SUSTAINABLE HIGH AND ULTRA HIGH PERFORMANCE CONCRETE

THE NEXT GENERATION BINDERS

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Contents

1. Background

In the 1980's, the laboratories of Aalborg Portland A/S in Denmark, now the Research and Quality Centre for the Cementir Group, conducted pioneering research to develop very dense cement based binder-matrices. These efforts based on AALBORG WHITE® portland cement resulted in the first ever patented ultra-high performance steel fibre reinforced concrete – Compact Reinforced Composite, CRC® [1]. In spite of the mixture technology being almost 40 years old, the composition of most modern HPC and UHPC mixes has changed little from the original recipes based on silica fume and quartz flours.

Unfortunately, it took decades before the construction market would begin realizing the advantages offered by fibre reinforced high and ultra high performance concrete, including its potential for highly efficient material optimization, provided excellent strength to mass ratios. Properly designed and installed UHPC building elements yield high energy efficiency, great resilience and durability, and are low maintenance. However, together with the growth in demand, some of the main challenges related to the technology and its complexity, become increasingly apparent, such as sourceability of the key ingredient, silica fume in terms of availability, price and quality, fresh concrete properties, such as fast loss of workability, and hardening properties, such as strong retardation and increased shrinkage.

2. Re-engineering HPC and UHPC binder technology

Sustainable HPC and UHPC binder technology

An Innovation Team in Cementir Group is further developing the very complex binder technology behind High and Ultra High Performance Concrete. The solution is based on a further refinement of Cementir Holdings recently patented sustainable binder technology, FUTURECEM™, which combines Portland cement clinker and supplementary cementitious materials derived from heat-treated aluminosilicate materials, and limestone[2]. The formulation does not include the use of scarce natural materials or waste materials from other industries which can be subject to volatile swings in quality, availability and cost. Furthermore, heat curing is not necessary for a succesful use of this technology.

Predictable and Reliable Performance

A successfull implementation of a technology assumes that what can be designed, mixed and manufactured in small specimens under laboratory conditions becomes transferrable to the conditions applicable to a full-scale production facility, where completely new requirements become decisive for the quality of the placed concrete in the final structure/element. A couple of examples of typical challenges are, ensuring a proper open time of the fluid UHPC mix to enable a controlled casting operation, and minimizing shrinkage potentially leading to cracks.

The challenges above require, among many others, an extensive investment and commitment to develop and document the properties of workable mixes, building up suitable quality control systems, knowhow, casting techniques, etc. To support and sustain the increased demand for HPC/UHPC solutions, Cementir Group has launched commercial UHPC ready to use, premixed products (see Table 1 for properties of AALBORG EXTREME™ Light120) based on this sustainable and reliable binder technology. These self-compacting products can be combined with fibres depending on the application served.

Table 1: Some key poroperties of AALBORG EXTREME™ Light 120

Table		**AALBORG EXTREME™ Light 120**
Aggreate size	mm	<3
Flow (EN-206)	mm	>900
Flow (ASTM C230/C1437-15)	cm	29±2 (initial and at 45´)
Hydraulic shrinkage	µm/m	<600
Compressive Strength (EN 12390-3)	MPa	1D: >75 / 28D: >120
E-modulus (EN 12390-13)	GPa	50
Flexural Strength (EN 12390-5)	MPa	>14
Splitting Tensile Strength (EN 12390-6)	MPa	12
Durability		
Chloride Migration Coefficient (NT Build 492)	$x10^{-12}$ m^2/s	28D: 0.35 / 56D: 0.27
Freeze/Thaw Resistance – Scaling (EN 12390-9)	kg/m^2	0.00
Water absorption, EN 1015-18	$kg/(m^2 min^{0.5})$	<0.02
Oxygen Permeability (UNE 83981)	m^2	$<2x10^{-21}$
Carbonation Rate (UNE EN 13295)	$mm/day^{0.5}$	0 (at 1 and 3% CO_2)

For this product, the optimum solution was found by combining AALBORG WHITE® with a highly reactive (reactive SiO_2 above 40%), relatively coarse, metakaolin and a finer ground high purity limestone, using a powder based PCE superplasticizer. Flow retention was ensured by using a commercially available additive offsetting the initial reactions without negatively influencing the early strength development. An obvious advantage of the binder technology results from the high flexural and tensile strength obtained at any given compressive strength. This becomes even further improved in combination with fibres.

A binder technology linked to the framework of the EN standards

The composition of the binder used in AALBORG EXTREME™ Light 120 fulfills the chemical requirements of a CEM II/B-M (Q-LL) according to EN 197-1, including a total SO3 content lower than 3.5% suitable for all strength class nominations.

3. Conclusions

Regardless of a HPC or UHPC mixture's makeup to be commercially viable, the technology must solve the persistent placement and workability issues these materials commonly experience today, such as flow retention and rheology. Following the binder technology principles in Cementir Goup´s patented FUTURECEM^{TM}, the Group has recently developed, tested and commercialized sustainable UHPC products which provide a safe and reliable solution to the issues mentioned above, which is based on AALBORG WHITE® cement, limestone and calcined clay.

References

[1] Bache, H.H., "Introduction to Compact Reinforced Composite," Nordic Concrete Research, No.6, 1987, pp. 19-33.

[2] Dai Z., Kunther W., Ferreiro S., Herfort D., Skibsted J. "Phase Assemblages in Hydrated Portland Cement, Calcined Clay and Limestone Blends From Solid-State 27Al and 29Si MAS NMR, XRD, and Thermodynamic Modeling". In: Scrivener K., Favier A. (eds) Calcined Clays for Sustainable Concrete. RILEM Bookseries, vol 10. Springer, Dordrecht, 2015.