Workability: *What's It All About?*

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LOOK AT STRATEGIES TO IMPROVE CEMENT WORKABILITY.

Introduction

Employees in the construction industry are well aware of the characteristics that are desirable in cement: compressive strengths that satisfy the correct standard and good workability. This term usually determines the ease of mixing and compaction of concrete and mortar. A cement with low mortar workability is not the best starting point for obtaining a concrete with the correct slump class with an acceptable quantity of water. On the other hand, the optimisation of cement workability simplifies the mix design of concrete. In this article, the main factors that can have a negative influence on cement workability are reviewed and several strategies for the improvement of water requirement are described.

Workability

From a practical point of view, the workability of cements is measured in mortar through the flow determination. While flow is not usually included in hydraulic cement specifications, it is commonly used in standard tests that require the mortar to have a water content that provides a specified flow level, and several test methods (such as ASTM C1437 or EN 1015) are available. Regardless of possible differences in the expression of results or testing equipment, all the methods measure the ability of a mortar to spread over a surface. Alternatively, the amount of water needed to create a cement paste with the right consistency (measured through the penetration of a needle in a fresh cement paste) is another common way to assess the water requirement of cement (as described in ASTM C187 or EN 196-3).

Whatever the method of practical evaluation, the workability and water requirement are directly linked to the early

hydration behaviour and to other characteristics such as particle size distribution. The presence of secondary additives (for example in pozzolan or flyash blended cements) is another factor that can reduce workability.

Factors influencing workability

The main factors influencing workability of cement are listed and described here. The reason for abnormal water requirement is a combination of different factors, rather than a single one.

Clinker reactivity

Early hydration of Portland cement is characterised by aluminate phases - basically C_3A. The reaction of tricalcium aluminate with water gives a wide range of products usually referred to as calcium aluminate hydrates (C-A-H). The morphology, crystal structure and composition of these products can be very different, but they generally have a high water content and precipitate as large plates on the grain surface, creating a decrease in workability or causing other negative phenomena such as flash set. Figure 1 shows accumulated C-A-H with an image from an environmental scanning electronic microscope (ESEM).

If sufficient gypsum is present, ettringite is the main hydration product. In favourable conditions, ettringite precipitates as a thin layer on the surface of clinker grains, controlling clinker hydration and providing the best conditions for workability control.

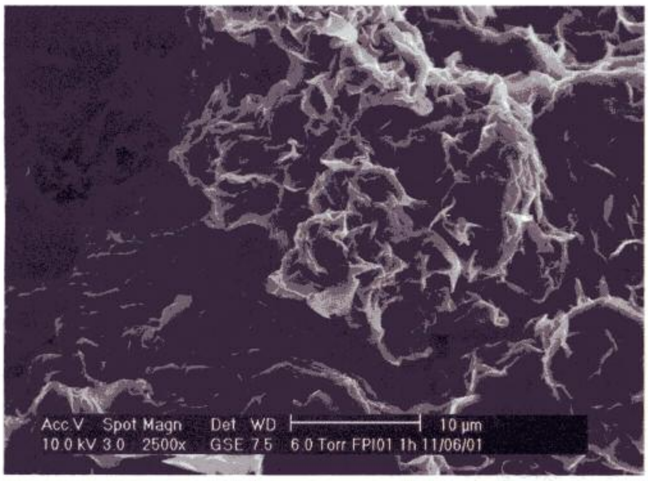

Figure 1. ESEM images of hexagonal hydrates on C_3A surface.

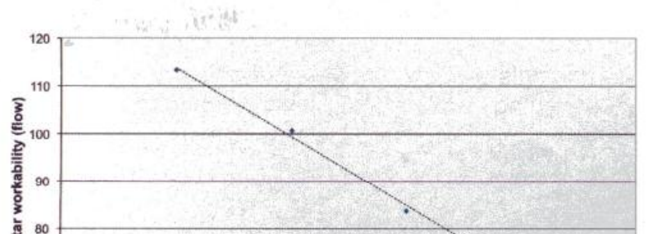

Figure 2. Effect of calcium sulfate hemihydrate on mortar workability.

In order to create the best workability, sulfate supply during clinker hydration should be optimised, especially in the presence of clinker with high amounts of C_3A (evaluated through quantitative X-ray diffraction analysis) and high fineness.

Calcium sulfate

Calcium sulfate is added to cement to control clinker reactivity. Sulfate ions react with calcium and aluminium from the aluminate phases, giving precipitation of ettringite on clinker grains, thus slowing the hydration and controlling the setting time. Several forms of calcium sulfate exist:

- Gypsum (calcium sulfate bihydrate $CaSO_4 \cdot 2H_2O$).
- Bassanite (calcium sulfate hemihydrate $CaSO_4 \cdot ½H_2O$).
- Anhydrite (anhydrous calcium sulfate $CaSO_4$).

Depending on temperature/humidity inside the mill, gypsum can lose water that is converted to other forms. Among them, calcium sulfate hemihydrate is characterised by a higher immediate solubility: higher amounts of sulfate are supplied during clinker hydration. Sulfate in excess, with respect to hydrating calcium aluminate, precipitates as secondary gypsum rather than producing ettringite. Secondary gypsum absorbs water, reducing fluidity and increasing viscosity due to the particular shape of secondary gypsum crystals.[1] The quantification of hemihydrate in cements requires specific X-ray diffraction analysis.

Figure 2 illustrates the results of a test performed in a laboratory showing the effect of hemihydrate. Clinker was ground to a constant fineness and mixed with different amounts of ground calcium sulfate hemihydrate, obtaining several cement samples whose mortar flow was evaluated. As the content of hemihydrate increases, the flow decreases linearly.

Particle size distribution

The expression particle size distribution (PSD) indicates the relative amount of each cement particle diameter. It is commonly evaluated through laser diffraction analysis and described with a graph reporting the percentage in volume or mass of each particle diameter. PSD can be narrow or broad, depending on relative diameter distribution: if dimensions of particles tend to extend over a short diameter interval (and thus particles have similar dimensions), PSD is narrow. If there are higher relative amounts of fine and coarse particles, PSD is broad. The 'broadness' or 'narrowness' of a cement PSD is usually described with the uniformity constant - a parameter obtained from specific mathematical modelling, the most common being Rosin-Rammler-Bennet distribution.[2] Higher uniformity constants (narrow PSD) are associated with high water requirement. A simple model can explain the reason: if particle diameters tend to be similar, there is a larger volume between particles that needs to be filled with water in order to produce a movable paste. On the other hand, if there is a good proportion of fines and coarses, the spaces between particles are lower and water requirement is lower.[3]

Presence of mineral additives

The use of pozzolan or flyash as mineral additives can pose workability problems. Tuff or natural pozzolan cements, due to the higher porosity and ability to absorb water, represent a typical example of high water requirement binders. On the other hand, there are mineral additives (e.g. granulated blastfurnace slag) with a positive effect of workability improvement.

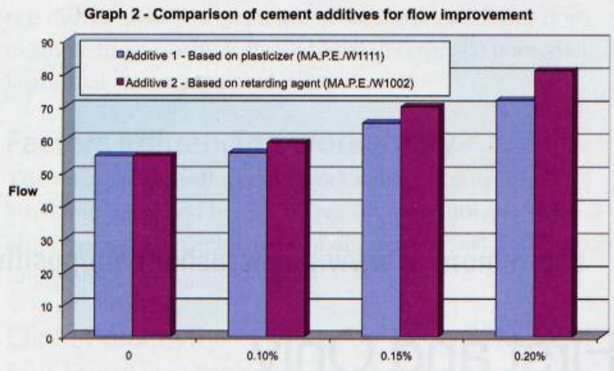

Figure 3. Comparison of cement additives for flow improvement.

Table 1. Reasons for high water requirement of cements and the strategies for workability improvement

Reason for high water requirement	Details	Evaluation methods	Strategies for workability improvement
Clinker reactivity	High C_3A levels, high fineness	Quantitative X-ray diffraction	Modification of clinker quality, gypsum optimisation, use of suitable retarding additives
Type of calcium sulfate	Presence of calcium sulfate hemihydrate	Quantitative X-ray diffraction	Use of different gypsum sources, control of grinding temperature
Particle size distribution	Narrow particle size distribution	Laser diffraction analysis with calculation of RRB-line slope	Modifications in grinding/ separation, use of suitable additives with dispersing/ plasticising effect
Mineral additives	High water request due to porosity or water absorption	-	Use of different secondary additions, use of suitable additives with dispersing/ plasticising effect

Strategies to improve workability

As it is related to several parameters (and sometimes to a combination of different parameters), the problem of high water requirement should be managed in several ways. Sometimes it is not practical to eliminate the reason for abnormal workability. For example, in the case of high C_3A reactivity, the modification of clinker production or the coarse grinding of cement pose problems of kiln efficiency or lower cement performances.
If particle size distribution is narrow, it is possible to increase the amount of coarse particles by reducing the efficiency of separation and, with overgrinding refinement (through an accurate control of recirculation), it is possible to increase the amount of fine material, thus improving the water requirement. On the other hand, this may have a negative effect on strength development.

The use of a cement additive is often the simplest way to eliminate the problem of high water requirement. The advantages of cement additives include:

- *Lower cost*. In comparison to modifications in clinker production or a reduction in the use of secondary mineral additions, the cost of introducing cement additives is relatively low.
- *Flexibility of use*. While a modification of clinker chemistry or mechanical operations on the separator affect all the cements produced in a plant, a liquid additive can be used only on specific cements, where the workability problems are more evident.
- *The possibility of having tailor-made formulations*. Sometimes there is the need for a proper balance between the retarding and dispersing effects, and it is possible to formulate according to each specific case.

Cement additives that affect workability can be divided into two main categories:

- *Dispersing agents, such as plasticisers/superplasticisers*. The action is to disperse the flocculated cement particles through a mechanism of electrostatic repulsion. These additives are supposed to be adsorbed onto the cement particles, giving them a negative charge, which leads to repulsion.
- *Retarding agents*. These act to slightly retard the hydration of aluminate phases, slowing the formation of calcium aluminate hydrates and allowing a high water availability during the early hydration stage, thus improving workability.

Of course, different reasons for abnormal workability require different types of cement additives. In the case of high reactivity of C_3A, the use of a dispersing agent can be useless, while the proper retarding agent can lead to interesting benefits. On the other hand, in the case of either incorrect PSD or natural pozzolan, the use of a dispersing agent is the most applicable. The following example clarifies the situation.

Example

Figure 3 shows the results of an industrial test carried out on a type I cement with a high water requirement. X-ray diffraction and laser diffractometry show that high water requirement is probably due to high clinker reactivity and poor PSD. Two additives were tested at different dosages: additive 1 (MA.P.E./W1111) based on a typical plasticiser, and additive 2 (MA.P.E./W1002), with formulation corrected with the addition of a retarding agent. Results are reported in Figure 3 and show that the addition of a retarding agent to the formulation provides improved workability at lower dosages than with a pure plasticiser. This means that the clinker reactivity was the main factor and the use of a retarding agent is crucial.

Conclusion

The water requirement of cements can be related to several factors, ranging from clinker chemistry to PSD, and sometimes a combination of different parameters. The development of a specific cement additive to improve workability should take into account a detailed investigation into the reasons for unusual water requirement, and the proper balance between retarding and dispersing effects should be carefully investigated.

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