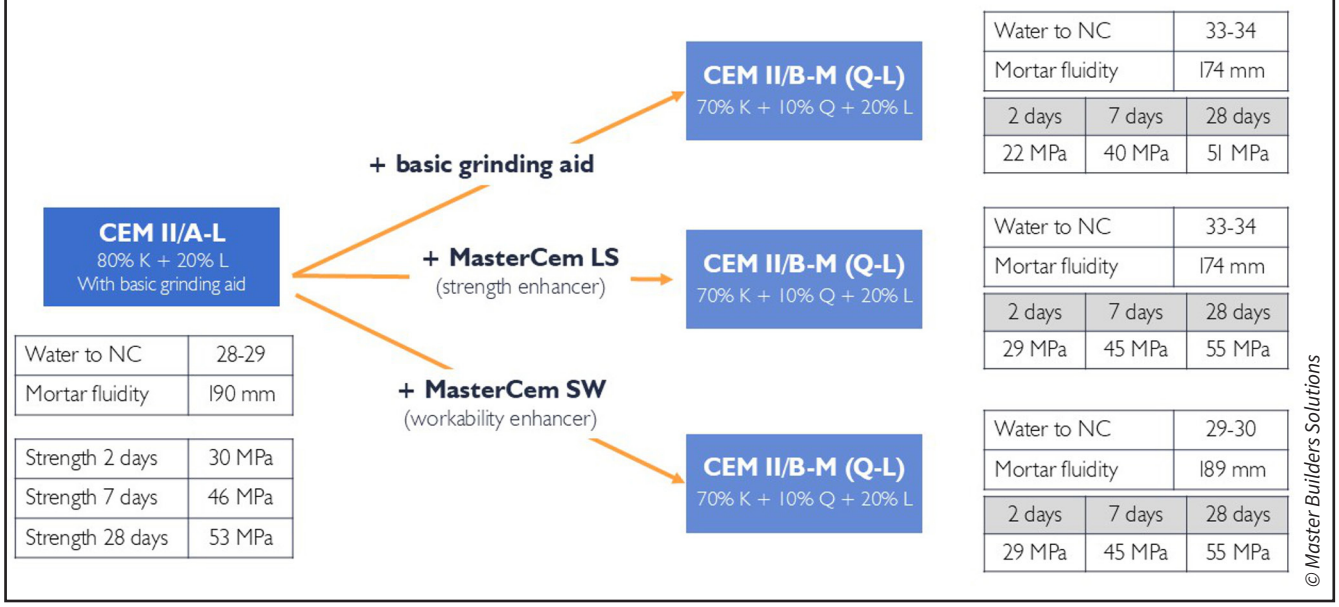
Mastering the challenges of absorbent SCMs

The use of calcined clays as SCMs in cement production both enables decarbonisation and poses challenges, as the absorbent nature of these materials may increase water demand and limit workability retention in concrete. A combination of cement additives and concrete superplasticiser technology has been shown to provide improvements at all stages by leveraging their synergistic effects.

■ *by **Pere Borralleras** and **Mario Vierle**, Master Builders Solutions*

Figure 1: expected effects of typical cement additives families



One of the key strategies on the road towards full decarbonisation of cement by 2050 is clinker substitution by supplementary cementitious materials (SCMs), with the goal of reducing the carbon footprint of cement while minimising the impact on its performance.

However, the availability of easy-to-handle, reactive SCMs is limited, especially when considering suitable fly ash as well as slag (ground granulated blastfurnace slag, GGBS), both products from industries under the same pressure to reduce carbon emissions. Consequently, clinker substitution options are increasingly focussed on limestone and calcined clays, as well as natural pozzolans where available. There are also new opportunities for additions deriving from concrete recycling, such as recycled concrete fines.

Limestone, natural pozzolans, calcined clay and recycled concrete fines can usually have a significant absorbent character, which affects both cement and concrete performance.

Cement additives to enhance cement performance

The contribution of cement additives in the clinker factor reduction process is well known and recognised. Master Builders Solutions' performance-enhancing MasterCem ES and LS series promote both early- and late-age compressive strength development, allowing cements with lower clinker content to achieve mechanical strengths comparable to reference cement with a higher clinker factor. Since they

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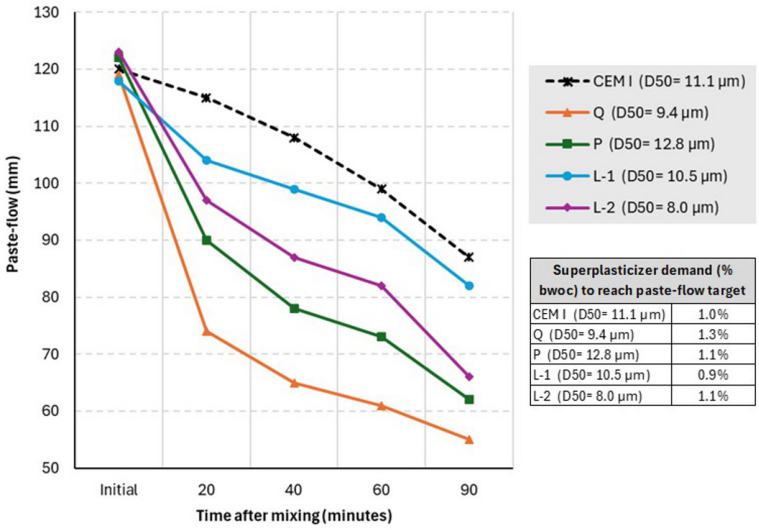
Figure 2: fluidity over time of SCMs and CEM I pastes prepared with superplasticiser admixture



Superplasticizer demand (% bwoc) to reach paste-flow target	
CEM I (D50= 11.1 µm)	1.0%
Q (D50= 9.4 µm)	1.3%
P (D50= 12.8 µm)	1.1%
L-1 (D50= 10.5 µm)	0.9%
L-2 (D50= 8.0 µm)	1.1%

Source: Master Builders Solutions

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provide grinding efficiency improvement as well, cements with higher SCM content can be produced without productivity losses and, in most cases, even increases. For this reason, the cement industry is currently transitioning from basic grinding aids to performance-enhancing additives.

With increasing SCM content or the implementation of new SCMs, the potential absorbent nature of these materials needs to be considered. Designed specifically for that purpose, the strength and workability-enhancing MasterCem SW series allows cement to overcome the negative impact of this absorbent nature by acting not only as a strength promoter but also helping to correct the increased water demand typical for cements incorporating SCMs such as natural pozzolans, fine limestones and especially calcined clays.

Figure 1 illustrates, as an example, the expected effects of the three main additive families, a basic grinding aid, MasterCem ES/LS (strength enhancers) and MasterCem SW (strength and workability enhancers) in the optimisation process of a reference cement type CEM II/A-L with 80 per cent clinker, where a further 10 per cent of clinker is replaced with calcined clay.

While basic grinding aids are not active on water demand improvement, a reduced mortar fluidity is observed. The loss of compressive strength at early and late age can be compensated by using MasterCem ES/LS series. With MasterCem SW series products, it is additionally possible to compensate for the impact on the water demand and, therefore, reduced mortar fluidity, while maintaining the improved early- and late-age performance.

With the appropriate use of cement additives, it is possible to optimise the clinker factor without altering the main cement characteristics established in routine control or its declared properties.

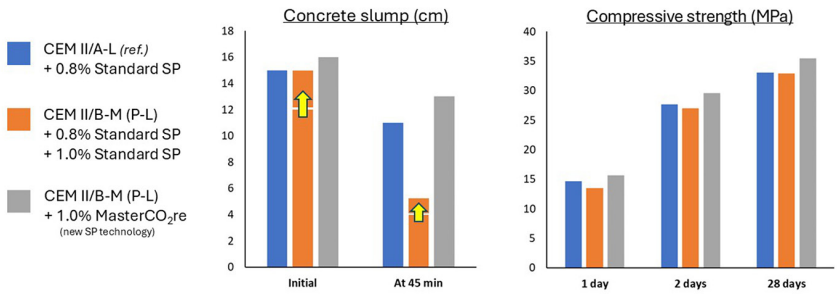
The challenge: slump retention in concrete

In concrete production, required open times of 60-120min are common. This means that, after being produced at the plant, the concrete must maintain its consistency class (level of fluidity) during this time.

One of the main problems associated with the use of absorbent additions in cement is that they can promote premature loss of fluidity. As these SCMs progressively absorb water over time, the concrete mix loses workability, making it unsuitable for proper placement. This phenomenon is especially critical in applications requiring prolonged transport of concrete or in complex structures where the material must remain workable even for several hours.

Reality and experience confirm that when working with cements containing calcined clay, natural pozzolan, or fine limestones, the initial water demand as

Figure 3: concrete slump and compressive strength of a C25/S3 concrete



Source: Master Builders Solutions

well as compressive strength development can be addressed effectively with cement additives. However, in many cases it is not possible with reasonable dosages of a cement additive to prevent workability loss in concrete occurring in the first 30min after mixing, due to the absorbent nature of the SCMs used. One indication of this behaviour can already be observed in pastes prepared with ground SCMs that are mixed with synthetic cement pore solution designed for simulating the ion concentrations in a cementitious pore solution, thus providing a realistic environment for superplasticiser adsorption studies.

Figure 2 shows the fluidity evolution of pastes prepared with calcined clay, natural pozzolan and limestone compared to neat CEM I mixed with water. These pastes were prepared at a w/c ratio of 0.40 with superplasticiser admixture (as in concrete production), adjusting dosage to achieve a similar initial paste fluidity close to 120mm.

Due to their adsorbent nature, these SCMs can significantly drive fluidity loss, mostly in the first 30min after mixing, along with increased superplasticiser demand, especially with calcined clay.

From our experience, proper use of workability-enhancing cement additives can avoid the need to increase superplasticiser dosage in concrete due to higher water demand but often cannot fully solve the problem of fluidity loss without risk of overdosing and providing negative effects on strength development. This limitation arises because the key mechanism to extend fluidity in cementitious systems relies on balancing the fraction of the superplasticiser that is adsorbed (active) and the fraction that remains inactive in solution until it adsorbs onto new hydrate surfaces, restoring the dispersing effect. Obviously, this mechanism cannot occur in the "dry mixing" that takes place in the cement mill during grinding.

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Cement–concrete synergistic approach: the most efficient way to mitigate workability retention issues

For efficiently and economically mitigating fluidity retention problems in concrete produced with cements containing absorbent additions, a holistic and synergistic approach is required, considering chemical additives that work well together at the cement stage and at the concrete stage.

From long-lasting experience in both concrete admixtures and cement additives R&D, Master Builders Solutions' MasterCO2re technology has been specifically designed for these situations involving absorbent SCM additions. By properly combining MasterCO$_2$re admixtures in concrete with cement treated with right additives, concrete can be produced that maintains fluidity for extended periods despite the absorbent character of the SCMs.

Figure 3 illustrates a situation that may be encountered regarding limitations in maintaining workability in concretes manufactured with cements containing less clinker and, in this case, a natural pozzolan compared to a reference cement type CEM II/A-L with higher clinker content.

The concrete used in this test corresponds to C25/S3 class with 275kg/m^3 cement and a w/c ratio of 0.60. The Blaine value for CEM II/A-L is 4900cm^2/g and for CEM II/B-M (P-L) is 5250cm^2/g, showing the higher fineness of the latter.

Similar concrete compressive strength can generally be achieved with the use of appropriate cement additive technology, such as performance-enhancing additives.

However, when using conventional superplasticisers, it is observed that, in addition to presenting lower initial workability (which could be corrected with cement workability enhancer additive to reduce the initial superplasticiser dosage and achieve similar initial flow), the concrete is unable to maintain its consistency class. Even by increasing the dosage of conventional superplasticiser to match the initial workability of the reference concrete, it is still not possible to significantly improve the workability retention. This can be solved by the new superplasticiser technology MasterCO$_2$re, and the retention of workability over time can significantly be improved.

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Strength-enhancing cement additives (together with the increase in fineness) allow for adjustment of the strength development of the cement without causing productivity losses in the mill, despite the increase in fineness. Strength- and workability- enhancing additives can compensate for the impact of absorbing SCMs on initial water demand and initial mortar/concrete fluidity. The most effective and economic way to compensate for the impact on workability retention is the synergistic approach of additionally using new concrete superplasticisers.

Conclusion

Cement decarbonisation through increased clinker substitution with SCMs is a key and effective strategy to reduce the carbon footprint of construction. However, while available and cost-effective, absorbent SCMs pose significant challenges related to concrete slump retention.

Addressing this challenge requires an integrated approach in which chemical treatments in cement and concrete works synergistically. Recognising that solutions are not always technically or economically viable when solely addressing the impact of absorbing SCMs with cement additives, it must be emphasised that advances in superplasticiser chemistry can efficiently and cost-effectively solve potential premature workability loss in concrete.

Thanks to this strategy, the environmental footprint of the cement itself can be improved while ensuring that such cements can be effectively used in modern construction projects, where increasing efforts are made to reduce the CO_2 footprint of concrete. ■