS and fly ash vary widely. In line with the required product properties it has to be taken into consideration that inter-grinding can result in finer fractions containing either very little or no GBFS or fly ash.

Depending on the reactivity of the GBFS, the mode of production can be achieved with inter-grinding as well with separate grinding of the single components. Operational experiences show that plants tend to grind clinker and GBFS together if GBFS is available with a good reactivity. One advantage of inter-grinding is the formation of a stable grinding bed due to clinker and GBFS granulometries which interact positively. If the GBFS needs to be ground to a high fineness due to lower reactivity the separate grinding might be a better way to achieve the overall required properties of slag cements. MVR mills are operated in both ways.

As cement is the most widely consumed building product in the world, a huge volume is produced. Cement production is responsible for about 8% of man-made CO_2-emissions.[4] The International Energy Agency (IEA) has highlighted four principle

CO_2 reduction levers. Key strategies to cut carbon emissions in cement production include improving energy efficiency, switching to lower-carbon fuels, promoting material efficiency (to reduce the clinker-to-cement ratio and total demand) and advancing process and technology innovations such as CCS.[5] Reducing the clinker proportion in cement is said to be by far the most effective measure.

The use of SCMs to replace clinker in cement is only part of the picture but gives a good indication in order to evaluate the effectiveness of composite cements regarding their carbon footprint.

For the evaluation of energy use and CO_2 emissions, the proportion of SCMs has to be considered, but also likewise does the product fineness of the composite cement, as it is impacted by the reactivity of the SCM in use. As not all SCMs give a sufficient reactivity at lower Blaine, the product fineness overall has to be increased under certain conditions.

Calcined clays are one promising material for future applications as SCMs. The number of industrial production sites is increasing, but information available on the impact of grinding on its properties is currently limited. The process of grinding has significant effect on the reactivity and performance of SCMs,[6, 7] but specific procedures for the grinding of calcined clays have not yet been established.[8] Several influences originating from the grinding of calcined clays are known based on laboratory tests. Mineralogical composition especially of common clays (e.g. content of clays and quartz) will impact the particle size distribution and may lead to an enrichment of calcined clay particles in the finer fraction, but the quartz will also promote a deagglomeration effect.[9, 10] The fineness of calcined clays can significantly affect compressive strength of concretes made with blended cements.[11, 12]

Table 1 shows a comparison of specific energy consumption and wear characteristics for CEM I, ground granulated blast furnace slag (GGBFS) and different calcined clays. The results of the calcined clays are based on grinding tests conducted in the pilot plant in the test centre of Gebr. Pfeiffer.[13]

The reactivity (determined by R3-Test and solubility of Si and Al ions) depends on product fineness and grinding parameters. Increasing the fineness of the material from 7600 – 12 500 cm^2/g results in 15% better reactivity.

The activity index, determined as compressive strength according to DIN EN 196, reaches up to 90% for mixtures with a replacement level of 40 wt.-% calcined clay after 28 days.[13]

Digitalisation

Industry 4.0 is also a driver for clients to cover operational support. This feature is offered as digital ‘modules’ where Gebr. Pfeiffer focuses on the maintenance and enhancement of operations at the moment. One of these digital modules is GPlink which stores sensor data for data analysis and enables 24/7 access to data from mobile devices. When transmitted to the company’s service team a solid basis for support and rapid and targeted assistance is given.

GPpro facilitates the Advanced Maintenance System with scheduled maintenance and is adapted for actual needs. This system includes a wider range of sensors as well as data analysis tools and reports partly with the help of artificial intelligence. Reacting on the changing requirements this product is developed further. The modular structure offers functions in the areas of e.g. preventative maintenance, protection of the mill, reduction of water consumption. The module ‘dynamic water injection’ enables the control of the injected water depending on vibrations in combination with working pressure and resulting bed height.

Outlook

The performance of a vertical roller mill is defined by a required throughput at a required

Table 1. Comparison of specific energy consumption and wear characteristics.

Material	Spec. powerd consumption in VRM in kWh/t	Fineness Blaine in cm^2/g	Fineness d50 in µm	Abrasive wear (grinding parts in VRM normalised)	Erosive wear (VRM internals)
CEM I	33 – 38	5500	~ 9 – 10	1	High – very high
GGBFS	35 – 40	6500	~ 7 – 13	2 – 4	High – very high
Calcined Clay A	40	11 000	10.3	9	High
Calcined Clay B	35	10 000	12.5	9	High
Calcined Clay C	31	12 500	7.4	1 – 3	Low

fineness paired with a low specific thermal and electric energy consumption. Some areas in general need special attention: feed uniformity, metal detection and extraction, and preventive maintenance, to name just a few. Operational parameters such as table speed, gas flow, working pressure, and mechanical adjustments as dam ring height and covering the nozzle ring are the levers to adjust for a well performing vertical roller mill that is efficient in terms of electric and thermal energy. Support during commissioning in regard to the setting of operational parameters, reduction of stoppages and stable and smooth operation is very important. In addition to setting the operational parameters and the GPpro or GPlink system, supplementary features as 'feed material detection' and 'optimisation by AI' can help to achieve a well performing mill where energy efficiency is ensured. First trials with both features have shown very promising results and will be implemented in the future.

Not only is the use of SCMs an effective measure to reduce the carbon footprint, improving energy efficiency is also a key factor for grinding plants.

In cement production more than 60% of electricity is used for the grinding of raw materials and cement. With this huge amount it seems mandatory that energy efficient technologies should be used.

State-of-the-art grinding technologies such as vertical roller mills can provide up to 70% electricity savings compared to ball mill systems. Other electricity saving strategies include cross-cutting measures such as upgraded cement process controls and the use of variable speed drives to run mechanical equipment across the site.

This applies in particular for the main drive of the vertical roller mill and the main fan. The use of efficient grinding and milling technologies decreases the global electricity intensity of cement by 14% by 2050 compared to 2014 in the 2DS.[14]

The GPpro system has helped during the pandemic to bring plants into operation, where commissioning was assisted from a distance with online meetings. By providing additional images and footage from the plant sites the support could be targeted to specific topics.

All of the features described, such as the design and the wide range of duties of the MVR mill, the flexibility when using clinker replacement materials, the performance for cement grinding, and the overall innovative approach provide a very flexible system for the industry that is reliable to support decreasing the carbon footprint of plants. ■

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About the author

Dr. Caroline Woywadt has been Director of Process Technology at Gebr. Pfeiffer since 2011.

After graduating from RWTH Aachen having studied Mineral Processing and obtaining her PhD in the field of grinding, she has worked as process and quality control manager at cement grinding plants in Germany and Poland and as the product manager for grinding products.

She is responsible for process technology and process development, pilot plants, and material characterisation. She is involved in projects and sales and plant optimisation.