VRM optimisation

The addition of grinding aids and refined process strategies can improve the performance of vertical roller mills (VRM). The use of suitable grinding additives combined with effective management of total moisture in the mill circuit will significantly contribute to a better VRM operation and ultimately, to an improved final cement quality.

■ *by **Keith Marsay, Larry Gibson and Josephine Cheung,** GCP Applied Technologies, USA*

The use of vertical roller mills (VRMs) in the production of cement is supported by compelling arguments, including:

- higher energy efficiency
- swifter response times
- smaller plant footprint
- reduced wear rates.

However, some VRM operators may experience lower cement quality. As the grinding mechanism of a VRM (compression milling) significantly differs from that of a ball mill (impact milling), some operators have speculated that each system yields a specific particle shape that ultimately impacts on cement performance. Based on the images in Figures 1a-1d, which compare the shapes of cement particles milled in a VRM and a ball mill, there is no obvious difference between the VRM product (see Figures 1a and 1c) and the ball mill product (see Figures 1b and 1d). This observation confirms that the underlying issue behind poor VRM cement performance is not a physical property. Therefore, this article focusses on the well-known culprit, cement pre-hydration, and provides several best practices to minimise or even prevent this phenomenon.

As a reminder, Tables 1 and 2 (from a 2014 study) summarise the degradation of cement performance as a function of cement pre-hydration. In this case, the extent of pre-hydration, expressed as loss on ignition (LOI), negatively affects mortar compressive strength at all ages of curing.

Figure 1: SEM micrographs of cement particles produced by VRMs and ball mills. Captured at 100x magnification (1a and 1b) and 1000x magnification (1c and 1d), respectively

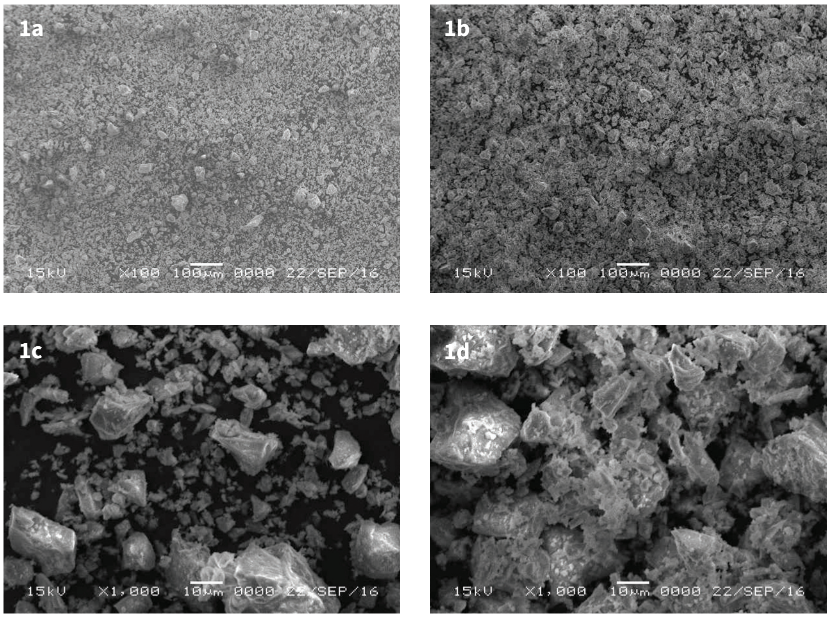


Table 1: mortar strength development

Cement	LOI[1]	Mortar compressive strength (MPa)			
		1 day	2 days	7 days	28 days
A	0.35		17.5		47.5
A	0.48	Ternary	14.5		44.0
B	1.14	17.2	31.8		58.2
B	1.64	6.1	18.3		53.2
C	0.66	15.7		40.0	49.6
C	1.22	5.2		28.1	40.7
D	0.68	16.5		42.2	48.9
D	1.55	7.9		35.9	45.0

[1] *Loss on ignition (LOI) determined 140-550˚C*

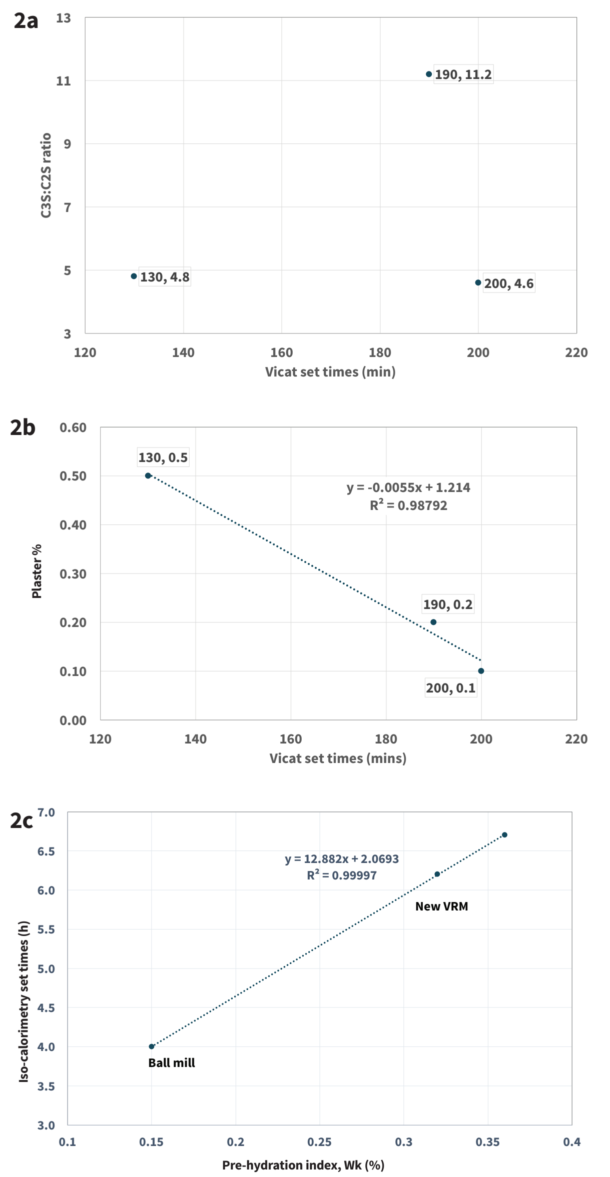
Impact on initial setting times

The impact of cement pre-hydration on the initial setting time (IST) is a further common issue that has become apparent in recent years. Cement plants often operate both ball mills and newer VRM systems concurrently. In most instances, the VRM-made cement has a significantly-higher IST. This often leads to unhappy

Table 2: mortar strength loss due to pre-hydration

Cement	Strength loss per 0.1% LOI MPa			
	1 day	2 days	7 days	28 days
A		2.3		2.7
B	2.2	2.7		1.0
C	1.9		2.1	1.6
D	1.0		0.7	0.4

Figure 2: relationships between set time and alite/belite ratio (2a), gypsum dehydration (2b) and pre-hydration index (2c)



concrete customers and can result in requests for GCP to supply a set time accelerator. However, traditional set time accelerators have proven to have limited benefit in such cements – to the frustration of both GCP and the cement plants.

In one investigation, after commissioning a new VRM system, a plant observed set time extensions ranging from 60-120min when compared with set times of previous cements produced by a ball mill or older VRM. Unfortunately, after performing QXRD, XRD and PSD analyses, correlations between set time and the alite/belite ratio (see Figure 2a), or with PSD, could not be established. However, set-time correlations were observed with other parameters highlighted in Figures 2b and 2c – the amount of plaster in the cement and the pre-hydration index (Wk). Wk indicates the amount of water in hydration products formed prematurely before intended use. More specifically, during thermogravimetric analysis of cement, Wk is a measure of the weight loss occurring between gypsum dehydration and portlandite degradation.

In addition, heat treatment of the cement in a 100°C oven for 30min enabled the conversion of gypsum to plaster. This conversion typically helps to recover extensions in set time. However, in this case, exposure of cement to elevated temperatures only partially recovered the set time, resulting in a reduction by 24min. Regardless, the performance loss due to the presence of pre-hydration products could not be recovered. SEM images of pre-hydrated cement were similar to those shown in Figure 3b.

Causes and remedies

The root cause of the delayed IST appears to be the pre-hydration layer on the surface of the particle. This effectively forms a physical barrier that delays the action of hydration and set time accelerators, thus delaying the setting time and ultimately, strength development. Inevitably the cement particles will eventually hydrate, resulting in a cement with high 28-day strength but unacceptable IST and two-day strength. In these cases, the cement plants will have to grind the cements to a higher fineness to achieve desirable set times and strengths.

One potential solution to this issue is to reduce the degree of pre-hydration. This in turn will result in lower grinding pressures and improved mill throughputs. Furthermore, a reduction in pre-hydration will enable swifter chemical activation of the clinker by traditional quality-improving grinding aids. Therefore, this solution requires process optimisation followed by a chemical acceleration (if this is needed). A number of plants have been able to overcome these challenges with the following best practices.

Routine testing

While hourly testing of the pre-hydration of finished cement is preferred, it is not practicable. A test of pre-hydration on a daily composite of hourly production samples is a good start. To minimise the exposure of cement to water during production, some plants restrict water usage for stabilising the grinding bed. Unfortunately, in some cases excessive amounts of water are added on the mill table to maintain stable milling and the negative impact on cement performance tolerated. Educating the operational team on the importance of moisture control is a better course of action than simply implementing an arbitrary water limit.

Tracking temperature

The mill outlet is often observed at temperatures adjusted to exceed 100˚C. Although this modification may ensure that all of the moisture from the table is evaporated, the strategy can be of limited value if all this evaporated water is then circulated back to the mill inlet. Experience has shown that most reliable VRMs run with a mill exit temperature of 85-95°C.

Figure 3: SEM images of a pristine anhydrous cement (3a) and pre-hydrated cement (3b)

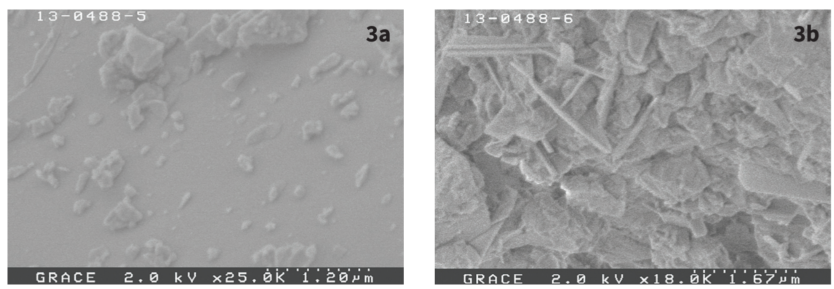


Figure 4: relationship between dew point temperature of outlet gas and water addition in a VRM operating under normal conditions

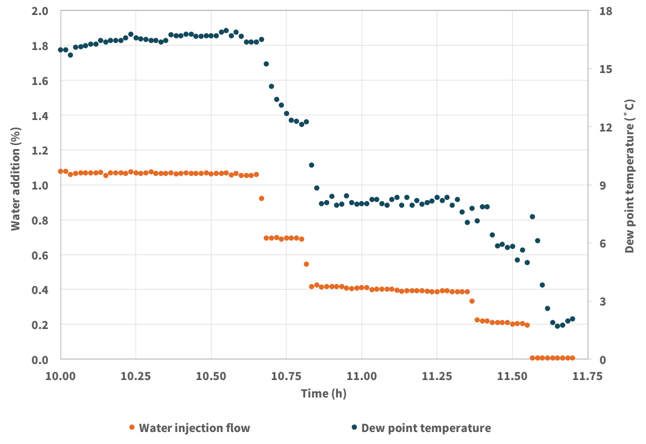
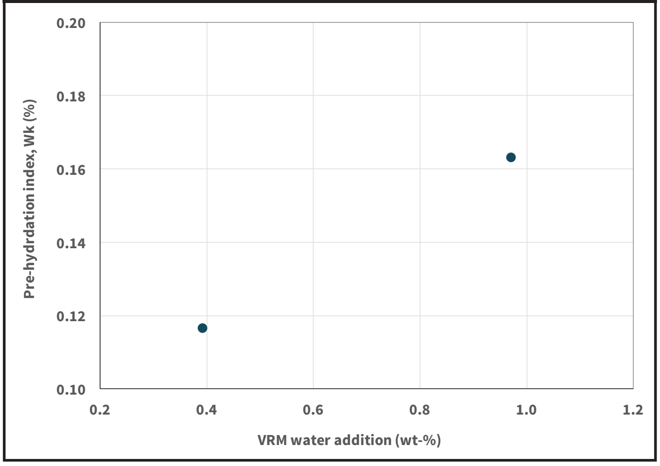


Figure 5: relationship between water addition and pre-hydration index, Wk



Thinking beyond direct water addition

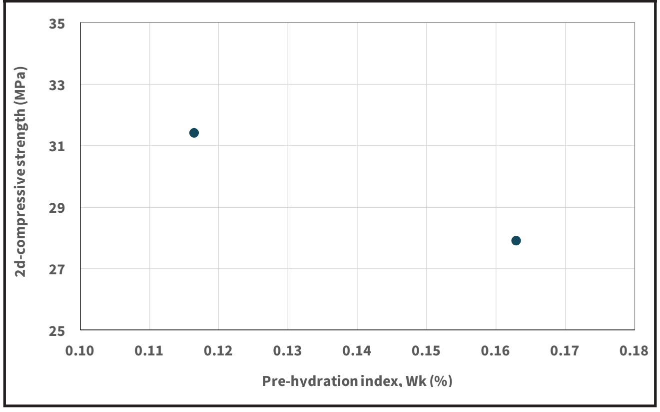
Limiting the volumetric rate of water applied to the grinding bed is only part of the solution. Management of total water used in the grinding process is key. VRMs are more efficient grinding systems and as such do not waste considerable energy through the generation of heat and noise. It is common to maintain heat in the VRM circuit by recirculating the mill process gases back to the mill inlet. While this is a commendable conservation of energy, it is often overlooked that this also recirculates moisture in the process gases back to the mill inlet. As a result, even relatively modest water addition rates (<1 per cent by weight) can still lead to pre-hydration issues if the moisture-laden process gases are recirculated.

The moisture content of the raw materials should also be taken into consideration. Generally this is not such an issue when a simple CEM I is being made. However, in the case of a high limestone or pozzolanic cement, considerable additional moisture could enter the system. A good example of this was a VRM plant producing a CEM II with 20 per cent of pozzolan with a moisture content of 7-15 per cent by weight. Despite the lack of water being used to stabilise the mill, the plant still suffered from pre-hydrated finished cement and this was most likely due to high recirculation of the process gases to keep the temperature of the mill outlet gas on target.

The solution in these cases is to ensure there is always some drier fresh air entering the mill circuit and some of the high-humidity process gases are continuously purged to atmosphere. Hot gases available from a kiln cooler are a good source of dry air to replace moist process gases leaving the mill outlet.

In an ideal process, one would perform a mass balance on the water in the system, and use this to control the amount of fresh air. However, a general rule of thumb is that one should purge and replace at least 20 per cent of all process gases. However, this can prove difficult to achieve in some mills. Therefore, it is not unusual for plants to operate with a second or even third fresh air damper.

Figure 6: dependence of compressive strength on cement pre-hydration (Wk) after two days of curing



Another way to manage this issue is to routinely monitor the mill exit gas humidity or dew point and use this to control the fresh air damper(s) via a PID controller. At one plant the mill outlet humidity was routinely monitored and controlled. If the humidity exceeded the set point for more than 20min, the mill would automatically shut down. While some may consider this approach to be rather drastic, this particular plant enjoys acceptable IST and early strength performance.

After optimal gas circulation is established, Figure 4 suggests that progressive reduction of water addition will further reduce the total moisture content in the mill, ultimately leading to lower cement pre-hydration. In general, a very effective process which enables the mill operator to reduce the water addition without disrupting the stability of the process is to increase the dosage of the grinding aid. From the same milling system as Figure 4, Figure 5 shows the relationship between the water addition to the grinding bed (ultimately the total moisture in the system) and the Wk.

Despite the exceptional correlation between total moisture and water addition shown in Figure 4, it should be noted that instruments used for the purpose of humidity control may not be the most reliable and can be sensitive to dust. Thus, regular routine maintenance and calibration is required prior to relying too closely on such methods.

Impact of chemical additives

Cement processing additives (ie simple grinding aids) work by dispersing agglomerated particles and improving the flowability of the finished cement. These characteristics are applicable to both a VRM and a ball mill. More controlled material flowability enhances the introduction of the raw materials to the rollers by 'smoothing' the de-aeration process. This reduces the variation in

Figure 7: conveyor belts of raw feed to respective VRMs

friction and resultant vibration. The improved cement dispersion also lowers the quantity of agglomerated fine material returning from the mill separator, which further assists milling stability.

Experience with a number of milling systems and grinding aid formulations suggests that some grinding aids are more suited for VRMs than others. However, in all cases, the use of a processing additive can help to reduce water demand for bed stabilisation. This in turn mitigates the cooling effect of the added water and helps maintain temperature in the circuit, reducing the need to circulate moisture-laden process gases.

The consequence of a high moisture content can be quite dramatic. However, it is possible with some vigilance and often a higher-than-usual grinding aid dosage to run a VRM without water. Figure 6 demonstrates the value in minimising the total moisture content in a VRM to improve compressive strength.

Moreover, the raw material size has a fundamental impact on mill stability. Internal data from a survey of over 200 VRMs revealed that cement grinding is generally more stable with coarser raw feed material, and problematic with fine to dusty raw material. As shown in Figure 7, in two different plants two VRMs (of same make and model) were each making the same cement type to the identical fineness.

The mill in Figure 7a was running at 128tph, four per cent water addition and 400ppm of a grinding aid. The mill in Figure 7b was running at 185tph, zero per cent water and 600ppm of a GCP grinding aid.

Although it is not always possible to stabilise a mill on a grinding aid alone, consideration of the raw meal size distribution, chemistry and clinker quality can often lead to considerable improvements in VRM stability. Depending on the expertise of the cement producer, this enhancement can be achieved at little or no cost but yield significant benefits to the entire process. GCP's products are aimed at improving cement performance by using appropriate grinding additives with a focus on ensuring that the process will give a dry and smooth VRM operation.

Summary

GCP has concluded that the difference in performance between ball mill and VRM cement is largely due to process factors. The observed performance discrepancy relates to the management of total moisture in the mill circuit and not just water applied for bed stabilisation.

Additionally, the use of a grinding aid coupled with best-in-class process expertise from an industry-leading cement additives supplier will result in substantial improvements in the performance and quality of the finished cement. ■

Figure 8: control room

Less Water.
More Strength.

Water is frequently added in **VRM** cement grinding to control mill vibration. Water “pre-hydrates” cement often leading to lower compressive strength, longer setting time, poor powder flowability and compromised concrete rheology.

GCP Applied Technologies’ **VRM** know-how and custom cement additives are specially formulated to control vibration with less water (or no water at all). And, our cement additives reduce the energy needed for cement grinding, thereby lowering both costs and carbon emissions.*

Control mill vibration and control your cement quality.
Contact GCP for a FREE **VRM** appraisal.

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* GCP Applied Technologies field trials demonstrate cement additives decrease injected water by up to 3 m³/h, or up to 100% (no water injection at all), increase output by up to 40% (or up to 70 t/h) and decrease energy consumption by up to 17% (or 6 kWh/t).

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