Ultra High Performance Fibre Reinforced Concrete (UHPFRC) for durable rehabilitation of bridges

Dr. Aljoša Šajna

Slovenian National Building and Civil Engineering Institute
0. OUTLINE

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1. Motivation ARCHES

- The goal of ARCHES (Assessment and Rehabilitation of Central European Highway Structures): reduce the gap in the standard of highway infrastructure between Central and Eastern European Countries (CEEC) and the rest of the EU.
- To develop more appropriate tools and procedures;
- To avoid unnecessary interventions (repairs/replacements) in structures;
- To prevent the development of corrosion by simpler, and less expensive techniques;
- To implement faster, more cost-effective, and longer lasting rehabilitation techniques (repair or strengthening) of substandard and unsafe bridges;
- To disseminate results and general best practice to the key stakeholders.
1. Motivation WP5

- Limited resources for management of road structures (time and money, including user’s costs)!
- Limit duration of construction sites
- Increase durability and efficiency
  - for rehabilitations
  - for new constructions
- Promote Strategy A
- Make best use of most advanced materials
- Combine materials in efficient composite structures!

![Graph showing performance and supply strategies](image)
1. Why UHFRPC

✔ Durable
✔ Outstanding protective properties
✔ Outstanding mechanical properties
✔ Tensile strain hardening
✔ Applicable on site
✔ Adoptable to site conditions
✔ Sustainable repair solution

Fractured surface of UHFRPC

10 mm
2. UHPFRC composition

✓ Ultra compact cementitious matrix

- Water/Binder = 0.125 to 0.140
- Cement: 1051 to 1434 kg/m³
- Silica fume: SF/C = 0.05 to 0.26 (mass)
- Superplasticizer: SP/C = 1 % (mass, dry extract)
2. UHPFRC composition

☑ Fibrous reinforcement

- Steel wool + steel fibres
- Total dosage 468 - 706 kg/m³ (6 to 9 % Vol.)

CEMTECmultiscale® developed by Rossi et al. (2002)
2. UHPFRC characteristics

- Selfleveling
- Outstanding protective properties

“Selfleveling”

“Low air permeability (Torrent)”
2. Tensile response

- Deformation capability > restrained shrinkage
- E modulus: 30% higher than usual concretes
- Tensile strength: 3 to 4 times higher than usual concretes!

UHPFRC results on 5 specimens, at 28 days, Mix CM23, cast on site

\[ f_{ct} = 13.5 \text{ MPa (mean)} \]
\[ \varepsilon_{\text{hardening}} = 1.5 \% \text{ (mean)} \]
3. What is proposed?

- Liquid water + Cl\(^-\) = XD2, XD3
- Most aggressive for structures!
  - Apply protective watertight UHPFRC overlay
  - Improve durability **without waterproofing membrane**
  - Increase load bearing capacity, if needed
3.2 Background

- Successful **structural rehabilitation** is a major challenge for engineers
- Cracking has both material and structural origins

![Diagram showing thermal and moisture interactions](image)

**Major issues:**
- Processing on site
- Monolithic behaviour
- Protective function
- Mechanical performance
- Durability
3.3 UHPFRC validation / application

• Numerous laboratory tests on UHPFRC materials and composite members, since 1999 at MCS/EPFL – EU Project SAMARIS.

Case 1: Bridge rehabilitation

Rehabilitation and widening of the Bridge over river La Morge – Wallis, CH

Execution: October – November 2004
Case 1: Bridge rehabilitation

Bridge over river « La Morge » - Wallis - CH

- No waterproofing membrane
- Protective function provided by UHPFRC
- Widening of the bridge
- Prefabricated UHPFRC kerb downstream
- Thin UHPFRC overlay (3 cm) applied on deck
- UHPFRC rehab. kerb upstream

Denarié et al. (2004)

Span 10 m
Case 2: Protection of a crash barrier

Owner: Canton Argovie, CH
Realisation: 2006

Challenge: Pouring of the UHPFRC in the limited space + high degree of restraint of the UHPFRC layer + batches of 1 m$^3$

A1 Furtbachbrücke, Würenlos

Oesterlee et al. (2006)
Case 3: Protection of a bridge pier

- Heavily trafficked highway
- 4 cm thick prefabricated UHPFRC shell elements
- Joints glued on site with epoxy resin

Owner:
Canton Argovie, CH

Realisation: spring 2007

Oesterlee et al. (2007)
Case 4: Strengthening of a slab

Autumn 2007
Geneva, CH

- Increased traffic load
- Increase load-bearing capacity and improve protective functions
- Replacement of mortar overlay by 4 cm UHPFRC with rebars
- 720 m² (i.e. 36 m³) of UHPFRC
5. Recent advances in Slovenia

Challenges of ARCHES project

- Develop UHPFRC mixes from local components (overcome cement-superplasticiser compatibility issues)
- Make the mixes tolerant to slopes of 5 %
- Improve surfacing technique («barefoot walk»)
- Repair a bridge!
5.1 ARCHES WP 5 team

Dr. E. Denarié, MCS-EPFL (CH) – WP Leader

- MCS-EPFL (CH): Prof. E. Brühwiler, Dr. H. Sadouki, Mrs. A. Switek, Mr. H. Kamyab, Mrs. T. Noshiravani, Mr. C. Oesterlee, Dr. J. Wuest

- ZAG (Slovenia): Dr A. Šajna, Mrs J. Šuput, Mr V. Bras

- Salonit (Slovenia): Mrs L. Resčič

- IBDIM (Poland): Prof. M. Lagoda, Mr. A. Sakowski

- LCPC/FEHRL (France): Dr. P. Rossi
5.2 New UHPFRC matrices

Denarié - 2007

A: pure CEM I 52.5 cement (Salonit)

B: CEM I 52.5 cement (Salonit) blended with mineral addition

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

- **Case A**: impossible to achieve sufficient workability when fibres are added
- **Case B**: excellent workability, comparable to reference UHPFRC mixes with reference cement - adapted for addition of fibres at high dosages
5.3 Improved slope tolerance

Slovene based similar recipes with W/C = 0.170
New unconfined slope test from EPFL/MCS

- Case A: no slope tolerance to 3 %
- Case B: tolerance to slope of 3 %

ZAG confirmed results and extended to 5 % slope
5.4 Validation - protective function

Recipes with Slovenian components exhibit excellent protective properties comparable to reference mix (project SAMARIS).

Air permeability testing

- Recipes with Slovenian components exhibit excellent protective properties comparable to reference mix (project SAMARIS).
5.4 Validation - mechanical performance

- Recipes with Slovenian components exhibit excellent mechanical performance comparable to the reference mixes (SAMARIS).

- Flexural response under 4PB
- Plates 50 x 20 x 3 cm
- Span 42 cm
- Average curves on 5 to 10 specimens

MA = Mineral addition
5.4 Validation - durability

Recipes with Slovenian components exhibit excellent free-thaw-salt durability.

500 cycles passed >> 50 cycles required
5.5 Field trial tests - Salonit, SLO

300 litres batches
Total 900 litres
Loss = 50 litres

Slopes of 5+ % can be cast without difficulties
Application time:
10 m² = 10 minutes
5.6 Full scale application - SLOVENIA

Log Čezsoški bridge – Soča river, NW Slovenia
Assignment: rehabilitation of the sidewalk and deck, replacement of dilation

Owner: Municipality of Bovec

4.50 m
65 m
Slope 5 %
5.6 12,7 km detour

**Challenge**

- Limit site duration
- Increase durability and efficiency of rehabilitation

The bridge
Village of Log Čezsoški
5.6 No-joint “coat”

Application of a continuous watertight UHPFRC on the deck and footpaths
5.6 Improved UHPFRC surface

- Surfacing technique of UHPFRC using DuPont Zemdrain® formwork liner (ZAG-2009)
5.6 Preparation works

Low roughness requirements
5.6 Preparation works

Minimum preparation works needed
5.6 Execution

- Batches of 320 litres in 500 l concrete plant
- Mixing time = 12 minutes
- Only 2 or 3 batches per truck
5.6 Execution

- 12 m³ UHPFRC applied in 2.5 to 3 cm layers.
- Execution in 2 days with a transversal joint at mid-deck surface.
5.6 The bridge after rehabilitation
## 5.6 Owner, user, contractor

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<th>vs.</th>
<th>UHFPRC repair</th>
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<td>12 MM</td>
<td>&gt;</td>
<td>12 m³ UHPFRC</td>
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*) G. Habert, LCPC, France: ARCHES final seminar
6. Conclusions

- Focus on the conceptual approach – why and where are UHPFRC really needed
- Provide concepts for "portable mixes" with universally applicable components
- Develop cast-in situ applications in different countries
- Take advantage of combination with rebars
- Dare try and be creative
- **UHPFRC concept = durable/sustainable repair of bridges**
7. Links and documents

- EU 5th FP SAMARIS/WP 14, deliverables D22 and D25 on http://samaris.zag.si

- EU 6th FP ARCHES/WP 5, deliverables D06 and D14 on http://arches.fehrl.org

aljosa.sajna@zag.si
emmanuel.denarie@epfl.ch
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Primorje: Mr. B. Ipavec (Designer)

CPG: Mr. M. Popović, Mr. Z. Jerkič, Mr. J. Brecelj (Contractor)
Thank you for your attention!