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Ultra High Performance Concrete: Mix design and practical applications

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ABSTRACT: Evaluating two interesting applications for UHPC, cladding panels and overlays, this project focused on some relevant aspects such as the mix design of UHPC, the shrinkage at early age, the fiber reinforcement and the flexural behaviour. As far as mix design concerns, the research optimized the choice of admixtures, (micro)fillers and the aggregate grading, obtaining a compressive strength between 125 and 180 N/mm^2 and excellent flexural behavior with the cocktail of micro- and macrofibers. Both restrained and unrestrained shrinkage have been evaluated, and the results seem not to limit the applications. Two practical applications have been studied and show the potential of this material: thin and large cladding panels with different types of reinforcement, together with new anchorage systems. Secondly, UHPC-overlays for old and new concrete elements seem to be an innovative solution for concrete surfaces exposed to wear or aggressive substances. Modeling and real-scale experiments have been compared for this application.

1 INTRODUCTION

Developments in admixture technology have been a boost for developing advanced concrete types, broadening the application field of concrete, allowing concrete solutions for existing problems. Some concrete researchers even see opportunities for concrete, Ultra-High-Performance Concrete (UHPC) in this case, for entirely new application fields, as a replacement for steel of ceramic material. Observing these possibilities, the BBRI and VUB evaluated the early age behavior and two promising applications: thin cladding panels and overlays for concrete. For this, two types of UHPC have been optimized, with a compressive strength of 125 and 180 N/mm^2 respectively.

2 MIX DESIGN AND SHRINKAGE

2.1 *Materials and mix design*

A first type of mixture (type 1) is based on a High Performance Concrete (HPC), with a moderate cement quantities of 400 kg/m^3. Applying the basic principles for a UHPC (Richard & Cheyrezi 1995), and theoretical models as for instance the solid suspension model (De Larrard & Sedran 1994), the second type uses higher quantities of cement and microfillers, and has been used as a reference mixture for further parameter variations (Cauberg et al. 2006). Mixture details can be found in Table 1. An adequate cement choice and the use of dispersed silica fume resulted in a self-compacting UHPC for the type 2.

Table 1. Reference mixtures for the tests and applications.

Composition	Type 1 [kg/m^3]	Type 2 [kg/m^3]
Porphyry 3/8	761	–
Porphyry 1/3	576	841
Quartz sand 0/0.5	640	363
CEM I 42,5 R HSR LA	407	833
Silica fume	102	167
Water	122	179
Superplasticizer	11	24
W/C	0.30	0.21
$f_{cm,cub}$ (28d.) [N/mm^2]	135	175

2.2 *Shrinkage*

Shrinkage is an important issue for UHPC. Restrained shrinkage can be the cause of micro- and macrocracking, and could limit the range of applications. This restrained shrinkage will often occur for long structural element and composite members.

This time-dependent behaviour of UHPC was observed by using long-term measurements in a climatic room (20 ± 2°C; 65 ± 5% RH). Measurements

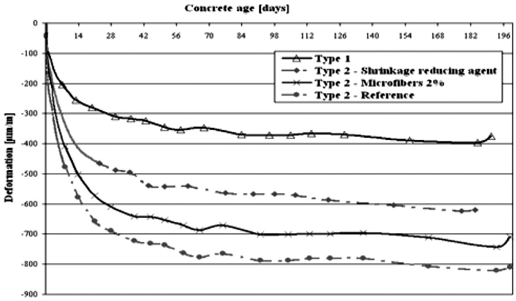

Figure 1. Long-term drying shrinkage of UHPC type 1 and 2.

started immediately after the end of binding (10–13 hours after casting). The evolution of the shrinkage is rather important, until 300 μm after 2 days. The shrinkage of the samples is measured vertically, after a 2-day curing. Figure 1 shows the results of drying shrinkage measurements for the reference mixture (type 2 in Table 1). Furthermore, the effect of admixtures, fibres and reduced powder content (type 1) show the possibility to reduce these shrinkage values.

3 UHPC CLADDING PANELS WITH HYBRID REINFORCEMENT: FLEXURAL BEHAVIOR

The flexural behavior of the UHPC has been enhanced with steel microfibers and E-glass textile. Figure 2 shows the displacement-force curves for small prisms ($40 \times 60 \times 160\,mm^3$). Especially for non-load-bearing elements, as for instance the cladding panels, these types of reinforcement could replace the steel rebar, preserving or even increasing the security level at failure.

The combination of this reinforcement, and alternative ways of anchorage systems allow for the production of larger and thinner panels than possible in traditional concrete of natural stone, amongst others because of the concrete cover.

4 OVERLAYS IN UHPC

The high durability and wear resistance of UHPC makes it very suitable for the protection of concrete elements, as for instance industrial floors, road surfaces or rehabilitation of surfaces exposed to chemical substances. Overlays combine UHPC and other concrete types, involving differential deformations, especially at early age. Debonding and cracking are the most important failure modes for this type of composite members because of the high shrinkage values (Figure 4).

Tests with composite members included UHPC overlays with and without steel fibers, ordinary mortar

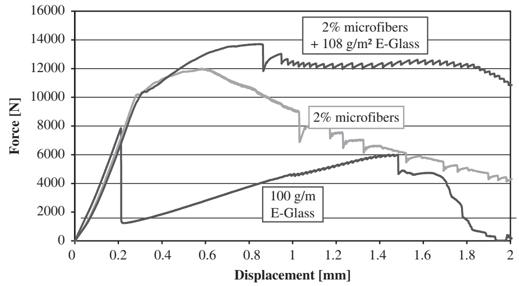

Figure 2. Displacement-force curve for three-point flexural tests for different types of reinforcement.

Figure 3. Four-point bending test for UHPC cladding panels.

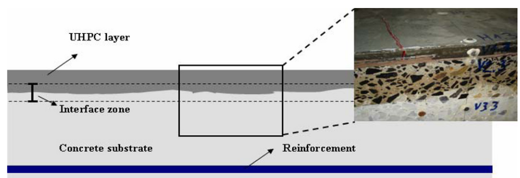

Figure 4. Composite member with UHPC overlay.

and a repair mortar, with overlays of 15 and 30 mm. After two months, none of the fiber reinforced overlays of 30 mm showed cracking or debonding, while this was the case for the other test specimens (UHPC without fiber reinforcement of 15 and 30 mm, the ordinary mortar and the repair mortar).

5 CONCLUSIONS

UHPC offers a range of new possibilities for concrete structures. The mix design of UHPC includes high amounts of cement, (micro-) fillers and admixtures, and a $f_{cm,cub}$ of 180 N/mm^2 can be obtained without any special curing. Integration of fiber mixes greatly increases the flexural toughness, allowing for the production of elements without any other structural reinforcement, as for instance thin cladding panels with large spans. Shrinkage measurements vary in the range 400–800 μm after 200 days, depending on the composition. This does however not limit the application for overlays, no cracking occurred for fiber reinforced UHPC.

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