MATEC Web of Conferences **361**, 05002 (2022) https://doi.org/10.1051/matecconf/202236105002
Concrete Solutions 2022

Upgrading structure existing components using multiple UHPC-class materials

Vita Mikutaite[1*], *Ted* Donchev[1], *Diana* Petkova [1], *Hasan* Haroglu [1]
[1] Department of Civil Engineering, Kingston University, London, UK,

Abstract. Durability and mechanical properties of UHPC help to develop solutions to upgrade structures. Cementitious UHPC concrete has a minimum specified compressive strength (120-150 MPa), superior resistance to compression, ductility, eco-efficiency and insulation. It is usually used with fibres included to achieve the specified requirements of the mixture. Sprayable UHPC types for inclined applications and leave leave-in-place form solutions have been developed and are used for repair and strengthening purposes. A combination of UHPC and post tensioning is used to create an optimal reinforcement solution. UHPC represented an innovation in post-tensioning for the first time in the United Kingdom, creating a possibility to cast anchoring blocks that are compact, aesthetically pleasing and safer to install. Prefabricated anchors for the bridge exterior and anchors poured on site for the bridge interior were used.

UHPC-steel composite deck is an effective solution to improve a steel bridge's strength and stiffness**.** Studies of overlays in bridge decks showed that UHPC substrates exhibit a higher bond strength than normal strength concrete (NSC) and further analysis of techniques for bonding surfaces with UHPC.

Future tendencies about structure improvements using UHPC and GFRP are reviewed.

1 History

The invention of UHPC (Ultra High Performance Concrete) started in Europe in the 1980s, when it was patented at Aalborg Portland by Hans Henrik Bache in 1986 (Hicon, 2019). Due to a high content of steel fibres in the concrete, its behaviour was similar to that of steel, which combined a compressive strength of more than 150 MPa with high tensile strength and ductility (Taktl, 2020). The research started in 1964 within the Concrete and Research Laboratory in Denmark with the purpose to develop an ultra-high strength and durable cement-based, soft cast material (Contec Group, 2020). The goals of this research were to achieve a much denser packing in the cement paste then a w/c ratio of 0.30 which would produce a higher strength concrete as well as an increase in utilisation. The Portland Cement Association reported a 280 MPa strength in small specimens of heavily compacted cement paste, indicating possibilities to achieve much denser cement packing and through this, higher strengths (Contec Group. 2020).

In the period from 1967 to 1972 in Denmark, more investigation was made into the combined action of pressure and vibration to compact concrete compared with 1930s Japan, Yoshida, reported that high strength concrete with a 28-day compressive strength of 102 MPa was obtained. The result was achieved by combining a pressure and vibration process (Nagataki, 1997).

Development of superplasticizers in the 1960's in Japan and West Germany helped to decrease the water to cement ratio while maintaining the workability of the concrete (Nagataki, 1997). In the 1970's, Hattori (Japan) made soft cast concrete in the laboratory with a w/c ratio of 0.25 and a fc up to 120 MPa (Contec Group, 2020). In addition, ultra-fine materials such as silica fume and finely ground blast furnace slag additives were studied and implemented in concrete mixes.

Ducon was the early developer of micro-reinforced UHPC (*D'mello, 2005*; *Miller, 2007*) which is the next generation of UHPC. Micro-reinforced UHPC exceeds UHPC in durability, ductility and strength, using a three-dimensional micro-steel mesh. The performance of the discontinuous and scattered fibres in UHPC is relatively unpredictable, whereas micro-reinforced UHPC is more reliable in blast, ballistic and earthquake resistant construction including structural, architectural overlays and complex facades.

The latest development in graphene offers to increase concrete strength using pristine graphene, which provides 34.3% improvement in compressive and tensile strength in 28 days (Losic, 2020) Development of cementitious materials focused on incorporating nanomaterials to enhance mechanical properties and prevent cracks. One of the two critical mechanisms accelerates progression of cement hydration and creates more Calcium Silicate Hydrate (CSH) Gels. The second mechanism acts as a filler (Losic, 2020). nanofibres and nanotubes also have a potential, although show a lack of full bonding with cementitious materials.

1.1 Definition

UHPC is classified as a new type of concrete, developed to improve infrastructure protection and it's use resulted in spreading to unlimited areas of application. Ductal,

Corresponding author : * k1617287@kingston.ac.uk

BSI, Dura, Taktl, Ducon are well-known types of UHPC in the market and differ from normal concrete in compression by their strain hardening, followed by a sudden brittle failure (Wiki, 2020). The key strength parameters to classify UHPC into concrete strength and performance classes are compressive strength and axial post-cracking tensile strength (BFT International, 2020). Four essential components of UHPC are;

(1) Powders and fine materials, such as Portland Cement, quartz sand or fine silica sand
(2) Polycarboxylate ether-based superplasticizers
(3) Steel fibres
(4) Water (Anusiya, 2017).

1.2 Method of Preparation

A carefully calibrated ratio of engineered ingredients and a mixing sequence that packs molecules closely together help to achieve the high performance of UHPC (Taktl, 2020). UHPC is achieved by creating a high binder content matrix, with a maximum particle size of 0.25mm. Usually about 25% of cement weight of micro silica or glass powder is used for UHPC production. The silica fume (SF), through its pozzolanic reaction, densifies the concrete micro-structure, in particular strengthening the paste-aggregate interfacial transition zone (Ole, 2014). Superplasticizers are used due to the low water/powder ratio and in order to ensure the ductility, steel fibres are used in quantities between 100 and 300 kg per m3. Using conventional concrete mixers can require more effort and time. Prestressing UHPC elements often requires high temperatures, helping to enhance mechanical properties and ensuring that most of the shrinkage has occurred beforehand (Hicon, 2019). This ultimately results in a type of concrete with enhanced and improved mechanical and durable properties like high compressive strengths (>150 MPa) and abrasion-resistant, corrosion-resistant concrete (Edwin, 2019).

1.2 Properties of UHPC

The high strength of UHPC is achieved by a low water-binder ratio (less than 0.2), an optimized gradation curve, use of thermal activation (Wan, 2016) and a high percentage of discontinuous internal fibre reinforcement (FHWA, 2019). The mechanical properties of UHPC, due to the addition of fiber as additional reinforcement, includes a high compressive strength from 150 MPa exceeding 250 MPa (*Redaelli, 2007;* György,2014) and sustained post-cracking tensile strength greater than 0.72 ksi (5 MPa) (FHWA, 2019). To create more durable and sustainable UHPC, the cement is often partially replaced by a large quantity of supplementary cementitious materials (SCMs) (Edwin, 2019). High-temperature curing or pressure curing (autoclave curing) is applied to speed up the chemical reaction, resulting in improved properties of the UHPC. A compressive strength of 200 MPa can be reached within eight hours of pressure curing for 3 or 4 percent fibre reinforcement UHPC (Wu, 2017). UHPC is also characterised by having a large ductility and typically a bending strength higher than 25 MPa. The properties of UHPC include porosity, freeze–thaw, toughness, durability, energy absorption, impact, fire resistance and corrosion resistance.

One of the ways to improve durability and enhance homogenity in UHPC is to decrease porosity (Edwin, 2019). The capillary pores are eliminated from UHPC due to tightly packed molecules and it will not absorb water, crack or degrade when subjected to freezing/thawing. Moreover, other material properties like shrinkage, resistance to chloride penetration and creep of concrete are enhanced due to the low porosity (Chao, 2016).

Improved homogeneity microstructure, lower permeability and the reduced porosity (Brühwiler, 2016) are three main factors for the high resistance to freeze-thaw exposure. Certified laboratory tests of freeze/thaw performance over 66 days of cycling, show an average 99% strength retention (97%-102%), whereas, the highest grade classification of Fibre Cement under ASTMC 1186 requirement is only 80% strength retention. The freeze/thaw durability property is expressed in terms of relative dynamic modulus (RDM). Established research records a decrease in RDM value of around 0-10% only with freeze-thaw cycles of around 300 and 1000 cycles (Lee, 2005).

Chloride ions penetrating through the concrete pores leads to corrosion of the steel reinforcement (Andrade, 2014). Compared to the chloride ion penetration value of conventional concrete (1736 coulombs) the typical value for UHPC is around 22 coulombs (Schmidt, 2003).

Saturated pumice (0.6-1.25mm) helps to increase permeability in UHPC allowing fluids or gases to flow through. This volcanic rock eliminates shrinkage in concrete without sacrificing material strength (Liu, 2018). The pumice creates an ongoing process of water release within the concrete (Edwin, 2019). Even though UHPC pores lack permeability, the effect on water absorption caused by Silica Fume (SF) results in the most effective water absorption reduction of UHPC of about 38-43% (Pyo, 2018; Sabet, 2018). SF and superabsorbent polymers (SAP), act like internal curing agents for concrete, which rapidly absorbs the fresh concrete water.

The abrasion resistance mass loss caused by friction in UHPC is 3-7 times lower compared to the abrasion resistance mass loss of NSC (Won, 2013). It is achieved using different SCMs to provide a denser Interfacial Transition zone (ITZ) created by a better pre refining effect (Yazici, 2018; Pyo, 2018).

The use of fibres help to increase ductility and the impact resistance in UHPC. In addition, fibres also have a high resistance in an alkaline environment which shows high strength and a high elastic modulus (Buttignol, 2018). The most commonly used steel fibres have a tensile strength of 2500 MPa and a volume fibre ratio between 0-5 percent (Graybeal, 2006). Different fibre lengths and types can be another strength increase factor (Shi, 2015).

Figure 1,2,3 Steel fibres, basalt fibres, polypropylene fibres (by Author, 2020)

2. Repair and Strengthening of existing structures

Nowadays, UHPC is used for various bridge construction and rehabilitation applications, including 100% UHPC structural elements, bridge deck overlays, jackets for columns and driven piles (Ductal, 2020). Structures such as bridges and tunnels need to be repaired or reinforced and respond to changing demands such as increased traffic, weather or chemical attack. Developed sprayable UHPC types for inclined applications and leave *leave-in-place* form solutions are used for repair and strengthening purposes. A combination of UHPC and post tensioning is used in structural reinforcement to create an optimal reinforcement solution. The high compressive and tensile strength of UHPC allows engineers to reduce the size of each anchor (by reducing the amount of rebar within a block) while increasing the post-tensioning load (Ductal, 2020). It also allows for continued structure use during repairs, reducing impact on the surrounding population**.**

Lafarge Holcim has developed the first UHPC Ductal Shotcrete, compliant with durability characteristics of the NF P18-470 standard, applicable on slopes inclined up to 18%, allowing it to be used on vaults and vertical walls (Ductal, 2020). Shotcrete does not require casing and reduces work time on renovation sites, while adding a thin layer of material following the geometry of metal culverts preserves the circulation dimensions**.**

Figure 4. Power Spraying of Shortcrete. Figure 8. Rehabilitation of a steel bridge (by Author)

UHPC is also used as a leave-in-place form for bridge columns. The thin skin of UHPC is designed to protect bridge columns from freeze-thaw damage and chloride splashes which can limit long-term maintenance**.** UHPC encasement can be driven without losing its integrity from water and as a protective surface against abrasion which allows for quick repairs without the need for forms or extensive on-site curing **(**Ductal, 2020**).**

Such Pier Jacketing was applied in the Canadian National Railway Bridge in Montreal. The existing pier was able to sustain the gravity and train loads, but the repair to the column was required to provide protection against chloride and freeze/thaw. The repair solution had to achieve twice the lifetime than a retrofit with conventional concrete. A fluid, self-leveling UHPC formulation was selected and for the formwork design hydrostatic pressure had to be considered. Watertight, pressure resistant formwork as well as high shear mixers to batch bulk bags are important factors **(**Doiron, 2016**)**.

Another example of seismic retrofit was Mission Bridge Abbotsford in British Columbia. V-shaped concrete pier columns (Pier S4) were retrofitted using UHPC jackets. Liquefiable sands and the lightly reinforced rectangular concrete columns were subjected to high displacement and threatened to collapse under earthquake loading. A detailed explanation of the problem statement and design rationale is available in a paper prepared by the design team of Associated Engineering (Kennedy, 2015). After removal of existing fiber-reinforced polymer (FRP) wrap, the surface was roughened and the pedestal was widened with NC concrete to force the plastic hinge at this location under seismic load. Additional steel dowels were postfixed into the existing column concrete and new 225 mm thick Ductal jackets were used to increase and stiffen confinement up to a height of approximately 3m (Doiron, 2016). JS1000 Field-cast UHPC solution produced by Ductail® was used with 2% of steel fibers. To minimise temperature rise during the batching, 100% ice was used instead of water.

Figure 5. Completed Retrofit (by Author)

3. UHPC Anchors - Blocks for Post-Tensioning

A phenomenally complex £100m innovative engineering solution was applied to strengthen the Hammersmith Flyover (HFO2) with 70,000 users every day on a key strategic route into London **(**Ductal, 2020**)**. The first major segmental precast post-tensioned highway structure in the UK, comprising 16 spans and measuring 626 m (2,052 ft) in length (863 m or 2,831 ft with its two ramps), the bridge is a key part of London's major A4/M4 link to Heathrow Airport and the west of England since it opened in 1961. Initially, designed with the intention that grout would protect the prestress tendons from corrosion and electric deck heating against de-icing salt. However, electric heating was stopped due to high electricity prices and post-tensioning tendons started corroding.

In 2009 further inspections revealed significant deterioration with wires breaking every day **(**Ramboll, 2015**)**. UHPC made it possible to create anchoring blocks that are compact, aesthetically pleasing and safer to install. Renovation required prefabricated anchors for the exterior and anchors poured on site for the interior, with two separate production methods. The mechanical properties of UHPC made it possible to design anchorage blocks that offer high performance and size reduction**,** while helping to reduce the effort of cable tensioning (Ductal, 2016). The 192 (1.32-2.75 ton) thermally treated prefabricated anchors reduced work at height**,** enhancing worksite safety and increased quality over elements poured on site. The blocks were then prepared for post-tensioning and joined to the bridge's different segments. UHPC anchor''blisters'' were designed to anchor HDG polyethylene protected tendons. Both internal and external anchors were also cast insitu using UHPC via a novel syringe. Detailed laser scanning and BIM modelling of the entire structure helped the team to get the orientation right on each blister.

The first application of UHPFRC (up to 170MPa strength) even though not compliant with Eurocodes was successfully validated by testing the performance under service loads, which confirmed blisters can transfer the prestressing anchorage forces. The prestressing system, in comparison to conventional reinforcement, reduced the size and weight by 50%, with an increase of the minimum headroom clearance to be maintained as well as the aesthetics of the structure.

Figure 6. UHPC Anchorage (by Author, 2020)

Figure 7. Hammersmith Flyover, London, UK, Post Tension Anchorage (by Author, 2020)

4. Overlays

Combinations of vehicle loading, freeze–thaw degradation, cracking, concrete cover delamination or corrosion of internal reinforcement cause bridge deck deterioration. Commonly, bridge decks are rehabilitated using overlays protecting the underlying deck and reinforcement from contaminants, providing additional strength and stiffness (FHWA, 2014).

Traditionally, rigid concrete overlays range in thickness between 2.5 inches (51 mm) and 6 inches (152 mm), which corresponds to dead loads between 30 psf

(1.4 kN/m^2) and 75 psf (3.6 kN/m^2). **(**Krauss, 2009**)** Previous deployments of UHPC as an overlay have used overlay thicknesses between 1 inch (25 mm) and 2 inches (51 mm), which corresponds to dead loads between 13 psf (0.57 kN/m^2) and 26 psf (1.2 kN/m^2) **(**Brühwiler, 2013**)**. Studies of overlays in bridge decks showed that UHPC substrates exhibited higher bond strengths than NSC concrete substrates. Mechanically roughening the deck substrate prior to overlay installation helps to achieve better results **(**ICRI Committee, 2013**)**. The hydrodemolition surface treatment method results in higher bond strengths than those obtained with a scarified substrate surface. This is attributed to the fact that mechanical preparation methods may introduce microcracking on the substrate material which might eventually affect the bond performance **(**Collins, 2014**).**

Another study of a 1.5 in (38 mm) UHPC overlay thickness with scarified and premoistened deck surface **(**Haber, 2014**)** showed that peak tensile stresses sustained by these specimens were higher than those exhibited by conventional grout-like materials bonded to a roughened concrete substrate. (De La Varga, 2017).

Waffle Slabs enhanced with UHPC offer a load-bearing ability at ⅔ of the weight of a typical deck, removing the need to alter the supporting structure and foundations. Steel fibre formulation in UHPC expansion joints via tight micro-cracks allows for the deformation while still providing a watertight matrix **(**De La Varga &SES Group, Graybeal, 2017).

Upgrading conventional reinforced concrete components involves adding a 25-80mm thick UHPC layer on the roughened surface (using sandblasting, and water jets). When reinforcing bars are added in the primary load bearing direction, steel-UHPC is also called compact reinforced composite (CRC) **(**Bruhwiller, 2011**).**

For a protective function, embedded reinforcing bars are unnecessary, and the thickness of the layer can be reduced to 25mm. Adding a layer of UHPC to a steel bridge deck can be particularly challenging as roughening of the surface will not be so straightforward. The effect of cracking due to autogenous shrinkage can occur in applications with steel plate. In the Netherlands, the developed UHPC mix showed lower autogenous shrinkage strain and high tensile strength. It was applied to the Calland Bridge in Rotterdam, Netherlands which was upgraded in the following sequence: first the asphalt was removed, shear studs to prevent uplift were then attached, the steel surface was covered with epoxy resin and after 3 mesh layers were installed, the UHPC was applied. The entire procedure took 120h, including 24h coverage with damp material and blast-cleaning of the new surface. Test showed concrete surface tensile strength values of 4-5N/mm^2 (Fehling, 2015). Strengthening with FRP materials showed a greater stiffness than compared to steel, but the cost of resins can be high and their fumes can be toxic during the application process **(**Karthik, 2017**).** Experimental tests were developed for M30 grade RC beams with the same dimensions. Beams were subjected to 90% of the ultimate load and then retrofitted with a 10mm or 20mm thickness RPC overlay. After a 28 day curing process, samples were tested for their flexural behaviour. To create a stronger bond between NSC and UHPC, the surfaces were roughend and cleaned from dust before bonding retrofit strips.

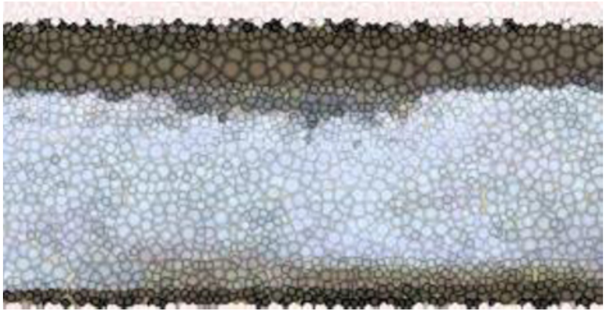

Figure 8. Grooving (by Author)

Figure 9 and 10. Meshing. Stitching

5. Prospects For Future Development

Research and development in civil engineering has advanced using FRP (Fibre Reinforced Polymer) with UHPC for structural elements and joints. Advanced qualities of UHPC and FRP helps to extend the service life of structures and the number of applications is rapidly growing. FRP and UHPC due to their high market value are often used for the purpose of strengthening, rehabilitation and joining elements of important structures **(**El-Hacha, 2018**)**. Advanced characteristics of both materials show how their performance improved or repaired existing building elements in the recent years.

FRP has been extensively investigated for its advantages in concrete (Scott, 2016; Bouwer, 2001) and is currently being used as a thermal break, sandwich panel anchor (Schöck, 2020) and fixing for rainscreen facades (Schöck, 2019). FRP includes corrosion and chemical resistance, thermal conductivity and non-magnetic, electrically non-conductive characteristics (Schöck, 2019). In comparison with conventional steel and stainless steel, it has higher tensile strength and lower self-weight (Larrard, 1994; Rossi, 1997) and could be used as a prestressed one-dimensional reinforcement in concrete structures, such as bridge girders and decks (Graybeal, 2010). In advanced hybrid structural systems**,** experimental tests suggested the use of UHPC as a main structural component in order to achieve a full composite action with FRP elements **(**El-Hacha, 2018**).** Analysis of such hybrid beam performance where a CFRP hollow box section beam was filled with UHPC and strengthened with CFRP/SFRP sheets showed increased flexural strength and flexural stiffness **(**El-Hacha, 2018**)**. Effective enhancement in flexural strength and ductility was demonstrated with embedded FRP bars in fibre reinforced concrete panels (FHWA,Graybeal, 2010). FRP bars and UHPC used in bridge decks, demonstrated good promise to replace the conventional steel grid deck (Wan, 2016), where the use of micro steel fibres provides good resistance to cracks that can be induced by early-age shrinkage (Baril, 2016; Coufal, 2016) and enhances the durability (Chao, 2016). Hybrid concrete members with FRP have proven to be a viable design option for bridge applications used in pile confinement and bridge deck improvements (Meng, 2018). In comparison with conventional methods (reinforced concrete and structural steel), hybrid members consisting of FRP materials have increased strength, decreased weight, dimensions and increased corrosion resistance **(**El-Hacha, 2018**)**. UHPC joints represent an alternative which can satisfy the requirements on mechanical properties of joints, on construction and on economy (Metrostav, 2016). Research suggests, FRP fabric reinforced UHPC panels to be a promising development of a lightweight, high-performance permanent formwork system and help with accelerated construction of critical infrastructure with enhanced crack resistance and extended service life (Meng, 2018).

UHPC is known as a viable replacement of steel for anchoring tendons. CFT-anchor is a steel tube filled with UHPC and can act as an anchor for post-tensioning elements. Combined with a steel anchor head and anchor plate, they can be produced with UHPC, which is a lighter, cheaper, non- corrosive, isolating material.

The concept idea of the hybrid was tested and used for anchoring bridge external steel cables. FRP as an innovative material requires a new anchoring system. FRP can be utilized better during the post-tensioning process, but there is a lack of suitable anchoring systems. UHPC can help to find a solution for anchoring and coupling FRP elements (Weiher, 2011).

6 Conclusion

Growing awareness of life cycle costs and carbon emission targets shows that UHPC is well positioned to provide alternative ways to minimize on-going costs. This is becoming a key driver for many owners who need to find new ways to upgrade structures or invent hybrid elements to avoid early maintenance problems.

A sprayable UHPC solution called Shotcrete helps to achieve required geometrical forms and reduces work time on site. It expands opportunities in the transport sector, where objects must remain in use at all times. Any disruptions can be the cause of delays in all the sectors.

It can also act as a protective layer and formwork of major construction elements such as bridge columns exposed to critical environmental conditions. UHPC has many advantages, such as resistance to freeze–thaw, toughness, durability, energy absorption, impact and abrasion resistance, fire resistance, corrosion resistance adds value to existing structures and eliminates short term repetitive maintenance.

In the field of retrofitting, UHPC layering using the method of meshing with a 20mm overlay showed the highest load carrying capacity recreated and enhanced.

In the precast sector, UHPC blocks have been confirm`ed to be a compact, aesthetically pleasing and safer to install solution for anchoring post tensioned steel elements. Prefabricated anchors have been confirmed to be a highly durable solution for segmental post-tensioned highways. A similar prefabricated hybrid anchoring system was proposed in geotechnical post-tensioned elements and for anchoring bridge external steel cables.

The invention can be seen as a future opportunity to enhance anchoring and coupling systems in the field of FRP.

References

Abbas, S. Nehdi, M.L, Saleem, M.A., (2016). “Ultra-High Performance Concrete: Mechanical Performance, Durability, Sustainability and Implementation Challenges’’ International Journal of Concrete Structures and Materials. Vol., 10, p.p. 271–295

Andrade C, D’Andrea R, Rebolledo N., (2014). “Chloride ion penetration in concrete: The reaction factor in the electrical resistivity model”.

Anusiya M, Oviya S, (2017). “Comparative study on reactive powder concrete with high strength concrete”.

Baril, M., et. all, (2016)’’The Effect of Casting Flow Defects on the Flexural Behavior of 2-way UHPFRC Slabs Investigated by Digital Image Correlation and Magnetic Assessment’’, First International Interactive Symposium on UHPC.

BFG Architecture, (2019).’’Introduction to UHPC’’ Available at: http://www.bfgarchitecture.com/introduction-to-uhpc) [Accessed: 5th December, 2019]

BFT International, (2020). ’’Classification of ultra-high-performance concrete’’. Available at: https://www.bft-international.com/en/artikel/bft_Classification_of_ultra-high-performance_concrete_3491462.html [Accessed: 5th Feb, 2020]

Brouwer, G. (2001) “Bridge to the future,” Civil Engineering Magazine, vol. 71, pp11.

Brühwiler, E. and Denarié, E. (2013). “Rehabilitation and Strengthening of Concrete Structures Using Ultra-High Performance Fibre Reinforced Concrete,” Structural Engineering International, vol. 23 no.4., pp. 450–457.

Brühwiler, E., (2016). “Structural UHPFRC”: Welcome to the post-concrete era! First International Interactive Symposium on UHPC.

Bruhwiller,E. (2011) “Entwurf, Bemessung und Ausfuhrung von Stahl-UHFB – Stahlbeton Verbundbauteilen[design and construction of steel fibre-reinforced UHPC/RC composite members], Ultra-Hochleistungs-faserbeton, entwerfen, bemessen, bauen [design and construction of fribre-reinforced UHPC]". conf. paper., pp. 121-136.

Buttignol TET, Sousa JLAO, Bittencourt TN. Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC): A review of material properties and design procedures. Rev IBRACON Estrut Mater 2017; 10(4): 957-71.

Chao, S., et.all., (2016)''Seismic Behavior of Ultra-High-Performance Fiber Reinforced Concrete Moment Frame Members''. First International Interactive Symposium on UHPC.

Collins, J., et.all., (2014). "State of The Practice and Art for Structural Health Monitoring of Bridge Substructures" Report. FHWA-HRT-09-040.

Contec Group, (2020). Available at: http://www.contec-aps.com/history.html [Accessed 1st February, 2020]

Coufal, R., et.all., (2016).''The First Large Application of UHPC in the Czech Republic'' First International Interactive Symposium on UHPC.

De La Varga, I., Z. B. Haber, and B. Graybeal. (2017). "Bond of Field-Cast Grouts to Precast Concrete Elements". Report.no. FHWA-HRT-16-081.

De La Varga, SES Group, and Dr. Benjamin A. Graybeal, (2017). "One Step Ahead: FHWA Investigates Commercially". Journal ASPIRE, pp. 44–46.

D'mello, S., (2005). "Explosion resistant cement in UAE". Khaleej Times. Retrieved 25 November 2020.

Doiron, G., (2016). "PIER REPAIR/RETROFIT USING UHPC EXAMPLES OF COMPLETED PROJECTS IN NORTH AMERICA. Project Manager Repair and Retrofit Markets - Ductal® , Lafarge North America Inc., Canada" First International Interactive Symposium on UHPC.

Ductal, (2016). Available at: https://www.ductal.com/en/engineering/hammersmith-flyover-post-tension-anchorage [Accessed 28th May, 2019]

Ductal, (2020). Available at: https://www.ductal.com/en [Accessed 21st August, 2020]

Edwin, P. S.; Zhijun.C., Muhammad.H., (2019).''Review of The Cement-Based Composite Ultra-High-Performance Concrete (UHPC)''. Open Civil Engineering Journal, 2019. Vol. 13, pp.147-162.

El- Hacha, R., Dona, C., (2018)." Behaviour of Hybrid FRP-UHPC beams subjected to static flexural loading'' Composites, Part B vol.43, pp. 582-593.

Fehling. E, Schmidt. M, Walraven. J., Leutbecher. T., Frochlich. S, (2015). ''Ultra-High Performance Concrete Uhpc". Fundamentals, Design, Examples (Beton-Kalender).

FHWA, (2014). "State of the Practice and Art for Structural Health Monitoring of Bridge Substructures" PUBLICATION NO. FHWA-HRT-09-040.

FHWA, Graybeal, B., (2019). "Design and Construction of Field-Cast UHPC Connections'' (FHWA-HRT-19-011), Available at: https://cms7.fhwa.dot.gov/research/structures/ultra-high-performance-concrete/ultra-high-performance-concrete) [Accessed: 20th January, 2020]

Graybeal BA. "Material property characterization of ultra-high performance concrete", Federal Highway Administration: Virginia, USA, 2006.

Graybeal, B. A., Lwin, M. M., (1997). "Deployment of Ultra-High-Performance Concrete Technology".

Graybeal, B.A .(2010)."Finite Element Analysis of UHPC: Structural Performance of an AASHTO Type II Girder and a 2nd-Generation Pi-Girder". Report no. FHWA-HRT-10-079.

György L. Balázs, (2014). Material and Structural Properties for Creating High Performance Concrete Structures, Key Engineering Materials, 10.4028/www.scientific.net/KEM.629-630.21, 629-630, (21-27).

Habel K, Gauvreau P., (2008). "Cement & concrete composites response of ultra-high performance fiber reinforced concrete (UHPFRC) to impact and static loading".

Hermann, W., (2011) "UHPC-ANCHOR PLATES FOR PT TENDONS, GROUND ANCHORS AND MICRO PILES''. ib Symposium PRAGUE 2011 Topic 3. Poster Session.

Hicon, (2019). Available at: https://www.hi-con.com/concrete-blog/crc-jointcast-joints-that-are-small-strong-and-simple-1 [Accessed 1st March, 2019]

ICRI Committee 310, (2013). "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair". International Concrete Repair Institute, Rosemont, IL.

Krauss, P., Lawler, J., and Steiner, K. (2009). "Guidelines for Selection of Bridge Deck Overlays, Sealers, and Treatments". NCHRP Project 20-07 Report, p.p. 51.

Larrard, F. S., (1994). T: Optimization of ultra-high-performance concrete by the use of a packing model. Cement and Concrete Research, vol. 24, no. 6, pp. 997–1009.

Lee MG, Te Chiu C, Wang YC (2005). "The study of bond strength and bond durability of reactive powder concrete".

Liu K, Yu R, Shui Z, et al. (2018). "Effects of pumice-based porous material on hydration characteristics and persistent shrinkage of Ultra-High Performance Concrete (UHPC)".

Losic, D., Ho, et. al. (2020). ''Electrochemically produced graphene with ultra large particles enhances mechanical properties of Portland cement mortar.''

Losic, D., Ho, V.D., Ng, C., Ozbakkaloglu, T., Goodwin,A., McGuckin, A., Karunagaran, R.,(2020) ''Influence of pristine graphene particle sizes on physicochemical, microstructural and mechanical properties of Portland cement mortars''. Construction and Building Materials.

Meng,W., et. al., (2018). ''Flexural behaviors of fiber-reinforced polymer fabric reinforced ultra-high performance concrete panels''. Cement and Concrete Composites, vol. 93, pp. 43-53.

Metrostav, J.L.V., et. all., (2016).'' UHPC Connection of Precast Bridge Deck''. First International Interactive Symposium on UHPC.

Miller, Steven H., (2007). "The "Explosion" in Blast Resistant Construction". Masonry Construction. Retrieved 25 November 2020.

Nagataki, S., (1997)''High-Strength Concrete in Japan: History and Progress''. International Concrete Abstracts Portal Symposium Paper.]

Ole M. J.,(2012) "The Pozzolanic reaction of silica fume''. XXI International Materials Research Congress, 2012. Cancún, Mexico Vol.1488.

Pyo S, Abate SY, Kim HK. Abrasion resistance of ultra high performance concrete incorporating coarser aggregate. Constr Build Mater 2018; 165: 11-6.

Pyo S, Abate SY, Kim HK., (2018). "Abrasion resistance of ultra high performance concrete incorporating coarser aggregate". vol.165: p.p.11-6.

Ramboll, (2015). Available at: https://uk.ramboll.com/projects/ruk/hammersmith-flyover-phase-2 [Accessed 22ndMarch, 2019]

Redaelli, D; Muttoni, A., (2007) "Tensile Behaviour of Reinforced Ultra-High Performance Fiber Reinforced Concrete Elements". Proceedings of CEB-FIP Symposium Dubrovnik. Concrete Structures.

Rossi, P., (1997). "High performance multimodal fiber reinforced cement composites (HPMFRCC): The LCPC experience," ACI Materials, vol. 94, no. 6, pp. 478–483.

S. Karthik and Karthik Sundaravadivelu* (2017)''Retrofitting of Reinforced Concrete Beams using Reactive Powder Concrete (RPC) Retrofitting of Reinforced Concrete Beams using Reactive Powder Concrete (RPC)''.

Sabet FA, Libre NA, Shekarchi M., (2013). "Mechanical and durability properties of self-consolidating high performance concrete incorporating natural zeolite, silica fume and fly ash". Construction & Building Materials vol.44.

Schmidt M, Fehling E, Teichmann T. (2003) Ultra-high performance concrete: Perspective for the precast concrete industry. Bet und Fert p.p. 10-23.

Schöck, (2019). "Schöck Isolink. Your link to the facade. Thermal bridge free anchors for sandwich and double walls". Technical brochure no 190321.

Schöck, (2020). "Schöck Isokorb. Meisterhaft bis in die letzte Faser. Der Schöck Isokorb® CXT". Technical brochure no. 804403/09.2020/DE/200460.

Scott D.A, et. all., (2016). "Influence of Steel Fiber Size and Shape on Quasi-Static Mechanical Properties and Dynamic Impact Properties of Ultra-High Performance Concrete". First International Interactive Symposium on UHPC.

Shi C., et. All., (2015). "A review on ultra high performance concrete: Part I. Raw materials and mixture design". Journal of Constrruction and Building Materials vol. 101., p.p.741-51.

Taktl, (2020). Available at: https://www.taktl-llc.com/what-is-ultra-high-performance-concrete [Accessed 1st February, 2020]

Wan, L., Wedner, R., Cusatis,G., (2016). "Behavior of Ultra High Performance Concrete at Early Age: Experiments and Simulations".

Won JP, et. al. (2013). "Shrinkage and durability characteristics of eco-friendly fireproof high-strength concrete". Constr Build Mater vol. 40: p.p. 753-62.

Wu C, Li J, Su Y., (2018) Ultra-high performance concrete columns Development of Ultra-High Performance Concrete Against Blasts ".

Wu Z, Shi C, He W., (2017) Comparative study on flexural properties of ultra-high performance concrete with supplementary cementitious materials under different curing regimes. Constr Build Mater vol.136: p.p.307-13.

Yazici Ş, İnan Sezer G. (2007) "Abrasion resistance estimation of high strength concrete". Engineering Science 2007; vol.13., no.1., p.p 1-6.

Z.B. Haber and B. Graybeal. (2017)'' Field Testing of an Ultra-High Performance Concrete Overlay CHAPTER 3. DETAILS OF THE LAPORTE ROAD BRIDGE''. Report no. FHWA-HRT-17-096.