Experience with prefabricated UHPFRC in the Netherlands

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Summary

Ultra High Performance Fibre Reinforced Concrete (UHPFRC) is a concrete type with superior performance compared to conventional concrete. The durability, the compressive as well as the tensile strength on the one hand and the aesthetical appearance on the other hand are reasons to choose UHPFRC for the design of concrete structures. In spite of intensified research efforts during the past decade, the number of applications with UHPFRC is still limited.

This article describes the experience of Hurks Beton, a Dutch producer of prefabricated concrete elements, with UHPFRC-applications. Several outstanding projects were realised during the past ten years. Examples of UHPFRC-applications of Hurks Beton are described and distinguished in three categories: durable applications, applications in infrastructure and architectural applications.

Keywords: Ultra high performance fibre reinforced concrete, applications, precast elements

1. Introduction

Ultra High Performance Concrete (UHPC) is an innovative material with the potential for a wide range of structural and architectural applications. Besides a high strength and an enhanced durability, UHPC has considerable benefits when being self-compacting. Due to the intrinsic brittleness of the material, fibre reinforcement often is required; UHPC almost always is an UHPFRC.

The application of new types of concrete depends on the availability of recommendations and guidelines. In other cases, a special permission is required. It takes time until a new material is accepted. The first UHPFRC-recommendation was published in France in 2002 [1]; Japanese and German guidelines followed. At this time, a fib-commission (Task Group TG 8.6) is preparing an international UHPFRC-guideline [2]. Eurocode EN 206-1 [3] distinguishes classes of concrete compressive strength; the highest strength category at this time is C100/115. In order to be classified 'UHPFRC', a minimum characteristic compressive strength of 150 MPa is required according to the French UHPFRC-recommendation. In addition to the compressive strength criterion of at least 150 MPa, a minimum ductility is required [1]. 'UHPFRC' with characteristic compressive strengths in the range of 115-150 MPa are not yet considered in recommendations; additional research effort is required to close this gap.

Fibres (for example steel, plastic or carbon fibres) increase the tensile strength and the ductility of concrete. The extremely dense structure of this type of concrete makes it almost impermeable for fluids and gasses. The resistance against chemical attack is significant better compared to conventional concrete or high strength concrete. Slender structural elements can be designed with a thin concrete cover or without reinforcement. A concrete cover of 15 mm often is sufficient to protect steel reinforcement even in a very aggressive environment. Under specific circumstances concrete elements with UHPFRC can be economically competitive with steel structures and are more durable. Fire-resistant UHPFRC has an additional competitive advantage compared to steel.
2. Development of UHPFRC at Hurks Beton

Hurks Beton is a Dutch producer of prefabricated concrete elements with more than 10 years of experience with applications in UHPFRC. During this period, Hurks Beton also participated several research projects in order to gather knowledge, to further develop UHPFRC and to optimize the production technique. Hurks Beton is a part of the Hurks Group (located in Eindhoven) and specialises in the production of concrete products like architectural elements, large-scale prestressed structures and fibre reinforced elements and recently build several towers of 100 m and a hybrid (concrete and steel) wind tower of 130 m. Special emphasis is related to the production of high quality structural elements and the application of innovative concrete types. At this time, prefabricated elements are in production for projects in Benelux, England, France and Germany.

The UHPFRC-development at Hurks Beton started 1998 as a cooperation with Quillery (part of Eiffage TP, France). Quillery developed BSI (‘Beton Speciale Industriel’ is a commercial product of the French contractor Eiffage TP), a UHPFRC, and wanted to transfer a laboratory-proven material into practice and to produce structural elements with UHPFRC. Many UHPFRC-projects of Hurks Beton were carried out in cooperation with Eiffage TP. At a time, when no recommendations were available (1998-2000), Hurks Beton already produced prestressed structural elements with UHPFRC. Without special heat treatment, BSI with steel fibres (Fig. 1) has a mean compressive strength of about 200 MPa (cubes of 100 mm, standard deviation: ± 7 MPa) 28 days after casting. Other fibres types (i.e. plastic fibres) also have been applied to replace steel fibres. Compressive strengths in excess of 110 MPa were obtained with heat treatment at an ambient temperature of 30°C until 22 hours after casting. No further heat treatment was applied afterwards. Self-compacting BSI has been applied for slender structures and architectural applications. Hurks Beton was involved in different French investigations on the characteristics of UHPFRC and participated the European 'Innoconcrete'-research project in order to determine and to improve the material characteristics of BSI. Significant research efforts were made and are ongoing in order to meet the changing demands concerning material technology and production technique for UHPFRC-applications.

![Fig. 1 Casting of a segment of the Folly 'Zonnestraal' with UHPFRC (BSI)](image)
3. Applications in UHPFRC

A structure with UHPFRC requires additional benefits compared to conventional concrete in order to compensate the higher material costs. Very slender elements can be produced with self-compacting UHPFRC. Successful applications with UHPFRC can be categorized in three 'functional' groups:

1) Durable applications
2) Applications in infrastructure
3) Architectural applications

Examples of applications with UHPFRC are the following: façade elements, columns, bridge decks, water-retaining structures, hollow-section elements, prestressed girders and sheet piles.

3.1. Durable applications

UHPC is an outstanding material for structures, which are in contact with very aggressive fluids or gasses. Examples of ‘durable’ applications are storage reservoirs, protecting layers, marine structures or nuclear installations. The pore structure of UHPC is very dense, which results in a very high strength and superior durability compared to conventional concrete. The penetration of fluids and gasses as well as the transport of minerals (like efflorescence) is significantly reduced or counteracted. The wear of BSI under normal weather conditions is much lower compared to conventional concrete. UHPC maintains a fair-faced appearance even after a long period of outside placement. Surprisingly, few road and marine constructions have been realised with UHPFRC. The girders of the nuclear reactor in Cattenom and Civeau are good examples concerning durability and demonstrate the potential of UHPFRC.

Girders for the nuclear power plants 'Cattenom' and 'Civeau' (France)

The aggressive environment in a nuclear power plant requires a very durable structure in order to avoid frequent replacement of the load-bearing elements. Prefabricated elements produced with conventional concrete placed in a cooling tower already had to be replaced after several years. A reactor can’t be stopped immediately but has to be cooled down, which takes many weeks. The starting procedure of the reactor again is time consuming with production loss and high costs as a consequence. By applying prestressed BSI-girders the technical life time was significantly increased and the maintenance costs decreased. Figure 2 shows prestressed BSI-beams for the reactor in Cattenom; Figure 3 presents girders for the nuclear reactor in Civeau.
3.2. Applications in infrastructure

UHPFRC can be loaded up to a very high stress and has a higher stiffness compared to conventional concrete. Very slender structures can be realised by prestressing UHPFRC-elements. Prestressed beams with UHPFRC can be designed with smaller construction heights compared to conventional concrete. A reduction in concrete volume and weight affects transport and storage; placing elements in the ground with a smaller surface (i.e. sheet piles) is easier and an additional benefit. Three-dimensional structures (with or without prestressing strands) are characterized by a significant stiffness and are able to carry high loads with a minimum of material. The mould becomes more complex due to the ribs. The demoulding of the elements requires special attention and techniques in order to avoid damage and cracking caused by autogenous shrinkage; the magnitude of shrinkage depends on the mixture composition. In case, this characteristic is critical measures have to be taken in order to minimize autogenous shrinkage. In the following, three examples of bridges with UHPFRC (bridge girders 'Bourg-Les-Valences', 'Pont Pinel' and 'Pont Sarcelles') are described, which have a high level of prestress as a basis of design. The application of UHPFRC for the construction or rehabilitation of road structures is also very promising.

Bridge girders 'Bourg-les-Valènces' (France)

The first not-conventional reinforced concrete bridge deck in a normal traffic category worldwide was realised with π-bridge girders (10 girders with a length of 22 meters) in Bourg-les-Valènces' in France [4]. The bridge consists of two viaducts. The girders (Fig. 4) did not contain bar reinforcement with exception of the joints between the elements; the joints were cast in-situ with UHPFRC. The prestressed girders were prefabricated in 2000 with BSI and were transported by train to France over a distance of 900 km (Fig. 4).

![Bridge girders 'Bourg-les-Valènces' (France) (Fig. 4)](image)

Fig. 4 A π-bridge girder type 'Bourg-les-Valènces' prepared for the transport by train

The effect of the fibres in UHPFRC was taken into account for the design of the girders. The steel fibres increase the shear strength of the web and, as a consequence, elements with thinner cross-sections can be produced. In 1999 no recommendations were available for UHPFRC. In order to verify and to approve the design, extensive testing was required. Full-scale test specimens (with a reduced length compared to the final elements) had to be produced since the fibre orientation is affected by the characteristics of concrete in the fresh state and the method of production. Several test specimens (for bending tests) were cut from the girders at different positions and in different directions in order to determine the orientation of the fibres (Fig. 5) and to verify the design assumptions of the material characteristics. The test results convinced the authorities and were used
in France as an input to formulate the first recommendation for UHPFRC. The procedure of full-scale verification of design assumptions is described in [1].

Fig. 5 A test girder was produced to verify the design assumptions for UHPFRC, several prisms were cut in order to determine the bending behaviour

Bridge girders 'Pont Pinel'/'Pont Sarcelles' (France)

In the period 2007/2008, Hurks Beton produced 43 bridge girders with BSI (Pont Pinel [5]: 17 girders; Pont Sarcelles: 26 girders) in a project with Eiffage TP. These bridges were cheaper than a comparable steel bridge taking into account the costs of investing, durability and maintenance over the lifetime of the bridge. The girders of the two bridges mainly differed in the number of prestressing strands. Figure 6 shows the cross-section of the Pont Sarcelles-girder. The height of the beam was 620 mm and the width was 795 mm. BSI with steel fibres was applied; the total volume of UHPFRC of the girders with a span of about 28 m was 215 m³ (both bridges together). The total prestress-load of 26 strands of the Pont Sarcelles girder was 6200 KN (before releasing the strands), a huge force that acts on a very slender cross-section (Fig. 6).

Fig. 6 View on the cross-section of a girder of the bridge 'Pont Sarcelles'
BSI is self-compacting and a highly thixotropic material; special attention is required to produce homogenous girders without the formation of layers. The orientation of the fibres has to be taken into account for the design. The demand on the passing ability was high since the clear spacing between the strands was only 25 mm. The strands of the girders were released about 22 hours after casting with a compressive strength of at least 110 MPa. The slender bridge girders (Fig. 7) were placed on the foundation and a bridge deck was cast in-situ with conventional concrete.

![Fig. 7 A bridge girder type 'Pont Sarcelles' after demoulding](image)

During the production of the girders for Pont Pinel the flow of BSI was measured at the plant of Hurks Beton. The results of the 85 mixtures of the 'Pont Pinel'-project are shown by Fig. 8; the target range was a flow spread of 580-650 mm. The flow test was executed with the German flow test cone; no compaction energy was applied during testing. Five mixtures were prepared to produce a single girder; rejecting a batch cause unacceptable time delay during production. In order to keep the flowability within a small range, strict quality control was required.

![Fig. 8 Flowability of UHPFRC during the production of girders for the bridge 'Pont Pinel](image)
Strengthening of steel bridge decks

The increase of road traffic in the Netherlands causes higher and more frequent loading of bridge decks. Strengthening has to take place without increasing the weight of the bridge since additional dead load was not accounted for in the design. By stiffening the bridge deck, the load is better distributed, the technical life time (fatigue loading resistance) is lengthened and the maintenance costs reduced. In the Netherlands, several bridges already have been repaired with UHPFRC (cast in-situ or prefabricated). A significant volume of UHPFRC has been cast for repair applications. Hurks Beton produced thin panels of CRC-concrete (Compact Reinforced Composite, characteristic compressive strength of the Contec-premix: 180 N/mm²) having a thickness of 45 mm that were placed on the 'Kaag bridges' [6]. The panels contained three layers of reinforcement (Ø 8 mm) and steel fibres and replaced the original wooden bridge deck.

3.3. Architectural applications

Materials with a well-known appearance but a surprising form or shape are attractive for architectural applications. Fibre reinforced concrete and UHPFRC are concretes but can be applied due to their special characteristics to realise very slender elements. Especially, designing without bar reinforcement offers freedom of shape. By adding pigments during the mixing process colouring can be integrated in the production process. The use of UHPC for architectural applications, furniture (i.e. table boards) and sculptures is promising. Due to the high stiffness and slender shape UHPC becomes an alternative for wood, plastic or other materials. Hurks Beton already produced many small scale prototypes in order to demonstrate the potential of UHPC, but which have not yet been produced in larger series. UHPFRC with or without rebars and a thin concrete cover has been applied to design very slender structures. Slender elements decrease the weight of a structure and enhance the appearance. Two examples of architectural applications are the black panels that cover the columns of the 'Viaduct du Cher' (route A85, France) and the Folly 'Zonnestraal'.

Panels for bridge columns of the 'Viaduct du Cher' (Route A85, France)

297 black-coloured UHPFRC panels (Fig. 9) were produced to cover bridge-columns of the 'Viaduct du Cher'. The durable elements had a thickness of 25 mm and were produced on a rubber mould surface. In order to obtain a homogenous aesthetical appearance of the panels an extensive study was performed on the interaction of formwork-oil in combination with black-pigmented UHPFRC and a rubber mould. Due to the slender shape of the panels, the transport was a major factor for the structural design.

Fig. 9 Thin panels for bridge columns
Folly 'Zonnestraal' (Hilversum, The Netherlands)

The Dutch Concrete Society designed together with ABT, Henket Architects and Hurks Beton a concrete folly (Fig. 10) in order to celebrate its own jubilee and that of the Sanatorium 'Zonnestraal' in Hilversum. This concrete structure was a demonstration of the state-of-the art of structural design with UHPFRC. The roof consists of four segments; the largest span is 8 meters. The thickness of the horizontal blades of the roof was only 25 mm.

![Fig. 10 Folly 'Zonnestraal' in Hilversum](image)

The roof of the folly was produced with BSI in a special wooden mould (Fig. 11) with steel fibres being the only reinforcement of the load-carrying structure. The four segments of the roof were connected by bolts. Rebar anchors transmit the locally high loads of the bolts at the joints of the segments. A column of stainless steel connects the concrete foundation and the four ultra-slender UHPFRC-roof girders.

![Fig. 11 Demoulding of a segment of the Folly 'Zonnestraal'](image)
4. Conclusions

UHPFRC is a material with special characteristics with which new types and shapes of structures can be realised. UHPFRC is an attractive building material and UHPFRC-structures can be economical and competitive. International design recommendations will support the acceptance of parties like contractors, architects and owners.

This paper described UHPFRC-applications of the past ten years from the perspective of Hurks Beton. The reasons for the use of UHPFRC are discussed. In some cases an optimized production technique had to be developed and special moulds were applied. UHPFRC accounts for only a small percentage (1-2 %) in concrete volume of the total production of Hurks Beton and the level of quality control during production is high. Nonetheless, the research efforts are reflected in the overall quality of the remaining volume of prefabricated concrete elements.

References


