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NEW GRINDING STRATEGIES FOR FUTURE CEMENTS

Authors from VDZ look at how to optimise clinker-efficient cements using a combination of ultra-fine and coarse-ground granulated blast furnace slag (GBFS) fractions.

When it comes to cement production, the term 'optimisation' can be ambiguous. For example, 'optimising' for high compressive strength may make 'optimising' for low energy consumption very difficult indeed. Highly-efficient grinding equipment and considered strategies can help. For example, high-pressure grinding can lower specific energy consumption,[1] while blending different components of well-defined finenesses, where all components are able to utilise their full hydraulic potential, contributes to a high compressive strength. A particle size distribution (PSD) that offers the highest possible packing density can decrease water demand, making the cement mortar more dense.[2]

State-of-the-art grinding strategies like 'intergrinding' and 'separate grinding' are well known,[3-5] but do not show a high potential for energy savings. Separate ultra-fine grinding has been suggested as a way to further reduce the specific electric energy demand from grinding by 15-25%, without negatively affecting the cement properties,[6-7] and other theoretical communition concepts have been suggested to investigate the complex relationships between product mass flows, finenesses and grindabilities.[8]

However, none of these approaches quantitatively considers both: **1.** Reduction of the specific electric energy demand, and; **2.** Enhancement of the cement properties - of future cement blends with more than two main components. This article describes a study that changes this.

Table 1: Composite cements used in this study. *Sulphate content is calculated for each cement based on SO_3^- content of the components.

CEM II cements contain 65-94% Portland cement clinker, gypsum and SCMs.

CEM VI cements are a class of low-CO_2 cements that contain 35-49% Portland cement clinker, gypsum and SCMs.

Cement*	Clinker	Limestone	GBFS
CEM II/C-M (S-LL)	50	20	30
CEM VI/S-LL	35	20	45

Looking to the future

It is widely accepted that the availability of granulated blast furnace slags (GBFS) will decrease in the future,[9] so it is reasonable to use the remaining GBFS efficiently. Besides GBFS, limestone is widely available, even though it does not contribute to strength. However, limestone is easy to grind finely, making it a key component to optimise the PSD. Therefore, this study considered the optimisation of cement blends comprising clinker, limestone and GBFS (Table 1).

Separate ultra-fine grinding

Ball mills represent the state-of-the-art for cement grinding, but are inefficient.[8] Conversely, high-pressure grinding devices like vertical roller mills (VRM) and high-pressure grinding rollers (HPGR) consume less energy, but are not able to reach the same high finenesses. To overcome this problem, it is necessary to consider ultra-fine grinding equipment like stirred media mills (SMM). However, SMMs can only handle low amounts of preground material.

Separate ultra-fine grinding uses high-pressure grinding and stirred media milling in two separate grinding steps, taking into account the specific limits of grinding of each technology. The concept, shown in Figure 1, is to grind the clinker and limestone to the same PSD as the corresponding products from a ball mill. The GBFS is ground to several different intermediate products (<3000cm²/g and <4000cm²/g). The intermediate product with the highest fineness (around >4000cm²/g) is subsequently ground in a SMM to produce sev-

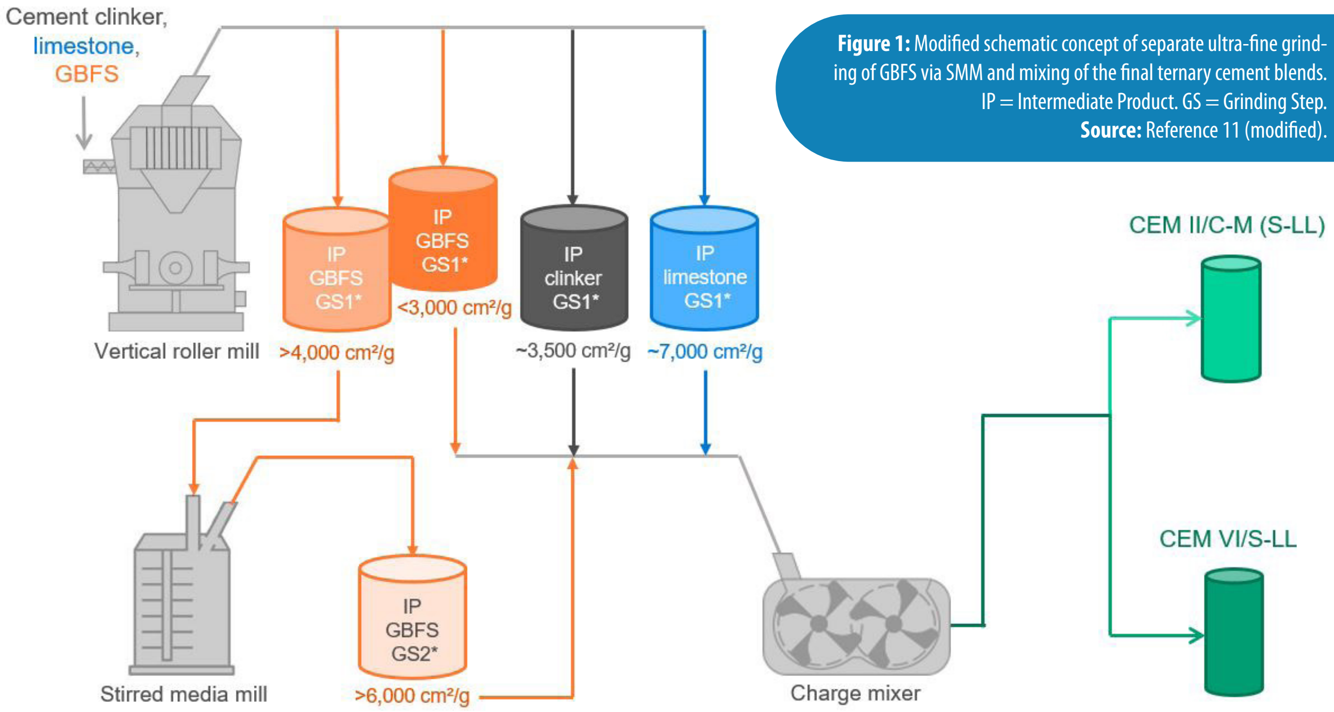

Figure 1: Modified schematic concept of separate ultra-fine grinding of GBFS via SMM and mixing of the final ternary cement blends. IP = Intermediate Product. GS = Grinding Step. **Source:** Reference 11 (modified).

eral ultra-fine intermediate products finer than 6000cm²/g. An example PSD of a ternary blend is shown in Figure 2.

This leads to a range of finely-ground products, which can be combined to produce different clinker-efficient ternary cement blends. The clinker and limestone have been ground to the same fineness level as their counterparts ground in the ball mill, so that ***only the ground GBFS varies*** from the ball mill reference. This makes it possible to mix the GBFS at different fineness levels and in various ratios of 'coarse' and 'ultra-fine' GBFS. It also ensures the adjustment of the specific energy demand of the final cement blend. This means that it is possible to evaluate how much energy could be saved, as well as the impact of fine or coarse GBFS on the compressive strength. This is an excellent basis for optimisation of the cements in Table 1. In summary, this study aimed to determine:

1. The highest possible amount of energy that could be saved relative to the ball mill reference without negatively affecting the compressive strength;

2. The highest possible compressive strength of cements made by separate ultra-fine grinding by using the same specific energy demand as the ball mill.

Practical grinding trials

As a reference, all main components were separately ground using a batch ball mill at a semi-industrial scale. Two multi-composite cements were subsequently mixed according to the composition given in Table 1. The specific energy demand for grinding was scaled up to that representative of an industrial

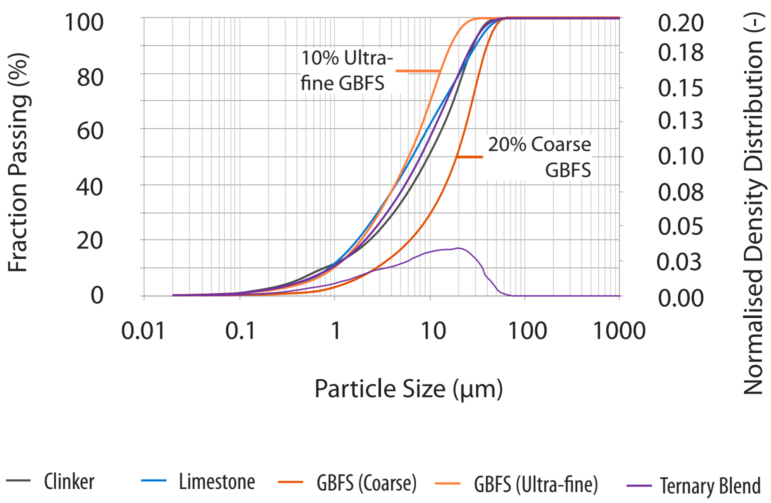

Figure 2: Design example of the PSD and fineness composition of the ternary blends.

Main Component	Fineness (acc. Blaine) (cm^2/g)	Spec. Energy Demand (System) (kWh/t)
Clinker	3340	
Limestone	6500	-
GBFS	3445	
CEM II/C-M (S-LL) (Ref.)	4200	54*
CEM IV/S-LL (Ref.)	4250	58*

Table 2: Fineness and specific energy demand of the ternary blends made in a ball mill (reference).

* Specific energy demand for blending and homogenisation included.

closed-circuit ball mill. The finenesses of all ball mill-made products and the scaled specific energy demand for the cement blends are shown in Table 2.

Grinding trials using semi-industrial technologies were conducted according to Figure 1. In the first grinding step, a semi-industrial vertical roller mill (VRM) with an installed drive power of 15kW was used to produce the intermediate clinker, limestone and GBFS products. The PSD and specific surface of the clinker and limestone products were comparable to that produced by the ball mill. However, the GBFS was ground to several different fine intermediate products as compiled in Table 3.

The intermediate product with the highest fineness level shown in Table 3 was used as feed material for the semi-industrial SMM in grinding step 2. An SMM with an installed drive power of 55kW was used for ultra-fine grinding. The results of the intermediate products from ultra-fine grinding are shown in Table 4.

The mixing procedure allows the combination of three different fine intermediate products from the VRM (coarse) with three different ultra-fine intermediate products from the SMM. In total, nine different combinations are possible for GBFS. Since the clinker and limestone fineness is kept constant with respect to the corresponding products from the ball mill, the result of the compressive strength development is directly linked to the variation of the GBFS.

Specific electric energy demand versus compressive strength

The specific energy demand of the cement blends derived from the separate ultra-fine grinding approach is strongly dependent on the ratio of coarse and ultra-fine intermediate GBFS products. The lower the fraction of ultra-fine GBFS in the cement blend, the lower the resulting specific energy demand. However, an acceptable early strength requires a certain amount of ultra-fine fractions in the cement mixture. A compromise must be found.

To ensure that all considered blends from separate ultra-fine grinding achieve a lower or similar specific energy demand than that of the reference condition (ball mill), a limiting ratio of coarse to ultra-fine fractions of 70/30 was identified. The values in this ratio refer to the total amount of GBFS in the cement mixture. Using this ratio for all possible combinations for CEM II/C-M (S-LL) and CEM VI/S-LL, the compressive strength of all cement blends from separate ultra-fine grinding and that of the ball mill reference (BM) were tested after 2, 7 and 28 days according to DIN EN 196-1. For CEM II/C-M (S-LL) a sulphate content of 4.5% was calculated and added to all blends separately. For CEM VI/S-LL, the sulphate content was set at 5.0%.

It was found that the combination of GS1-S-24 and GS2-S-08 in the cement mixtures led to comparable strength development with respect to the reference blends from the ball mill (Figures 3 & 4).

The energy required to produce CEM II/C-M (S-LL) by separate ultra-fine grinding (70/30) was 33% below the ball mill, with similar compressive strength development. The same was true of the

GBFS Intermediate Product	Fineness (acc. Blaine) (cm^2/g)	Spec. Energy Demand (System) (kWh/t)	Thoughput (kg/hr)
GS1-S-40 (coarse)	1985	16	310
GS1-S-30 (coarse)	2690	20	230
GS1-S-24 (coarse)	2865	24	170
GS1-S-18*	3925	29	190

Table 3: Fineness, specific energy demand and throughput of the intermediate products of GBFS ground via vertical roller mill.

* Only used as feed material for the SMM. The throughput rate is higher than that of GS1-S-24 due to varied operational settings of the grinding plant.

GBFS Intermediate Product	Fineness (acc. Blaine) (cm^2/g)	Spec. Energy Demand (System) (kWh/t)	Thoughput (kg/hr)
GS2-S-08 (ultra-fine)	~6100	136	350
GS2-S-06 (ultra-fine)	~7195	163	300
GS2-S-05 (ultra-fine)	~8665	284	180

Table 4: Fineness, specific energy demand and throughput rates of the intermediate products of GBFS ground in an SMM.

* Includes the specific energy demand for pre-grinding by VRM.

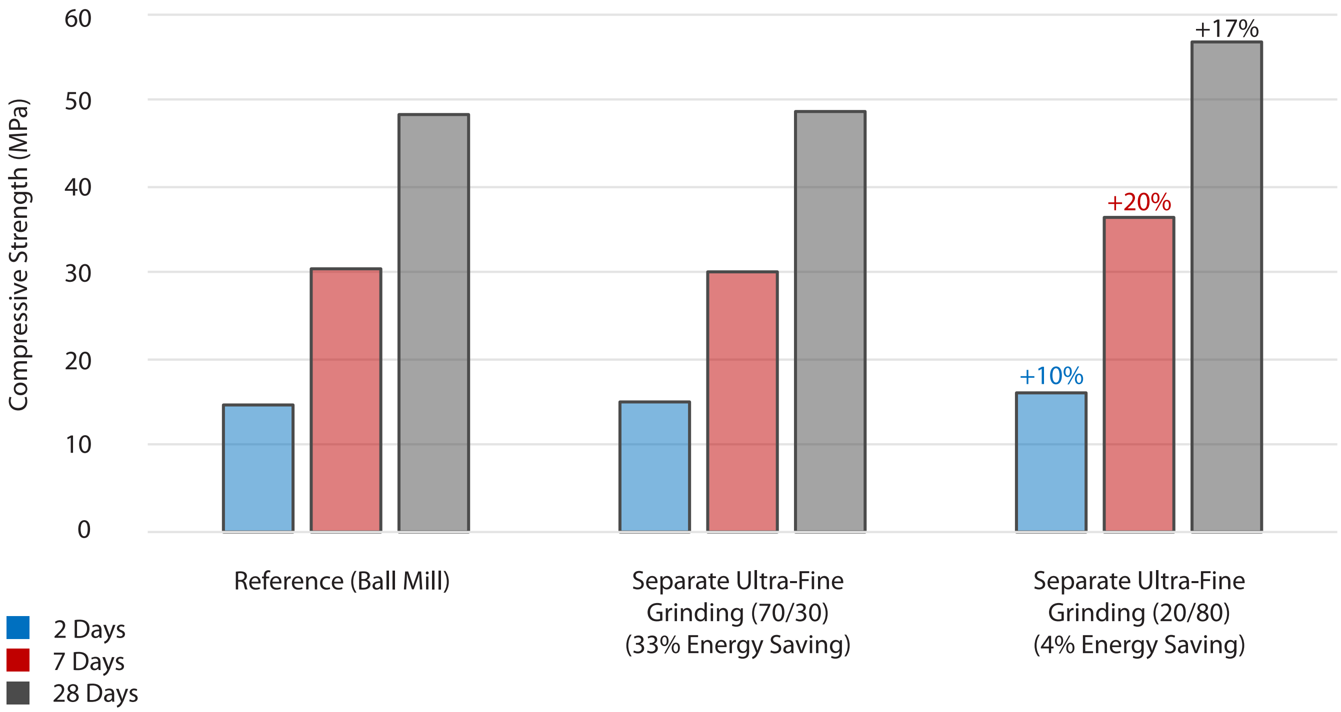

Figure 3: Development of the compressive strength of CEM II/C-M (S-LL) after 2, 7 and 28 days for the ball mill reference condition and selected blends prepared by separate ultra-fine grinding, using the intermediate GBFS products of GS1-S-24 and GS2-S-08 in different ratios.

compressive strength of CEM VI (Figure 4), while the 70/30 blend shows a negligibly higher compressive strength at all ages compared to the mixture derived from the ball mill. Here, the energy demanded is 30% less than the reference.

Besides the 70/30 blends, additional cement blends were tested for both cement types. In Figure 3, the results of a ratio with 20/80 show an improvement of the strength development at all ages. For the mixture 20%/80% the portion of ultra-fine GBFS (GS2-S-08) was increased to 80% of the total GBFS content. In this special case, the energy consumption is no different to the reference, but the average gain in strength is 16% - the maximum possible strength development identified under the conditions of this study.

The same strategy was followed considering a 30/70 ratio mix of GBFS for CEM VI (Figure 4). The energy consmption is the same as the reference when mixing 70% ultra-fine GBFS fractions into the ternary blend, with the strength higher by 28% on average.

A small 'but'...

The determination of water demand according to DIN EN 196-3 showed that all blends made using the separate ultra-fine grinding protcol exhibit a higher water demand compared to the reference. For CEM II/C-M (S-LL) the water demand was 1.0% higher for the 70/30 ratio product. For the corresponding mixtures of CEM VI, the water demand is increased by 2.0%.

Discussion

It is possible to produce slag-containing and clinker-efficient cements with much lower specific energy demand than is commonly achieved with ball mills. The energy savings are around 30% for both CEM II/C-M (S-LL) and CEM VI. Moreover, compared to the ball mill reference, the same development of compressive strength could be achieved using a sufficient combination of coarse and ultra-fine fractions of GBFS. Therefore, the first of the two optimisation objectives could be achieved with separate ultra-fine grinding. It is also possible to improve the compressive strength by using more ultra-fine GBFS.

It can be concluded that, the higher the total content of GBFS, the greater the potential to improve the development of compressive strength. As a consequence, the total amount of clinker can theoretically be reduced to even lower levels. This needs to be investigated further. Regarding the improvement of compressive strength for both types of cement, it was possible to accomplish the second optimisation task successfully.

In terms of the higher water demand in the separate ultra-finely ground mixture, it is unlikely that this effect is related to a significant change in the

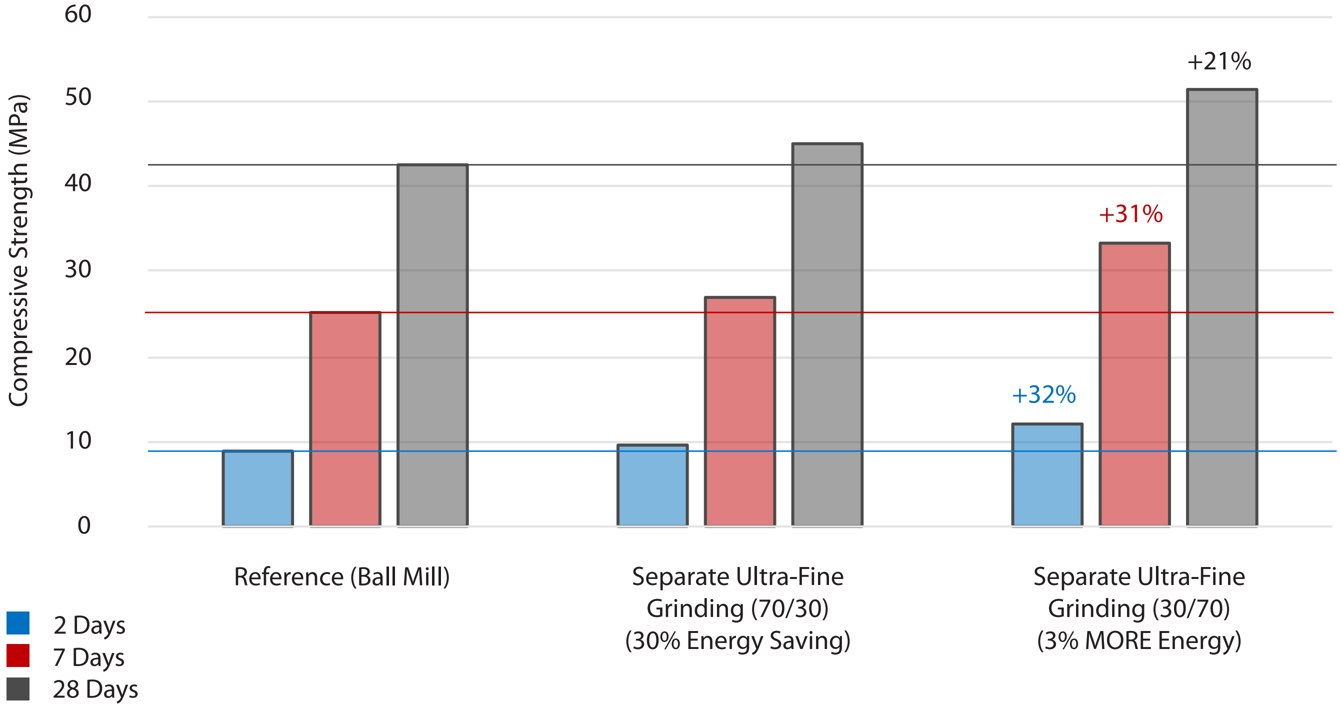

Figure 4: Development of the compressive strength of CEM VI/S-LL after 2, 7 and 28 days for the ball mill reference condition and selected blends made via separate highly-fine grinding using the intermediate GBFS products GS1-S-24 and GS2-S-08 in different ratios.

PSD. For example, the PSD parameters of the ball mill mixture and the 70/30 ratio blend of CEM II/C-M (S-LL) do not vary significantly.

The same statement is valid for the corresponding mixtures of CEM VI, where the water demand is 2.0% higher in the separate ultra-fine grinding blend. It is more likely that the higher water demand is dependent on the amount of ultra-fine GBFS fractions in the cement blend. This can partly be observed by checking the water demand of the 20/80 blend and 30/70 blend, which is 1.5-2.0% higher than the ball mill reference. The water demand of the 20/80 product gained another 0.5%, as the ultra-fine GBFS fractions are greatly increased. However, this effect was not observed for the 30/70 ratio product of CEM VI.

From a practical point of view, the production of only one coarse and one ultra-fine GBFS fraction in the first and second grinding steps is reasonable. In most cases, silo capacities are very limited. Also, the complexity of grinding several different materials and finenesses requires accurate planning and flexibility. It is therefore important to identify 'the best suitable' design of the PSD and the finenesses of all components therein. Once identified, the finenesses of the GBFS produced with the available grinding equipment will remain constant.

Concluding remarks

The use of GBFS in cement blends may be limited in the future due to the tendency of decreasing availability. Slag-containing and clinker-efficient cements, therefore, can be seen as an interim solution on the path to a future-oriented cement portfolio. However, the modified ultra-fine grinding approach introduced here may also be useful for other (latent-) hydraulic materials. Also, the possibility to adjust the fineness of clinker and limestone might hold at least some optimisation potential in ternary cement blends.

Acknowledgments

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References

References can be found online at:
www.globalcement.com/VDZ-references