

Cast-on site UHPFRC for improvement of existing structures – achievements over the last 10 years

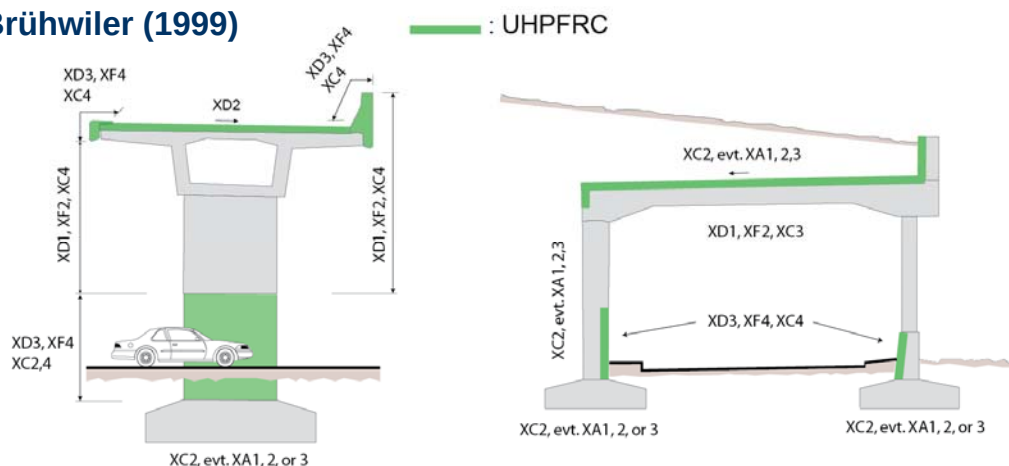
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HPFRCC7: 7th workshop on High Performance Fiber Reinforced
Cement Composites, 1-3 June 2015, Stuttgart, Germany.

1. Concept of application

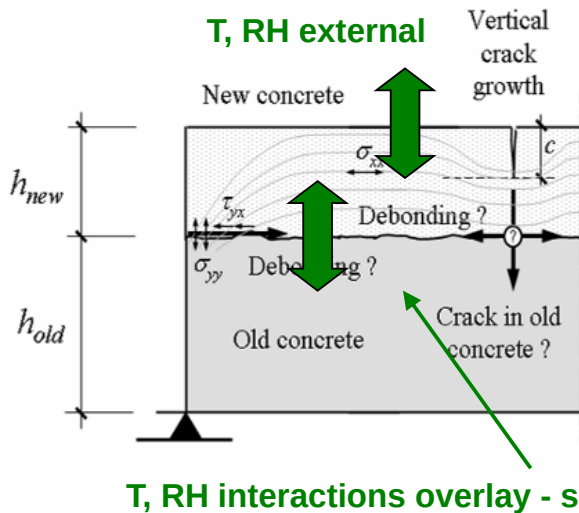
Brühwiler (1999)



➔ Long-lasting, targeted « hardening » of critical zones subjected to severe mechanical and environmental loads by means of a dense UHPFRC layer

Challenges and Research domains

- ➔ Successful « Structural rehabilitations » are a *major challenge for engineers*
- ➔ *Cracking has both material and structural origins*

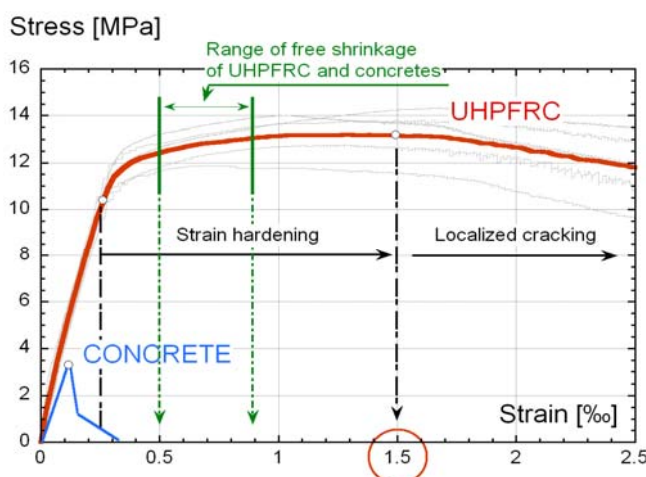


Major issues:

- ➔ Processing
- ➔ Monolithic behaviour
- ➔ Protective function
- ➔ Mechanical performance
- ➔ Time dependent response

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Deformational balance



Additional positive effects

-Relaxation of eigenstresses by factor 2 thanks to UHPFRC creep at early age

-Degree of Restraint < 100 %
(50 to 90 % depending on structure)

! Validate performance in conditions of application i.e.: representative fiber orientation and geometry (thickness, etc.) !

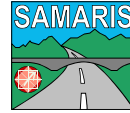
- ➔ **Tensile strain hardening UHPFRC**
- ➔ **Free shrinkage < strain hardening deformation capability**
- ➔ **Very favorable "deformational balance"**
- ➔ **Eliminate macrocracking in structures at Serviceability Limit State**

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Research and applications

→ Numerous laboratory tests on UHPFRC materials and composite members, since 1999 at MCS/EPFL and since 2006 at ZAG (Slovenia).

EU Projects SAMARIS, ARCHES



→ Over 40 successful full-scale applications in Switzerland on road bridges and industrial buildings and 1 on a bridge in Slovenia (July 2009) in various challenging conditions.

→ Plain UHPFRC or Reinforced «R-UHPFRC» (with rebar)

→ Multiple UHPFRC mixes with various SCM: GGBS or Burnt Oil Shale (HOLCIM), Limestone Filler (MCS, ZAG), etc.

2. Cast-on site UHPFRC



2.1 Portability of mixes (Slovenia)



UHPFRC with CEM I 52.5 cement (Salonit)

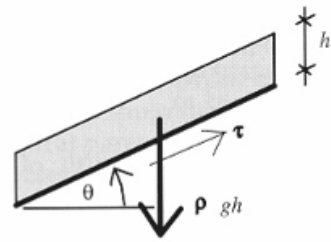


UHPFRC with CEM I 52.5 (Salonit), 50 % replacement by Limestone Filler

Similar recipes with Water/(Cement+Filler) ratio = 0.155

- 50 % cement replacement by limestone filler of equivalent size distribution
- Dramatic improvement of matrix workability
- Take benefit of low degree of hydration of UHPFRC mixes with equivalent mechanical and protective performances (also validated in project) + reduction of CO₂ emissions

Improved slope tolerance



Principle, after De Larrard (1999)



- Slovene based UHPFRC recipes with Water/Fines= 0.170
- Unconfined slope test - EPFL/MCS
- Slope tolerance = 5 %

2.2 Examples of application



Log Čezsoški bridge – Soča river/SL (2009)



- Rehabilitation of the sidewalks and deck with UHPFRC, no dry joints
- Cemtec^{multiscale}® fibrous mix after Rossi et al. (2005)
- Matrix with 50 % cement replacement by limestone filler, Slovene components

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Concept of intervention

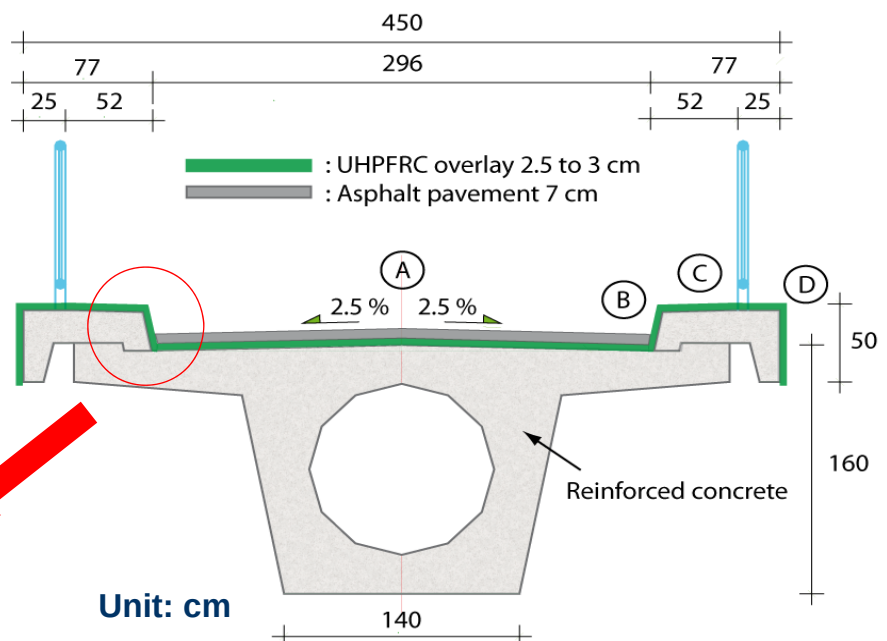
Two UHPFRC mixes

CM32_13 : thixotropic

CM32_11 : fluid

Parts A,B,C: CM32_13

Part D: CM32_11



- Continuous watertight UHPFRC overlay on the deck and footpaths

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The bridge after rehabilitation (2009)



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Tests in 2011 after 2 years exposure

➔ June 2011 – tests performed by ZAG on the bridge and cores taken for lab tests:

- Pull-off strength- footpath: in situ ➔ excellent
- Skid resistance footpath: in-situ ➔ excellent
- Corrosion current: in-situ – nothing noticeable
- Air permeability: in-situ
- Capillary absorption: on cores – in laboratory

A. Šajna, V. Bras – ZAG - 2011

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Test results (average values)

UHPFRC

Reference	Air permeability [10^{-16} m^2]	Capillary water absorption coefficient [$\text{g/m}^2 \cdot \text{h}^{0.5}$]
Concrete (poor)	2	1200
Concrete for XD3/XF4	0.03	300
CM23 (ref.)	0.003	45 (EPFL meas.)
CM24	0.008	53 (EPFL meas.)
Log Čezsoški CM32_11	0.004	60 (ZAG meas.)



Air permeability testing

→ Mixes CM24 and CM32_11 with Slovenian components exhibit excellent protective properties comparable to reference mix CM23 (project SAMARIS), confirmed by measurements on bridge after 2 years.

Col des Mosses road / CH (2011)



- Thixotropic – «Green» «Swiss» UHPFRC
- Cement = Limestone filler = 636 kg/m^3
- Water/Fines = 0.175 (Fines = Cement + Filler), 4.5 % vol. 10/0.16 mm Fibers



Mix-design: MCS/EPFL
Denarié et al. (2011)

- 8 days between application of UHPFRC and laying of bituminous pavement
- Casting on over 10 % combined slopes
- Very significant financial and time savings for road owner
- Method is currently spreading for other sites

Reinforcement of lighthouses

Access = weather + tide permitting

"La Jument" lighthouse
Ouessant /France 47 m high

Heritage structure – 104 years old
Construction = 7 years (1904-1911)
Masonry / Concrete core structure

Multiple reinforcements over time



- ➔ Severely limited access time + aggressive environment
- ➔ Issues similar to conservation of existing bridges
- ➔ Apply UHPFRC to protect/reinforce

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Turret « le Cabon » Brittany / F (2013)



- ➔ Coarse concrete masonry - age $\approx$ 70 years, cracked
- ➔ Suspected swelling reactions
- ➔ 500 such turrets along coast of Brittany
- ➔ Prototype for reinforcement of offshore heritage lighthouses

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Concept of intervention

- Continuous 60 mm UHPFRC overlay on all surfaces of the turret, including top = « Ring test » !
- 7 days curing before formwork removal

- **Casting in preplaced steel formwork able to withstand the hydrostatic pressure of fresh UHPFRC**



Installation of formwork

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Materials

Requirements

- Strain hardening (between 1 and 2 ‰ on average)
- Tensile strength > 10 MPa
- Minimization of autogenous shrinkage
- Self compacting (SCC class SF2)
- Workability range: 2 to 3 hours
- Mix design and Production by Lafarge

-Validation of tensile response by inverse analysis of bending tests (Finite Elements)

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Quality control on site

Workability (2 h)

Compressive strength

Tensile strength

Strain hardening

Slump flow spread

Cylinders 7/14 cm 28 days

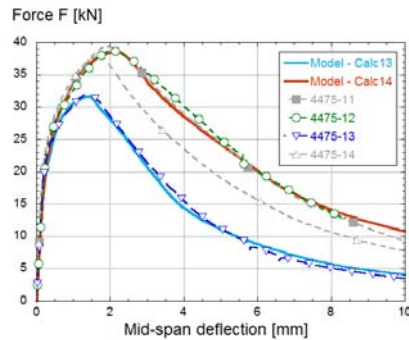
Bending + inv. analysis
at 28 days

(590)/660/670 mm

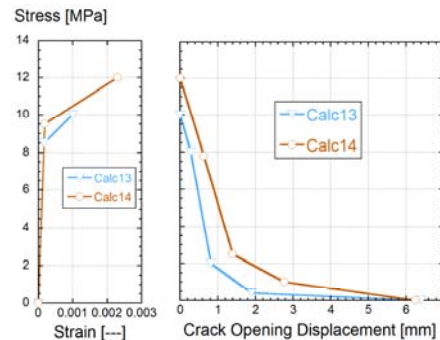
135 ± 6.8 MPa

10 to 12 MPa

1 to 2.3 ‰



4 PT Bending test on prisms 600/150/62 mm cut from 700/700/62 mm plate vs models



Tensile laws from inverse analysis (FEM- MCS)

➔ All requirements were successfully achieved

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UHPFRC processing

- ➔ UHPFRC batches up to 1.25 m³ produced in concrete plant - total 4.2 m³ used
- ➔ Transport by truck till shore (37 km), then by helicopter (skip with maximum 300 litres UHPFRC)



June 26, 2013



➔ Total 18 Helicopter runs in less than 2 hours

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The turret after the intervention

Septembre 6, 2013



- Excellent surface rendering
- No change after 2 winters exposure
- New applications foreseen for 2014/2015 (turrets and lighthouses)



Septembre 12, 2014

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3. Long term feedback

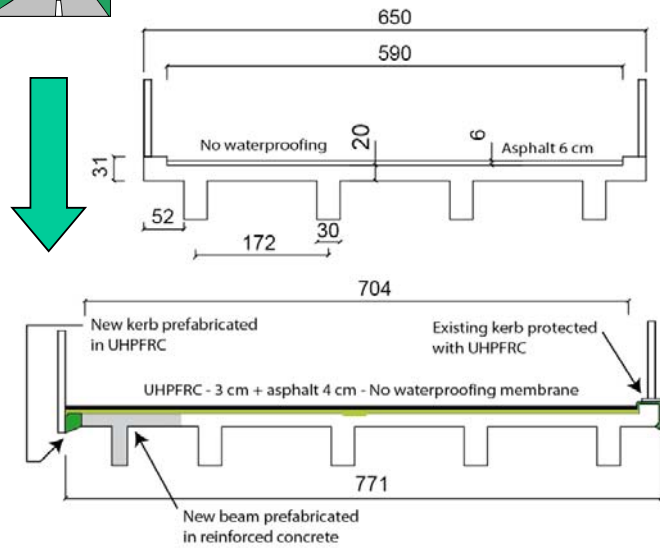
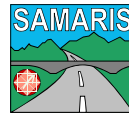
Bridge over river la Morge / CH (2004)

- First cast-on site UHPFRC application in Switzerland
- Bridge deck + curbs rehabilitated with CEMTEC_{multiscale}[®] (no thermal treatment)
- Durability assessment after 10 years
- Chloride profiles on cores (UHPFRC and repair mortar) + sorptivity of UHPFRC
- Determination of chlorides diffusivity

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Concept of intervention

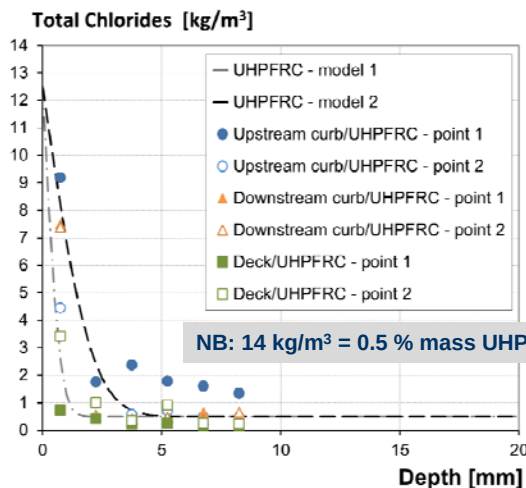
- Span: 10 m
- XD3, XF4 exposure
- No waterproofing membrane
- Protective function provided by UHPFRC
- Widening of the bridge
- Prefabricated UHPFRC curb downstream
- Thin UHPFRC overlay (3 cm) applied on deck – high restraint
- UHPFRC curb upstream rehabilitated with 3 cm UHPFRC



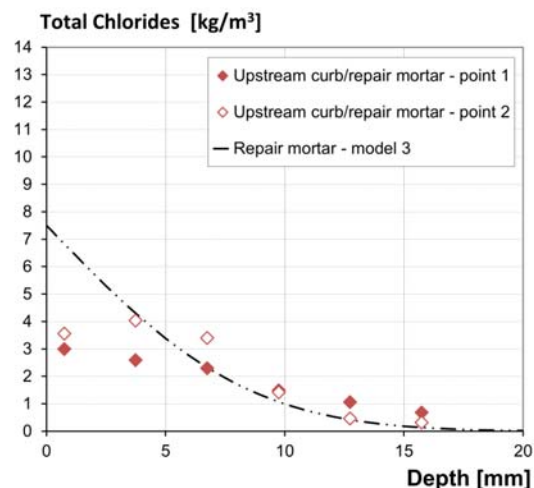
unit: cm

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Chloride profiles (for similar exposures)



UHPFRC, after 10 years



Repair mortar, after 7 years

- Repair mortar was used to fill coring holes in upstream curb (2007)
- Much deeper Cl⁻ penetration (15 mm) than in UHPFRC (few mm)

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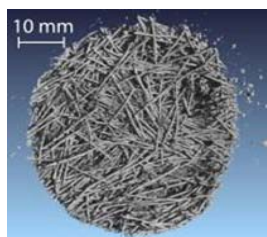
Chlorides diffusivities

Material	Unit	UHPFRC Model 1	UHPFRC Model 2	Repair mortar Model 3
Diffusivity	[m ² /s]	4.7×10^{-16}	4×10^{-15}	1×10^{-13}

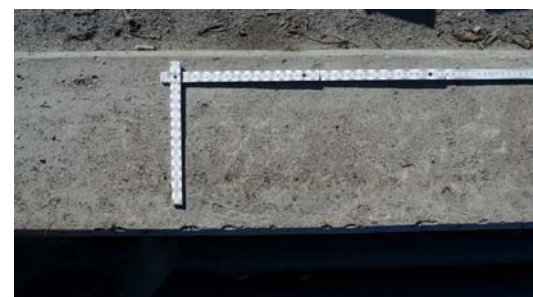
- Extremely low values in UHPFRC after 10 years, even without thermal treatment, for cast –in place and prefabricated UHPFRC
- For comparison, for Sakata Mirai Foot bridge (Japan), UHPFRC with thermal treatment, after Kono et al. (2013), between 3.1×10^{-15} and 1.3×10^{-14} m²/s for specimens placed inside the open box girder and 0.9 to 1.2×10^{-15} m²/s for cores taken in the walls of the box girder, Kono et al. (2013). Concrete for XD3/XF4 (E/C=0.35), 10^{-12} m²/s

→ UHPFRC cast in place without thermal treatment on bridge over river la Morge has excellent performance.

Upstream side after 10 years exposure



CT Scan



Upper surface



Lateral surface

Downstream side after 10 years exposure



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4. What we learnt (or confirmed) !

- UHPFRC can be reliably cast-on site over large surfaces, with existing technology
- Contractors very quickly assimilate the technique, just sufficient training time needed (preliminary tests)
- Properties must be validated in representative specimens (composition + processing)
- «High» fiber dosages (≥ 3 or 4 % vol. steel) are not a critical issue in comparative assessment of solutions
- Fibrous mix must be sufficient to achieve significant strain hardening response (a few per mille) **in structural members**
- Fiber orientation effects must be understood, not feared
- Tensile strength is as important as deformability

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5. Conclusions

- «Targeted local hardening» of structures, in most critical zones, by using UHPFRC or R-UHPFRC.
 - Simplification of the construction process.
 - Increase of the efficiency of existing and new structures (protection and reinforcement).
 - Concept and sustainability successfully validated (technically and economically) in numerous applications in Switzerland over 10 years.
 - Becoming common practice in Switzerland
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Thank you for your attention !



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