Ultra high performance fibre reinforced concrete as a waterproofing solution for concrete bridge deck renovations

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ABSTRACT
The ability of ultra-high performance fibre reinforced self-compacting concrete to act as a waterproofing on renovated concrete bridge decks is investigated. For such an application the concrete must exhibit specific features, such as deformability, low permeability and high strength. In this paper, the effect of the amount of steel fibres on the shrinkage crack distribution and on the workability of the material was investigated. The impact of a proper treatment of the underlying concrete layer on the bonding strength of the high strength concrete was also studied.

Key words: SCC, Fibres, Shrinkage, Cracking, UHPFRC, Waterproofing

1. INTRODUCTION

Majority of the existing concrete bridge decks in Denmark are currently being renovated by a traditional bitumen waterproofing. Such a renovation results in a lengthy and costly process. A typical traffic disruption due to the renovation is in the range of 3 months. A significant portion of that period is taken by the replacement of the waterproofing layers. Alternative waterproofing materials capable of reducing the duration or frequency of the renovations are therefore of a great interest. Ultra-high performance fibre reinforced concrete (UHPFRC) has been in the last decade investigated as an alternative waterproofing by e.g. Habert et.al. 2013. Insufficient knowledge of the material however restricts its wider adoption. This paper therefore aims to contribute to the knowledge by focusing onto the effect of fibre volume fraction on shrinkage crack distribution and workability of the concrete. This paper also focuses on the bonding strength of the UHPFRC with the underlying concrete.

2. MATERIALS AND METHODS

Mixture design of the UHPFRC used in the following studies followed ECO-UHPRFC presented in Habert et.al. 2013.

2.1 Concrete paving blocks 80 x 62 x 10 cm

Approximately 1 cm thick layer of the UHPFRC was cast onto 6 concrete paving blocks of dimensions 80 x 62 x 10 cm. Three different fibre volume fractions (0%, 4% and 8%) were used to study the effect of fibre amount on the shrinkage crack distribution. Concrete of the same fibre volume fraction was cast onto two separate concrete blocks. The specimens were covered by a plastic foil and left to harden. Subsequently, the shrinkage crack pattern of individual specimens was studied by e.g. visual quantification and plane section analysis. Rheology of the UHPFRC was measured using the 4C-Rheometer (Thrane et.al. 2010).

2.2 Concrete blocks 30 x 30 x 7 cm

In total 10 blocks of dimensions 30 x 30 x 7 cm were cast of an ordinary bridge deck concrete. The blocks were left to harden for a period of 28 days. Six of the blocks were roughened by sand blasting, whereas four of the blocks were left with a very smooth surface. Two blocks of each surface type were covered with a very thin layer of dust. One day before casting, upper surfaces of all the blocks were soaked with water. Two of the sand blast blocks were treated with a mortar bonding agent. Approx. 3 cm thick layer of the UHPFRC was cast on top of all the blocks. The blocks were left to harden for 7 days. The bonding strength between the UHPFRC and the blocks was then measured by means of tensile and shear tests.

3. RESULTS

A minor parametric study of the UHPFRC workability for various fibre amounts was performed. Figure 1 presents results of the slump flow test performed using the 4C-Rheometer. The figure clearly indicates a decreasing workability of the concrete with increasing fibre volume fraction. A severe interlocking among the fibres was observed when the fibre volume fraction reached 8%. These observations are in line with Martinie et.al. 2010.

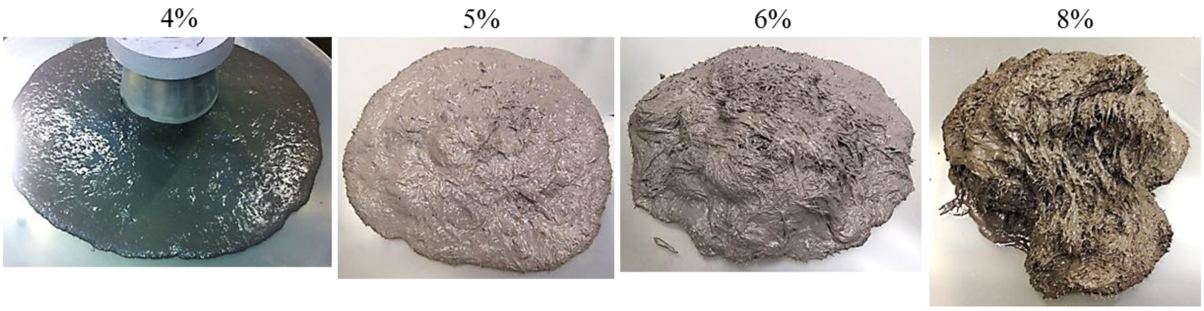

Figure 1 – Slump test of UHPFRC concrete for different fibre volume fractions.

3.1 Concrete blocks 80 x 62 x 10 cm

Figure 2 shows top views of the UHPFRC layer cast on the concrete paving blocks for 0% and 4% fibre volume fraction. The left figure indicates a clear pattern of relatively large shrinkage cracks. The right figure doesn't indicate any visible shrinkage crack pattern. The only crack was observed in the bottom right hand corner of the concrete block. The maximum thickness of the crack was in the range of 0.1 mm. The position and orientation of the crack indicates that it was primarily caused by an unfavourable local orientation of the steel fibres (Švec et.al. 2013).

Figure 2 – Shrinkage cracks in UHPFRC. Fibre volume fraction: Left – 0%; Right – 4%.

3.2 Concrete blocks 30 x 30 x 7 cm

Delamination

The bonding strength between the concrete and the UHPFRC was negligible for all the specimens that were not treated by the mortar bonding agent. When a thin layer of dust was present on the concrete block, the UHPFRC completely delaminated. A severe delamination was also observed when the surface was intact, i.e. smooth (see Figure 3 for an example).

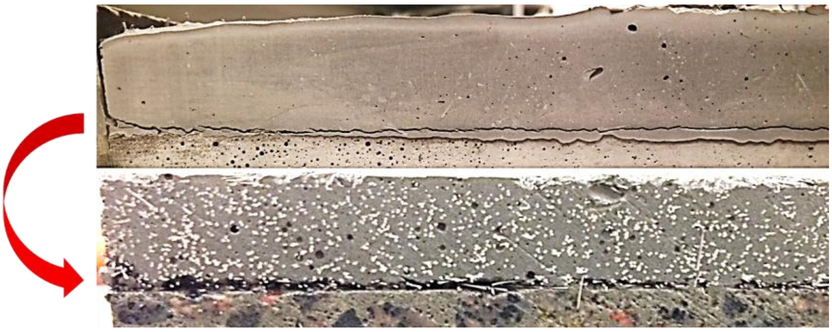

Figure 3 –An example of a severe delamination of the UHPFRC layer resulting in negligible bond strength.

The best results in the absence of the bonding agent were obtained when the surface of the concrete blocks was sand blast. When the surface of the blocks was penetrated by the mortar bonding agent (see Figure 4), the bonding exhibited a relatively high strength in the range of 4 – 5 MPa.

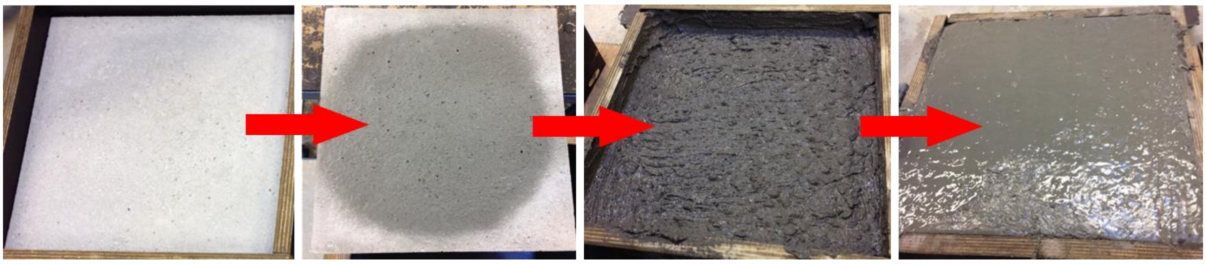

Figure 4 – A proper treatment of the substrate concrete before casting. The concrete surface was sand blast, moistened, and "penetrated" by a mortar bonding agent.

Shrinkage crack distribution

Similarly to Section 3.1, the effect of steel fibres on the shrinkage crack distribution was analysed for the concrete blocks of dimensions 30 x 30 x 7 cm. The block was cut and analysed by plane section analysis. Results of the analysis are presented in Figure 5. The top figure shows a photograph of the plane section. The bottom figure shows a sketch of all the cracks noticeable in the plane section. Thickness of the majority of the cracks was under 0.005 mm. All the cracks in the plane section were classified as micro-cracks, i.e. the UHPFRC can be seen as waterproof. Approximately 40 cracks were counted along the length (203 mm) of the plane section. The crack density was therefore approximately 0.2 cracks per millimetre.

4. CONCLUSIONS

A set of experiments was performed to analyse the ability of the UHPFRC to act as a waterproofing layer on the concrete bridge decks. The following main conclusions were drawn from the performed studies:

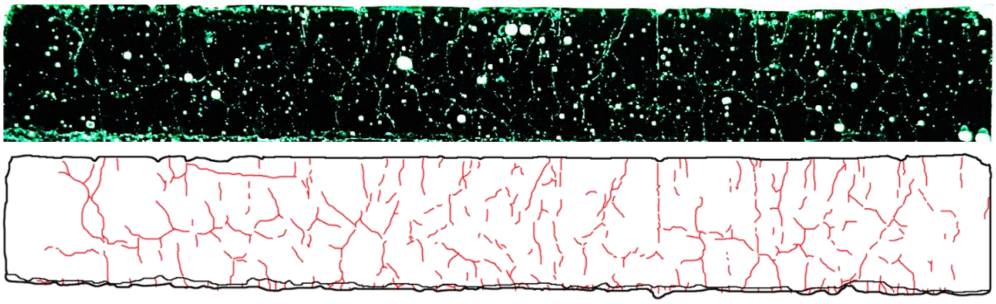

Figure 5 – Top: Plane section analysis of the UHPFRC cast onto a block of ordinary concrete. Bottom: Illustration of the crack pattern obtained from the plane section analysis.

- A proper surface treatment of the underlying concrete and a proper casting process is crucial to avoid delamination of the UHPFRC.
- Workability of the UHPFRC was reduced as the amount of steel fibres increased.
- Fibre volume fraction has a strong influence on the shrinkage crack distribution. A few large cracks were observed when no fibres were added. Many microscopic cracks were observed when a sufficient amount of steel fibres was added to the concrete.
- The distribution of shrinkage cracks is similarly to the fibre volume fraction influenced by the fibre orientation. To avoid shrinkage cracks, the excessive fibre orientation has to be avoided – i.e. the flowability of the concrete must be limited.

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