SLAG CEMENTS: GREEN, STRONG AND COOL!

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Introduction

As sustainability and durability of concrete are becoming increasingly important, there is a need for cements with additional properties and characteristics. Blast furnace slag cements according EN 197-1 (CEM III) do have these properties. CEM III cements are composed mainly of granulated blast-furnace slag (GBFS). Slag has latent hydraulic properties that are activated by Ordinary Portland Cement clinker (OPC). Already since decades, slag cements are the most commonly used cements in the Netherlands (CEM III/B with 66-88% slag) and in Belgium (CEM III/A with 36-65% slag), mainly in ready mixed- and pre-cast low end concrete.

Recently, two new special CEM III cements have been developed to contribute to the durability and sustainability ambitions of the construction sector.

CEM III/A 52.5 N – SR:

This cement is an alternative to CEM I 52.5 N, reducing its CO₂-footprint by 50%. It has several other beneficial properties such as light colour, early strength development comparable to CEM I 52.5 N, higher final strength, high and stable fineness, high resistance against chloride and sulphate ingress and is in line with alkali silica reaction guidelines. This cement can be considered as a perfect solution for the precast high end industry. With this cement, self-compacting concrete can be produced but also, due to its fineness, high- and ultra-high strength concrete. Concrete based on this cement is very durable, especially under marine conditions.

Cement Composition / Properties

Properties of cement are strongly determined by source and content of the constituents and the particle size distribution (PSD). OPC has as a feature to be very reactive and contributes to a rapid early strength development. GBFS is less reactive but allows for a denser cement stone structure in concrete more resistant to attack by chlorides, sulphates and acids. CEM III/A 52.5 N – SR is composed with a minimum of 50% slag and a particle size distribution that leads to a strength development in the 52.5 N class.
Concrete properties

Strength development of concrete is very important especially looking at demoulding, prestressing and transporting of prefab concrete elements. Besides type of cement also water cement ratio (WCR) and temperature during curing play an important role. Research has shown that especially at higher temperatures concrete with CEM III/A 52.5 N – SR performs a rapid hardening. At temperatures of 40°C performance is equal to concrete with CEM I 52.5 N and at 60°C even better. CEM III/A 52.5 N – SR fits in the design of (Ultra) High Performance Concrete [(U)HPC] and Self Compacting Concrete (SCC). Many concretes-compositions have been investigated. The dense concrete structure contributes to high strength levels in the classes C50/60 to C100/C115 or even to very high strength classes of > 150 MPa. For SCC the high fineness of around 6000 cm²/g is essential in the mix design. Flow and viscosity of concrete is improved with enough fine particles and an optimal PSD of all concrete constituents.

Concrete Durability

Concrete structures are exposed to conditions which could disintegrate concrete itself or reinforcement. It is up to the concrete technologist to design concrete compositions in such a way that there is enough resistance to environmental impacts like Carbonation, Chloride and Sulphate ingress, Freeze Thaw (including de-icing salts), Alkali Silica reaction (ASR) and Acid resistance (AR). The choice for the right cement type plays an important role. The diffusion resistance of chloride in concrete improves when more slag is applied. Sulphate attack of concrete becomes more sensitive when more C₃A is present. C₃A is a constituent of OPC and application of slag in cement dilutes the presence of C₃A. Also, GBFS in cement leads to a more dense concrete structure which results in an improved sulphate resistance of the concrete. Based on a European Technical Approval (ETA) CEM III/A 52.5 N with > 50% slag is assessed as Sulphate Resistant (SR). ASR and AR are also better compared with CEM I also because of the lower amount of soluble alkalis (ASR) and the dense Concrete structure (AR). GBFS cements are less Freeze Thaw- and Carbonation- resistant compared with CEM I, but research has shown that resistance with ± 50% clinker is acceptable and fulfilling requirements.

Environmental Performance

CEM III/A 52.5 N – SR is a so called “green” cement. One of the important environmental-indicators is the carbon-footprint (Figure 1). This cement containing at least 50% GBFS produces 450 kg CO₂ per ton cement (cradle-to-gate). Besides CO₂ there are more environmental parameters indicated as LCA (Life Cycle Analysis). For example, the extent of eutrophication and acidification of the environment, the depletion of resources, ozone depletion etc.
Figure 1: CO₂ footprint of CEM III/A 52.5 N – SR compared with CEM I 52.5 N

CoolCem®
This is a CEM III/B with almost 80% slag. Concrete structures are designed to withstand stresses due to loads. Nevertheless, reinforced concrete always contains cracks. Those cracks are very often induced by thermal stresses which are caused by the heat released upon cement hydration. Therefore, a “Cool” cement, characterised by a low heat release, will minimise the thermal stresses. The experiences with CoolCem® demonstrate that it is an ideal solution for example in mass concrete applications.

Thermal Shrinkage
Hardening concrete heats up. The reaction between cement and water is an exothermic reaction. This heat will further accelerate the reaction that releases more heat and rises the temperature in a concrete element. Due to this heat development, concrete will expand. Expansion will result in compressive stress which is no problem because concrete can withstand pressure stresses. But after the warm up phase inevitably cooling follows. Cooling concrete will shrink and shrinkage inhibition will lead to tensile stresses. When the tensile stresses are larger than the tensile strength of the concrete cracks will be formed. This is called thermal shrinkage (see Figure 2). Temperature development in concrete strongly depends on dimensions of the construction, but also concrete composition. Especially in Mass Concrete temperatures could rise up to 60-70°C. In most of the applications it is not easy to reduce dimensions of a construction. Therefore, solutions to reduce heat via optimised concrete compositions are favourable.

Cement content and type
Heat released in concrete during hydration reactions depends on cement –content, -type, -composition and PSD. In mass concrete cement content is already at a minimum.
Therefore, applying a cement with a low heat of hydration is desired. GBFS is compared with OPC less reactive and generates less heat during hydration. Replacing OPC in cement by GBFS reduces the heat of hydration in a cement. One of the most applied cements is CEM III/B 42.5 N with a heat of hydration according EN 197-1 of 235 J/g. This cement has a OPC/GBFS ratio of 30/70. For further reducing heat development in concrete a new CEM III/B 42.5 L is created with almost 80% GBFS and only 215 J/g heat of hydration; named “CoolCem®”. Beneficial in mass concrete applications is that for GBFS negative durability aspects like carbonation and freeze thaw resistance are less sensitive. Existing regulations allow this type of cement to be applied.

Product development

Question is if this CoolCem® applied in concrete is able to significantly reduce the risk on crack formation in concrete constructions. Therefore both cement- and concrete research has been performed. It is known that not only heat of hydration but also strength development and deformation behaviour contribute to the risk of crack formation. To predict this risk several tests on cement and concrete have been performed and test results show no significant risks in applying this cement in “heat sensitive concrete applications”. Since September 2015 CoolCem® is commercial available and applied. The underground parking “Toernooiveld” in the Hague is constructed with concrete based on CoolCem® with limited risks on crack formation. Figure 3 shows the adiabatic heat development in the concrete comparable to a CEM III/C.

![Figure 2: Crack formation in concrete](image1.png)

![Figure 3: Adiabatic heat development of CoolCem® vs CEM III/C concrete (C30/37 320 kg cement WCR 0.50 Dmax = 32 mm)](image2.png)

References