Competitive and Sustainable Growth (GROWTH) Programme

SAMARIS

Sustainable and Advanced MAterials for Road InfraStructure

WP 14: HPFRCC (High Performance Fibre Reinforced Cementitious Composites) for rehabilitation

Deliverable D25b

Guidance for the use of UHPFRC for rehabilitation of concrete highway structures

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ABSTRACT

The premature deterioration of reinforced concrete structures is a heavy burden for society. In order to manage structures effectively and to reduce this burden to the minimum, the number and extent of interventions have to be kept to the lowest possible level. The extremely low permeability of Ultra-High Performance Fibre Reinforced Concretes (UHPFRC) associated with their outstanding mechanical properties make them especially suitable to locally "harden" reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses. Composite UHPFRC-concrete structures promise a long-term durability which helps avoid multiple interventions on structures during their service life. UHPFRC materials can be applied on new structures, or on existing ones for rehabilitation, as thin watertight overlays in replacement of waterproofing membranes, as reinforcement layers combined with reinforcement bars, or as prefabricated elements such as kerbs. This document gives an overview of the conceptual approach, and provides basic guidance in view of the application of UHPFRC for the rehabilitation of reinforced concrete structures.

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FOREWORD AND ACKNOWLEDGEMENTS

This report is the fifth of a series covering all aspects necessary to the implementation of UHPFRC (Ultra High Performance Fibre Reinforced Concretes) for the rehabilitation of reinforced concrete structures, within the framework of work package (WP) 14 "HPFRCC for rehabilitation" of project SAMARIS. The other reports are:

- D13 - Report on preliminary studies for the use of HPFRCC for the rehabilitation of road infrastructure components
- D18a and D18b - Report on tests of UHPFRC in the laboratory, parts a. and b.
- D22 – Full scale application of UHPFRC for the rehabilitation of bridges – from the lab to the field
- D26 - Modelling of UHPFRC in composite structures
- D31 - Guidelines on selection of innovative techniques for the rehabilitation of concrete highway structures.

Contributors to WP 14 are: MCS-EPFL (contractor and WP leader), LCPC – Dr. P. Rossi (contractor), and TRL – Dr. R. Woodward (contractor).

The original concept of application of UHPFRC for the rehabilitation of reinforced concrete structures was proposed at MCS, by Prof. Dr. E. Brühwiler, in 1999.

The researchers and technicians who contributed to these works at MCS-EPFL under the lead of Dr. E. Denarié (WP 14 leader) and Prof. Dr. E. Brühwiler (Director of MCS-EPFL) are:

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- Aicha Kamen (civil engineer, doctoral student at MCS-EPFL).
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- Prof. Dr. Jean-Philippe P. Charron (former collaborator of MCS-EPFL).
- Roland Gysler (technician)
- Sylvain Demierre (electrical engineer)

The support of the road administration of the Swiss Canton Wallis for the first application of UHPFRC is gratefully acknowledged.

Finally, Dr. Pierre Rossi of LCPC-France, inventor of $\text{CEMTEC}_{\text{multiscale}}^{®}$ and worldwide known expert of Fibre Reinforced Concretes, proposed the original UHPFRC recipes used in this study and the concepts for their tailoring to the specific applications of rehabilitation.

Lausanne, May 25, 2006 Dr. Emmanuel Denarié

EXECUTIVE SUMMARY

Introduction

Highway structures are constantly subjected to physico-chemical phenomena that can result in their deterioration and subsequent reduction in their reliability to perform adequately. *Among all exposure cases, those where a direct contact with liquid water containing aggressive chemical substances is involved are the most severe. (exposure classes XD2 - direct contact, or XD3 splash zone).* Over the last 10 years, considerable efforts to improve the deformational behaviour of cementitious materials by incorporating fibres have led to the emergence of Ultra-High Performance Fibre Reinforced Concretes (UHPFRC) characterized by a very low water/binder ratio and high fibre content. These new building materials provide the structural engineer with an unique combination of excellent rheological properties in the fresh state, extremely low permeability, high strength and tensile strain hardening in the range of the yield strain of construction steel (up to 0.2 %). UHPFRC are very well suited to locally "harden" reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses.

A comprehensive series of tests in the laboratory on composite UHPFRC-concrete structural members have successfully validated this concept for various geometries, and boundary conditions, with various degrees of restraint, with or without reinforcement bars in the UHPFRC layer, Habel (2004), SAMARIS D18a (2005), SAMARIS D18b (2005), and the outstanding protective properties towards ingress of aggressive substances of the UHPFRC CEMTEC$_{multiscale}$® were confirmed both in the laboratory and on site.

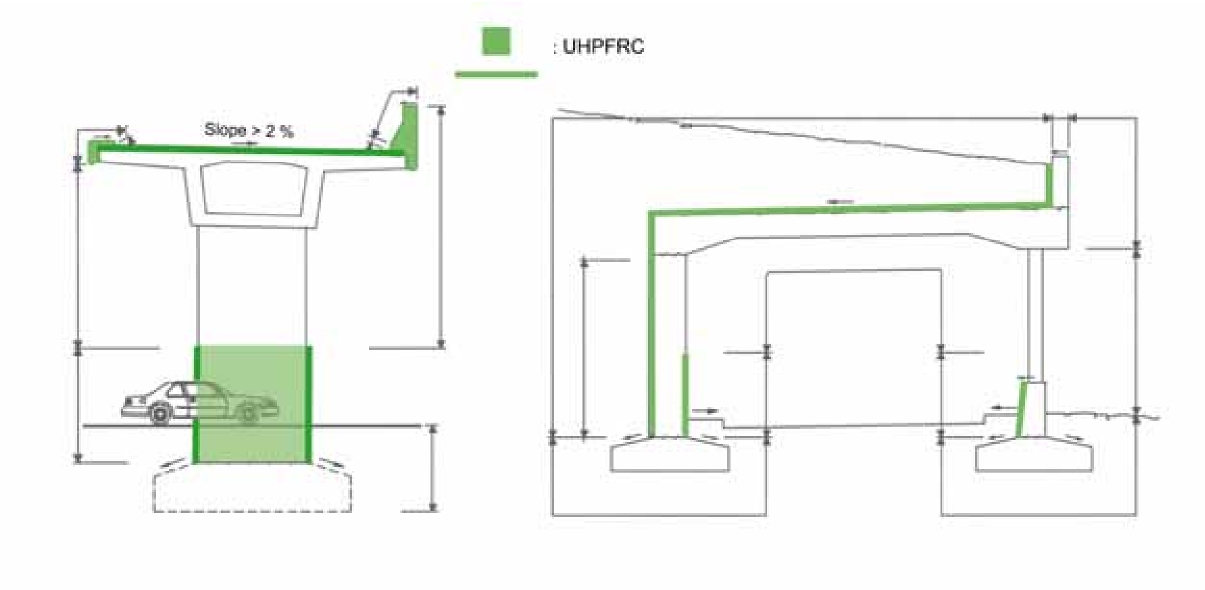
A first application of this concept has been successfully realised and the required properties of the UHPFRC were achieved with standard equipments, and verified in-situ.
The construction costs of the proposed technique were not significantly higher than more traditional solutions, and the duration of the construction works and closing of traffic lanes could be largely reduced, to the greatest satisfaction of the bridge owner SAMARIS D22 (2005).

This report gives practical and conceptual recommendations for the application of UHPFRC for the rehabilitation of reinforced concrete structures. It is not intended as a prenormative document but rather as a practical tool to help engineers and owners be able to answer following questions:

- Are UHPFRC adapted for my case ?
- What can I expect from UHPFRC ?
- How do UHPFRC compare with other materials ?
- How to classify my structure in terms of degree of restraint ?
- Which level of UHPFRC performance is needed for my case ?
- How can I take UHPFRC into consideration for design ?
- How to verify the properties of UHPFRC ?
- How to produce and process UHPFRC cast on site ?

Concept of application

An "everlasting winter coat" of UHPFRC is applied on the bridge superstructure, only were it is needed, in zones of severe environmental (XD2, XD3,) and mechanical loads. Critical steps of the construction process such as application of waterproofing membranes or compaction by vibration can be prevented, and the associated sources of errors avoided. The construction process becomes then simpler, quicker, and more robust, with an optimal use of composite construction.



This new construction technique is specially well-suited for bridges but might also be implemented for galleries, tunnels, retaining walls (exposure classes XA2, XA3), or even parking, following the same approach.

The waterproofing capabilities of the UHPFRC exempt from applying a waterproofing membrane. Thus, the bituminous concrete can be applied after only 8 days of moist curing of the UHPFRC.

This constitutes a very significant time saving with respect to the drying period of up to 3 weeks necessary prior to the application of a waterproofing membrane on a usual mortar or concrete.

Further, the thickness of the bituminous concrete layer can be limited to the absolute necessary for the traffic loads. It is unnecessary to increase its thickness to apply weight on the waterproofing membrane to prevent the formation of air pockets.

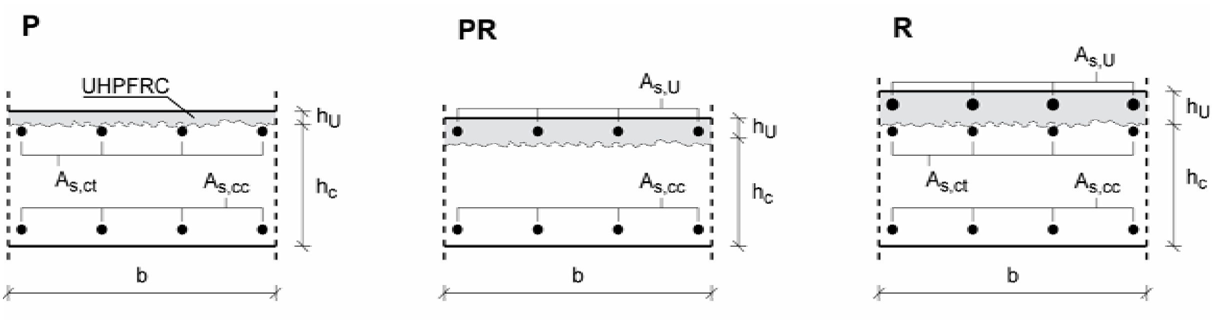
Geometries of application

For the example of UHPFRC layers applied on bridge deck slabs, following geometries of application can be proposed, Habel (2004):

(1) Cross section (P) with a thin UHPFRC layer is designed for protection purposes. The tensile reinforcement in the existing concrete is situated near the interface between the two concretes. Such cross-sections are obtained when the tensile reinforcement of the existing RC structure ($A_{s,ct}$) is not or only slightly deteriorated and the load carrying capacity is sufficient.

(2) Cross section (PR) represents the case when additional tensile reinforcement is placed into the UHPFRC layer to replace and/or to complement the existing strongly deteriorated reinforcement bars. This configuration provides both an improved protection function and an increase in load carrying capacity.

(3) Cross section (R) is designed primarily to increase significantly the load carrying resistance of the structural element. The cross-section consists of the original reinforced concrete section which is complemented by the reinforced UHPFRC layer which can be seen as an externally bonded additional reinforcement. Also, the UHPFRC provides the protection function for the structural element which is beneficial to durability of the element.



When UHPFRC and reinforcement bars are combined, the stiffness and the load-carrying capacity of the member are significantly increased, even for a new reinforced UHPFRC layer of 5 cm.

Optimum combinations of reinforcement bars (quantity and strength) and UHPFRC layer thickness can be designed in order to provide an efficient and safe reinforcement of structural members, with compact cross sections Habel (2004). *With this respect, a new layer of 5 cm thickness appears to be a good and economical compromise in association with reinforcement bars.*

The thickness of the UHPFRC layer to be applied also depends on the roughness of the surface to be overlaid. A minimum roughness of 0.5 cm with a wavelength of 1 to 1.5 cm appears to be sufficient to provide a monolithic behaviour of the composite members.

On another hand 1.5 cm is the minimum cover necessary to provide a sufficient protective function with an objective of over 100 years durability, for the underlying structure or reinforcement bars embedded in the UHPFRC layer. Further, depending on the diameter of the rebars embedded in the UHPFRC this cover should be sufficient to avoid bond cracks. A minimum cover equal to the rebar diameter is recommended with this respect. Finally, if active cracks are present in the concrete substrate, a minimum UHPFRC thickness of 3 cm should be applied, to provide a sufficient structural hardening behaviour.

Classification of applications

Two basic types of applications of UHPFRC for the rehabilitation of existing structures can be distinguished:

- Prefabrication of new elements such as kerbs
- Cast-in place UHPFRC

In both cases, the most important load cases at serviceability shall be: eigenstresses induced by restrained shrinkage and fatigue under traffic loads. The following table summarizes the classes of requirements as function of the *degree of restraint with respect to restrained shrinkage deformations, and severity of traffic loads (number of vehicles per day)*.

Classes of mechanical loading for UHPFRC in composite structures

Class	Application	Degree of Restraint μ [––]	Traffic load	Example
A	Prefabrication	0	None	Precast kerb elements
B	Cast-in-place	0.4 to 0.6 moderate	Moderate	Overlay on deck slab of box-girder bridge
C	Cast-in-place	0.4 to 0.6 moderate	High	Overlay on deck slab of box-girder bridge
D	Cast-in place	0.75 – high	Moderate	Overlay on “multiple beam bridge”
E	Cast-in place	0.75 – high	High	Overlay on “multiple beam bridge”
F	Cast in-place	0.8 to 0.9 very high	None	Cast-in place kerbs
G	Cast-in place	0.8 to 0.9 very high	Moderate	Overlay on “multiple beam bridge”
H	Cast-in place	0.8 to 0.9 very high	High	Overlay on “multiple beam bridge”

Requirements

Following the experiences gathered during the project in laboratory tests, numerical simulations and practical applications on site, requirements for the quality of UHPFRC in composite structures are proposed in the following table. In all cases, the basic requirements are: outstanding protective function (determined on the basis of air permeability tests for instance as described in Appendix 3), no localized macrocracks, and minimum fibre dosage of 1.5 % vol. (for steel fibres). These requirements are based on experiences with a single type of UHPFRC (CEMTEC$_{multiscale}$® with a pure Portland cement and high quantity of steel fibres with a moderate aspect ratio of 50).

Further research will be needed to extend this table to other types of UHPFRC with different kinds of binders and fibrous mixes.

Requirements for UHPFRC in composite highway structures

Class	Tensile strength f_t [MPa]	Strain hardening ε_{peak} [‰]	Shrinkage at 3 month [‰]	Workability
A	8 to 10	No limits	No limits	Self-compacting - fluid Self-levelling
B	11	1	0.6 max.	Self-compacting Tolerance to slope
C	11	2	0.6 max.	Self-compacting Tolerance to slope
D	14	1.5	0.6 max.	Self-compacting Tolerance to slope
E*	14	2	0.6 max.	Self-compacting Tolerance to slope
F**	14	1.5	0.6 max.	Self-compacting - fluid Self-levelling
G	14	2	0.6 max.	Self-compacting Tolerance to slope
H*	14	2	0.6 max.	Self-compacting Tolerance to slope

Notes:

- All mechanical properties are average values at 28 days.
- Tensile strength is the maximum value of the stress obtained in an unnotched uniaxial tensile test such as described in Appendix 2
- Strain hardening is the total deformation at the peak stress under uniaxial tension, determined as the average value on a measurement basis of 3 times the width of the specimen, as described in Appendix 2

- Determination of mechanical properties on specimens cast according to the direction of casting in application.

Additional requirements:

- *For high traffic loads, in classes E and H, partial fibrous reinforcement by high-bond profiled fibres (non straight-smooth) is recommended.
- **For casting of plain kerb elements on site, class F, the thermo mechanical effects at early age can play a significant role depending on the thickness of the element.
- In classes A, E and F, the kerb must be designed with reinforcement bars and proper connection to the superstructure of the bridge to support the accidental actions in case of vehicles accidents (shocks).
- In those cases, suitable mixes and geometries of application must be studied and validated by preliminary laboratory tests and/or numerical simulations.

1 MOTIVATION

Highway structures are constantly subjected to physico-chemical phenomena that can result in their deterioration and subsequent reduction in their reliability to perform adequately.

Among all exposure cases, those where a direct contact with liquid water containing aggressive chemical substances is involved are the most severe. In the very frequent case of deteriorations by chloride induced corrosion (exposure classes XD2 - direct contact, or XD3 splash zone), both the initiation time and the corrosion rate of reinforcement bars are mostly dependent on the availability of liquid water.

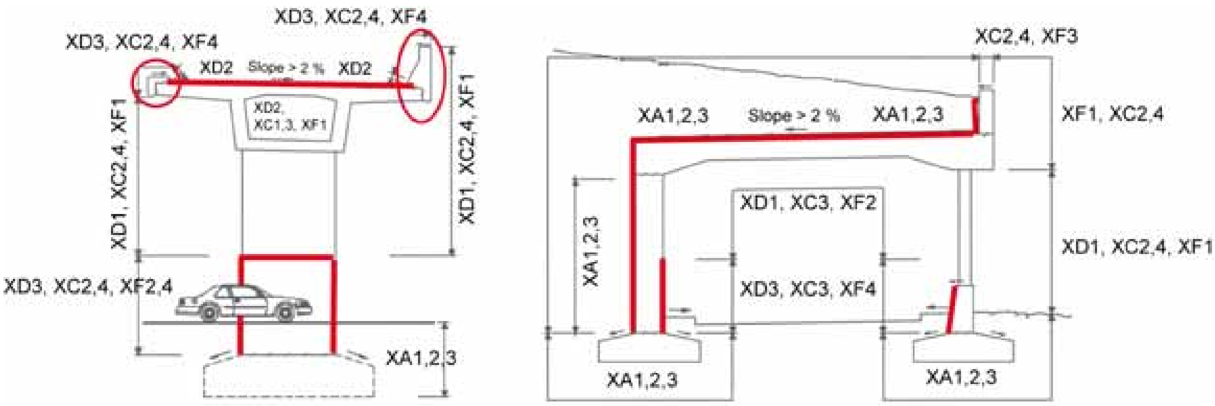


Figure 1: Exposure classes in highway structures and zones of most severe exposure (outlined).

The premature deterioration of reinforced concrete structures is a heavy burden for our society. In order to manage structures effectively and to reduce this burden to the minimum, the number and extent of interventions have to be kept to the lowest possible level, with only preventative maintenance. *However, too often, rehabilitations fail and it is needed to "repair the repairs". Further, usual reinforced concretes or mortars hardly can withstand exposure classes XD2 or XD3 for long periods of time.*

Over the last 10 years, considerable efforts to improve the deformational behaviour of cementitious materials by incorporating fibres have led to the emergence of Ultra-High Performance Fibre Reinforced Concretes (UHPFRC) characterized by a very low water/binder ratio and high fibre content. These new building materials provide the structural engineer with an unique combination of:

(1) excellent rheological properties in the fresh state,

(2) extremely low permeability,

(3) high strength and tensile strain hardening in the range of the yield strain of construction steel (up to 0.2 %).

UHPFRC are very well suited to locally "harden" reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses, Brüwhiler et al. (2004), (2005). Composite UHPFRC-concrete structures promise a long-term durability which helps avoid multiple interventions on structures during their service life. UHPFRC materials can be applied on new structures, or on existing ones for rehabilitation, as thin watertight overlays in replacement of waterproofing membranes, as reinforcement layers combined with reinforcement bars, or as prefabricated elements such as kerbs. However, the cost of these materials imposes use only where they are worth it and to take the maximum benefit of their outstanding mechanical properties with an optimum level of loading at service state. Further, UHPFRC are rather a family of materials with a wide range of performances and compositions, than a single material. It is thus important to be able to distinguish between various materials and have the background for taking sound decisions.

A comprehensive series of tests in the laboratory on composite UHPFRC-concrete structural members have successfully validated this concept for various geometries, and boundary conditions, with various degrees of restraint, with or without reinforcement bars in the UHPFRC layer, Habel (2004), SAMARIS D18a (2005), SAMARIS D18b (2005), and the outstanding protective properties towards ingress of aggressive substances of the UHPFRC CEMTEC$_{multiscale}$® were confirmed both in the laboratory and on site.

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This document is based on the experiences gathered during the European project SAMARIS, more specifically during the laboratory tests and the execution of the first application of the UHPFRC CEMTEC$_{multiscale}$® for the rehabilitation of the bridge over river Morges, Wallis, Switzerland, SAMARIS D22 (2005). Detailed information and examples of design of composite UHPFRC-concrete bridge deck slabs with or without reinforcement bars can be found in Habel (2004).

2 UHPFRC MATERIALS

UHPFRC are characterised by an ultra-compact matrix with an extremely low permeability, Roux et al. (1995), and by a high tensile strength (above 10 MPa) and tensile strain-hardening. They are part of the group of HPFRCC as described in Figure 2, after Habel (2004). The very low water/binder ratio of UHPFRC (0.130 to 0.160) prevent the complete hydration of a major part of the cement and gives the material a significant hydrophilic behaviour and a self healing capacity for microcracks, Charron et al (2005). In the fresh state, despite their very low water/binder ratio, UHPFRC can be tailored to be self-compacting and tolerate slopes.

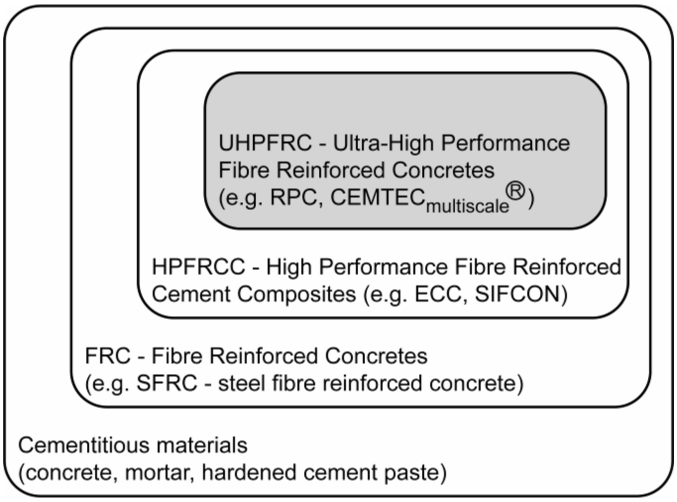


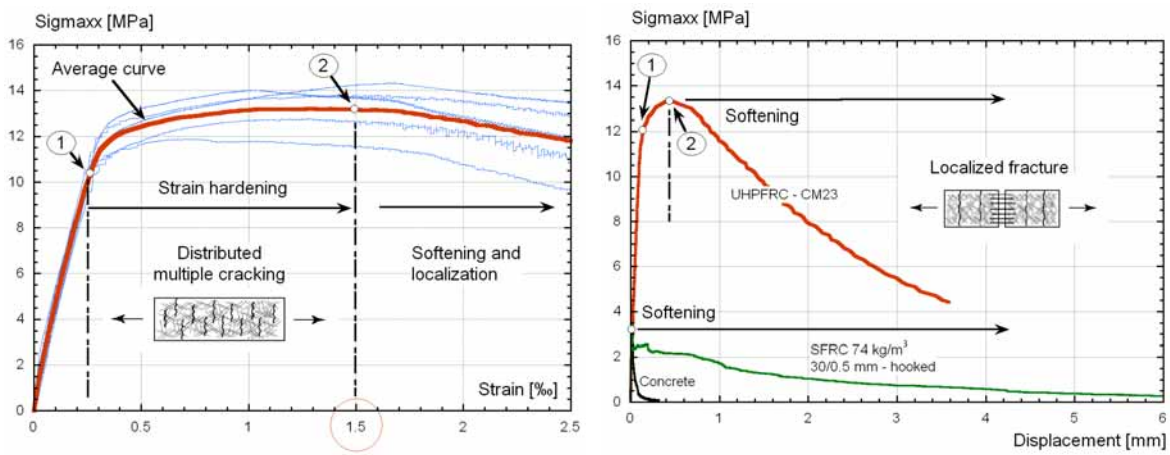
Figure 2: Classification of cementitious composites, after Habel (2004).

Various types of UHPFRC exist with different kinds of fibre mixes. With only one type of fibres, a compromise has to be found between the tensile behaviour pre and post peak, with limited strain hardening, Rossi (2000). On the contrary, the combination of multiple types of fibres with different length, Rossi et al. (2002), Parant (2003), creates a multi-level reinforcement that induces significant tensile strain hardening (up to 0.2 %), and multiple cracking under tension. In the context of the project SAMARIS, the UHPFRC family CEMTEC$_{multiscale}$®, developed at LCPC, Rossi et al. (2002), Boulay et al. (2003) was used and optimised for rehabilitation applications.

Figure 3a illustrates the tensile behaviour of an UHPFRC (mix CM23, see Appendix 4) used in this study, in the strain hardening range. The magnitude of strain hardening of UHPFRC, such as CEMTEC$_{multiscale}$® (1 to 2 ‰), falls into the range of the yield strain of construction steel. This property opens up very promising domains of combination of UHPFRC with reinforcement bars with high yield strength (700 MPa or above).

Compared to usual Steel Fibre Reinforced Concretes (SFRC), UHPFRC exhibit a significant tensile strain hardening behaviour (points 1 to 2) and a much higher tensile strength, Figure 3b. Their mechanical behaviour in tension can be considered in structural applications.

The modulus of elasticity of UHPFRC is 30 % higher than usual concretes but their tensile strength is 3 to 4 times higher.



a) **b)**

Figure 3: Tensile behaviour of UHPFRC (CEMTEC$_{multiscale}$®), a) strain hardening range, b) softening behaviour and comparison with other materials

The fractured surface of a UHPFRC specimen after a tensile test shows numerous steel fibres, pulled out from the matrix, Figure 4. The work of fracture of these numerous micro-reinforcements explains the extremely high specific fracture energy of UHPFRC (up to 30000 J/m^2 compared to 200 J/m^2 for normal concrete). A significant part of this fracture energy is dissipated in volume, during the strain hardening phase, in the form of finely distributed, multiple cracks.

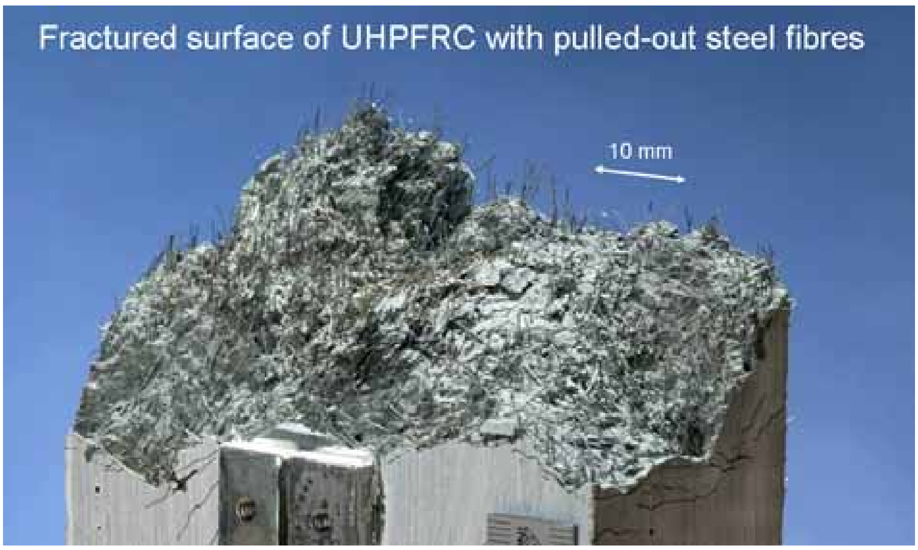


Figure 4: Fractured surface of a tensile specimen in UHPFRC, Photo A. Herzog.

3 COMPOSITE STRUCTURES

3.1 Background

The successful rehabilitation of existing structures is a **major challenge** for civil engineers. When existing concrete needs to be replaced, *a new composite structure* formed of the new material cast on the existing substrate will result from the intervention, as shown on Figure 5.

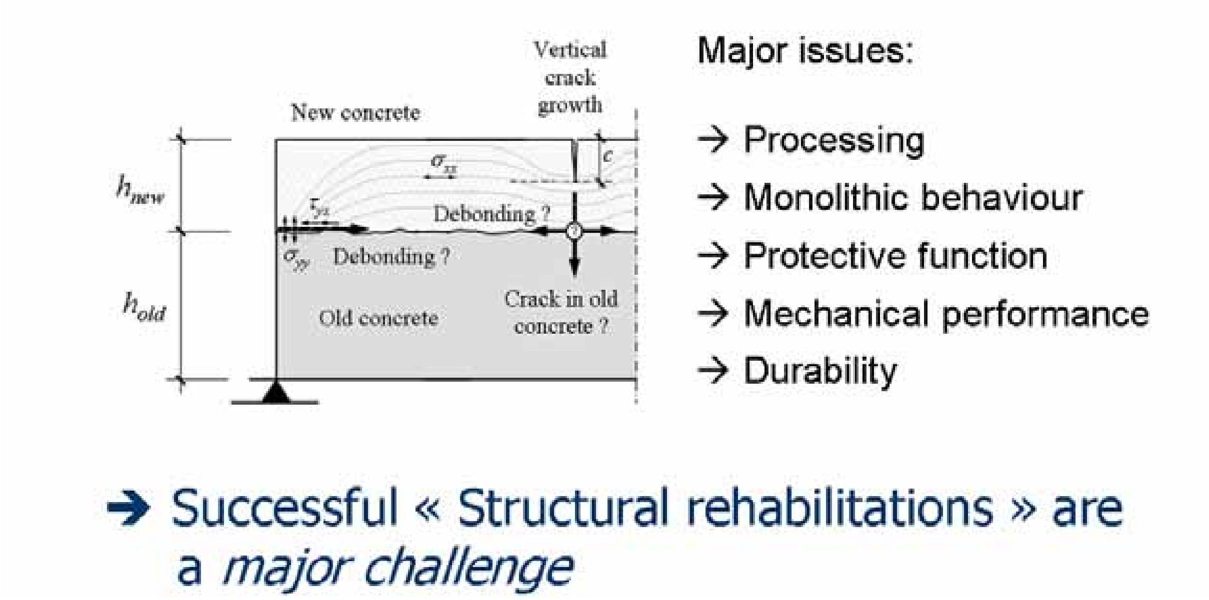


Figure 5: Composite concrete-concrete members - replacement of existing concrete, adapted after Bernard (2000).

Both the protective function and the mechanical performance of the composite system have to be guaranteed over the planned service life.

More or less pronounced tensile eigenstresses due to restrained shrinkage deformations at early age and long term are induced in a new layer applied on an existing one, Bernard (2000). These eigenstresses constitute a net loss of the performance in terms of potential tensile capacity.

On another hand, restrained shrinkage almost never occurs under full restraint in structures. Both the deformability of the structure and the creep of the materials (new and substrate) contribute to significantly decrease the induced stresses.

It is thus very important to investigate the « mechanical compatibility » of a new material in terms of structural consequences: eigenstresses compared to the tensile strength, and the evolution of these two parameters as a function of time.

A simple parameter that summarizes this interaction of material and structural properties is the so-called degree of restraint.

Stresses due to restrained movements can principally be computed by the product of three factors according to the following equation:

Stress = stiffness × free strain × degree of restraint

Consequently, all three factors are equally important. The stiffness is dependent on modulus of elasticity but also on creep or relaxation. The free strain is the strain that a completely free member would develop due to thermal or moisture changes, shrinkage, or any other internal or external source causing volumetric change of the member material. The degree of restraint μ defines the conditions of restraint as the ratio between the actual stress σ_{real} taking into consideration the effective stiffness of the composite structure and the stress σ_{full} that would occur in a totally restrained composite structure:

$$\mu = \frac{\sigma_{real}}{\sigma_{full}} \tag{1}$$

Restraints can be associated to all degrees of freedom of a structure. For a composite beam, 2 degrees of freedom can me mobilized, one axial, one flexural.

➔ *Many structural engineers are not aware of the fact that complete bond between overlay and substrate does not necessarily cause complete restraint in the repaired concrete structure.*

The reason is that the stiffness of the remaining part of the old structure is not infinite. The striving of the overlay to contract is only partly prohibited by the remaining part of the old structure. The absence of a complete restraint leads to substantial stress reductions. Combined with creep these reductions will limit the maximum tensile stress below the tensile strength and, hence, explain the absence of shrinkage cracking.

One must emphasize that two parameters have also a major an influence on the degree of restraint of a new layer:

- Time: the mechanical properties of a new layer change rapidly with time at early age. As a consequence, the degree of restraint is always high at early age
- Reinforcement bars if the reinforcement ratio is high.

The degree of restraint can be calculated for any structure from its geometrical characteristics and elastic material properties (modulus of elasticity). Simplified diagrams are available for simple geometries such as composite slabs with constant height. A detailed procedure for the calculation of the degree of restraint is given in Appendix 1.

3.2 Suitability of UHPFRC for rehabilitation

A well established principle for the application of a rehabilitation layer on an existing substrate is to try as far as possible to select a new material with mechanical properties close to those of the substrate. With this respect, UHPFRC with a high elastic modulus up to 55000 MPa might appear to be a bad choice. *This argument is however wrong for several reasons:*

- First of all, in the elastic domain, the elastic modulus of UHPFRC is around 40 % larger than that of normal concretes (48000/35000 MPa = 1.37). This difference is however largely compensated by the improved tensile strength of the UHPFRC (10 MPa for the matrix and up to 14 for the composite compared to 3 to 4 MPa for normal concretes).
- Secondly, UHPFRC exhibit a significant strain hardening, several times larger than its maximum elastic elongation, which is not the case for normal concrete.
- Finally, UHPFRC exhibit significant viscoelasticity at early age, comparable to high performance concretes, Habel (2004). Restrained shrinkage tests on UHPFRC specimens at an early age show that the development of stresses under full restraint remain moderate (45 % of the tensile first crack strength) with respect to the uniaxial tensile characteristics of the UHPFRC tested, Kamen et al. (2005).

The ultimate shrinkage of UHPFRC is not higher than that of usual concretes (in the range of 600 µm/m = 0.6 ‰ at 6 month). The driving force for this shrinkage is however different. In UHPFRC, with a very low water/binder ratio, drying shrinkage is negligible after 8 days of moist curing. The main source of deformations in UHPFRC is autogenous shrinkage, instead of drying processes in usual concretes.

Strain hardening UHPFRC turn out to be an excellent compromise of density, high tensile strength and significant deformation capability, perfectly suited for combination with normal concretes, in existing or new structures.

4 CONCEPT OF APPLICATION

4.1 General

An "everlasting winter coat" of UHPFRC is applied on the bridge superstructure, only were it is needed, in zones of severe environmental (XD2, XD3,) and mechanical loads. Critical steps of the construction process such as application of waterproofing membranes or compaction by vibration can be prevented, and the associated sources of errors avoided. The construction process becomes then simpler, quicker, and more robust, with an optimal use of composite construction.

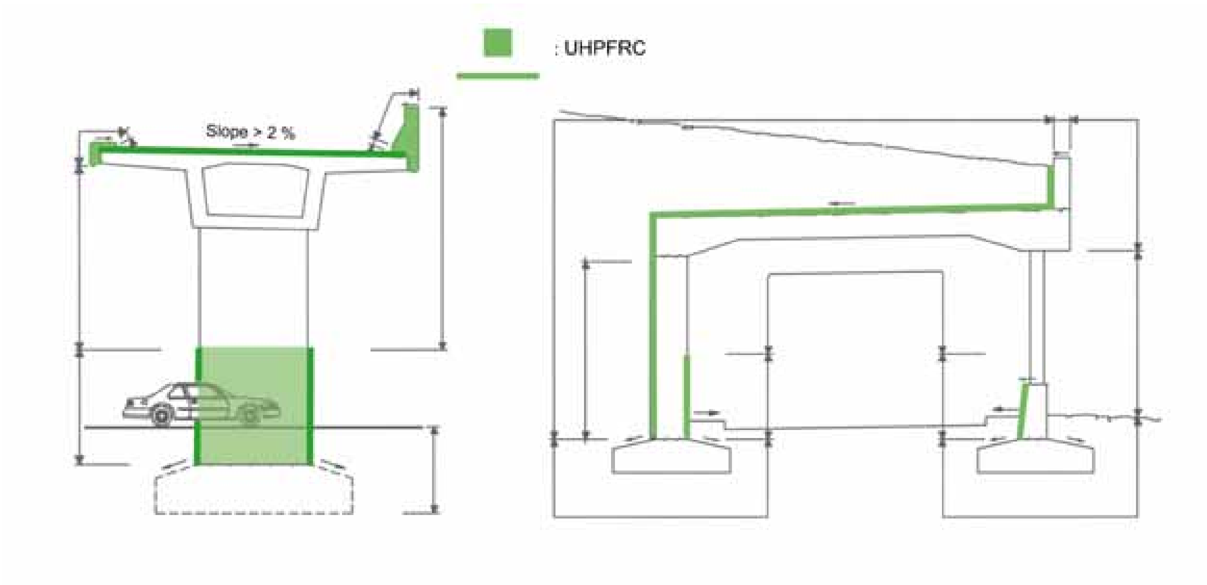


Figure 6: General concept of application of UHPFRC.

This new construction technique is specially well-suited for bridges but might also be implemented for galleries, tunnels, retaining walls, (exposure classes XA2, XA3), or even parking, following the same approach.

The waterproofing capabilities of the UHPFRC exempt from applying a waterproofing membrane. Thus, the bituminous concrete can be applied after only 8 days of moist curing of the UHPFRC.

This constitutes a very significant time saving with respect to the drying period of up to 3 weeks necessary prior to the application of a waterproofing membrane on an usual mortar or concrete.

Further, the thickness of the bituminous concrete layer can be limited to the absolute necessary for the traffic loads. It is unnecessary to increase its thickness to apply weight on the waterproofing membrane to prevent the formation of air pockets.

4.2 Geometries of application

For the example of UHPFRC layers applied on bridge deck slabs, following geometries of application can be proposed, Habel (2004), Figure 7:

(1) Cross section (P) with a thin UHPFRC layer is designed for protection purposes. The tensile reinforcement in the existing concrete is situated near the interface between the two concretes. Such cross-sections are obtained when the tensile reinforcement of the existing RC structure ($A_{s,ct}$) is not or only slightly deteriorated and the load carrying capacity is sufficient.

(2) Cross section (PR) represents the case when additional tensile reinforcement is placed into the UHPFRC layer to replace and/or to complement the existing strongly deteriorated rebars. This configuration provides both an improved protection function and an increase in load carrying capacity.

(3) Cross section (R) is designed primarily to increase significantly the load carrying resistance of the structural element. The cross-section consists of the original reinforced concrete section which is complemented by the reinforced UHPFRC layer which can be seen as an externally bonded additional reinforcement. Also, the UHPFRC provides the protection function for the structural element which is beneficial to durability of the element.

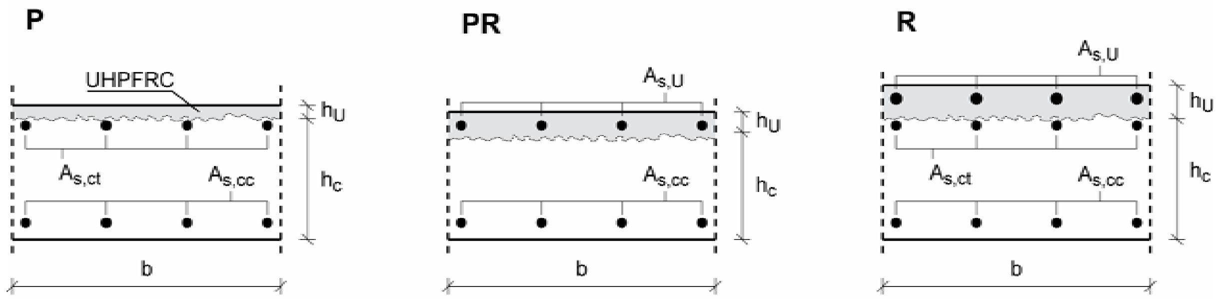


Figure 7: Geometries of "UHPFRC-concrete" elements for bridge deck slabs, after Habel (2004).

When UHPFRC and reinforcement bars are combined, the stiffness and the load-carrying capacity of the member are significantly increased, even for a new reinforced UHPFRC layer of 5 cm.

Optimum combinations of reinforcement bars (quantity and strength) and UHPFRC layer thickness can be designed in order to provide an efficient and safe reinforcement of structural members, with compact cross sections Habel (2004). *With this respect, a new layer of 5 cm thickness appears to be a good and economical compromise in association with reinforcement bars.*

The thickness of the UHPFRC layer to be applied also depends on the roughness of the surface to be overlaid. A minimum roughness of 0.5 cm with a wavelength of 1 to 1.5 cm appears to be sufficient to provide a monolithic behaviour of the composite members.

On another hand 1.5 cm is the minimum cover necessary to provide a sufficient protective function with an objective of over 100 years durability, for the underlying structure or reinforcement bars embedded in the UHPFRC layer. Further, depending on the diameter of the *rebars embedded in the UHPFRC this cover should be sufficient to avoid bond cracks. A minimum cover equal to the rebar diameter is recommended with this respect.*

Finally, if active cracks are present in the concrete substrate, a minimum UHPFRC thickness of 3 cm should be applied, to provide a sufficient structural hardening behaviour.

4.3 Classification of applications

Two basic types of applications of UHPFRC for the rehabilitation of existing structures can be distinguished:

- Prefabrication of new elements such as kerbs
- Cast-in place UHPFRC

In both cases, the most important load cases at serviceability shall be: eigenstresses induced by restrained shrinkage and fatigue under traffic loads. Table 1 summarizes the classes of requirements as function of the degree of restraint and severity of traffic loads (number of vehicles per day).

Table 1: Classes of mechanical loading for UHPFRC in composite structures

Class	Application	Degree of Restraint μ [––]	Traffic load	Example
A	Prefabrication	0	None	Precast kerb elements
B	Cast-in-place	0.4 to 0.6 moderate	Moderate	Overlay on deck slab of box-girder bridge
C	Cast-in-place	0.4 to 0.6 moderate	High	Overlay on deck slab of box-girder bridge
D	Cast-in place	0.75 – high	Moderate	Overlay on “multiple beam bridge”
E	Cast-in place	0.75 – high	High	Overlay on “multiple beam bridge”
F	Cast in-place	0.8 to 0.9 very high	None	Cast-in place kerbs
G	Cast-in place	0.8 to 0.9 very high	Moderate	Overlay on “multiple beam bridge”
H	Cast-in place	0.8 to 0.9 very high	High	Overlay on “multiple beam bridge”

4.4 Requirements

Following the experiences gathered during the project in laboratory tests, numerical simulations and practical applications on site, requirements for the quality of UHPFRC in composite structures are proposed in Table 2.

In all cases, the basic requirements are: outstanding protective function (determined on the basis of air permeability tests for instance as described in Appendix 3), no localized macro-cracks, and minimum fibre dosage of 1.5 % vol. (for steel fibres).

These requirements are based on experiences with a single type of UHPFRC (CEMTEC$_{multiscale}$® with a pure Portland cement and high quantity of steel fibres with a moderate aspect ratio of 50).

Further research will be needed to extend this table to other types of UHPFRC with different kinds of binders and fibrous mixes.

Table 2: Requirements for UHPFRC in composite highway structures

Class	Tensile strength f_t [MPa]	Strain hardening ε_{peak} [‰]	Shrinkage at 3 month [‰]	Workability
A	8 to 10	No limits	No limits	Self-compacting - fluid Self-levelling
B	11	1	0.6 max.	Self-compacting Tolerance to slope
C	11	2	0.6 max.	Self-compacting Tolerance to slope
D	14	1.5	0.6 max.	Self-compacting Tolerance to slope
E*	14	2	0.6 max.	Self-compacting Tolerance to slope
F**	14	1.5	0.6 max.	Self-compacting - fluid Self-levelling
G	14	2	0.6 max.	Self-compacting Tolerance to slope
H*	14	2	0.6 max.	Self-compacting Tolerance to slope

Notes:

- All mechanical properties are average values at 28 days.
- Tensile strength is the maximum value of the stress obtained in an unnotched uniaxial tensile test such as described in Appendix 2
- Strain hardening is the total deformation at the peak stress under uniaxial tension, determined as the average value on a measurement basis of 3 times the width of the specimen, as described in Appendix 2
- Determination of mechanical properties on specimens cast according to the direction of casting in application.

Additional requirements:

- *For high traffic loads, in classes E and H, partial fibrous reinforcement by high-bond profiled fibres (non straight-smooth) is recommended.
- **For casting of plain kerb elements on site, class F, the thermo mechanical effects at early age can play a significant role depending on the thickness of the element.
- In classes A, E and F, the kerb must be designed with reinforcement bars and proper connection to the superstructure of the bridge to support the accidental actions in case of vehicles accidents (shocks).
- In those cases, suitable mixes and geometries of application must be studied and validated by preliminary laboratory tests and/or numerical simulations.

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APPENDIX 1 – STRUCTURAL BEHAVIOUR OF COMPOSITE MEMBERS UNDER RESTRAINED SHRINKAGE

(Adapted after Denarié et Silfwerbrand (2004))

The easiest way to explain the notion of restraint is by studying a composite beam exposed to differential shrinkage. This analysis was done first by Silfwerbrand (1997) and further refined by Bernard (2000) to distinguish the contribution of the various degrees of freedom, as shown on Figure 8, for a statically determinate beam, with $\sigma_{new,2}$ [MPa]: tensile stress in the new layer at the interface, μ [-]: degree of restraint, E_{new} [MPa]: modulus of elasticity of the new layer, ε_{free} [-]: mean shrinkage strain in the new layer.

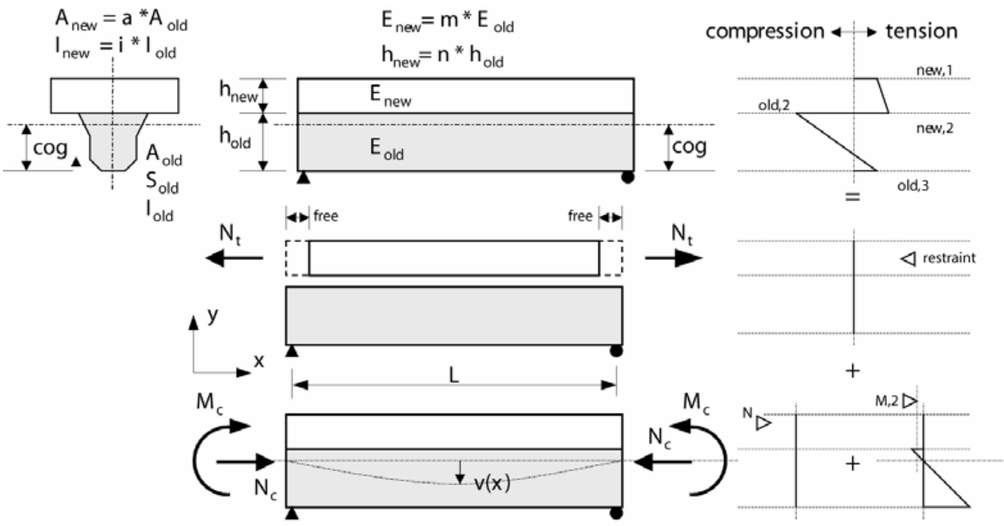


Figure 8: Eigenstresses in a statically determinate composite member, combination of axial (σ_N) and flexural ($\sigma_{M,2}$) release effects, adapted from Bernard (2000).

The degree of restraint is calculated under the following hypotheses: linear-elastic material behaviour, Poisson's ratio ν =0, cross-section of the new layer is a rectangle, the cross-section of the substrate can be of any shape, plane sections remain plain (hypothesis of Bernoulli), perfect bond between new layer and substrate.

The principle of the analysis consists in determining the tensile force N_t that is necessary to compensate the unrestrained shrinkage deformation ε_{free} in the new layer. The tensile force is balanced in the composite member by a compressive force N_c and a bending moment M_c acting at the centre of gravity (cog) of the composite section. The stress state in the composite element is determined by the superposition of the resulting effects of N_t,, N_c and M_c on the composite cross section.

The degree of restraint is defined as "1" minus the axial release minus the flexural release, equation (2), *to clearly associate the notion of degree of restraint to the effect of release of the stresses for each degree of freedom available.*

$$\mu = \frac{\sigma_{new,2}}{\sigma_{full}} = \frac{\sigma_{full} - \sigma_N - \sigma_{M,2}}{\sigma_{full}} = 1 - \mu_N - \mu_M \quad (2)$$

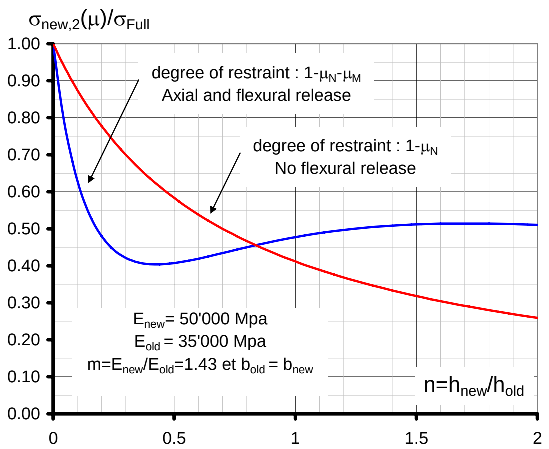
The individual expressions of the release factors are:

$$\mu_N = \frac{m \cdot a}{m \cdot a + 1} \quad (3)$$

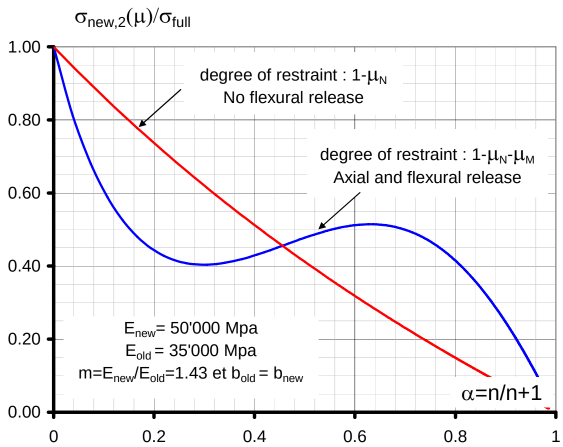
$$\mu_M = \frac{N_t (cog_{new} - cog)}{W \cdot \sigma_{full}} = \frac{A_{new} \cdot (cog_{new} - cog) \cdot [m \cdot (h_{old} - cog)]}{[I_{old} + A_{old} (cog - cog_{old})^2 + m \cdot (I_{new} + A_{new} (cog_{new} - cog)^2)]} \quad (4)$$

$$cog = \frac{S_{old} + m \cdot S_{new}}{A_{old} + m \cdot A_{new}} \quad \text{Centre of gravity (cog) of the composite section} \quad (5)$$

The graphical representation of equations (2) to (4) is shown on Figure 9 for m=1.43 (E_{new}= 50 000 MPa – UHPFRC and E_{old}=35 000 MPa – concrete substrate) and rectangular sections of similar width for the old and new layers ($b_{old}=b_{new}$) . Two representations are shown, one a), with the ratio of the layer thicknesses n, and the other b) with the ratio α between the thickness of the new layer and the total thickness of the composite section as x-axis. In each diagram, two cases are illustrated: (1) axial and flexural release: finite axial and flexural stiffness of the composite system, (2) no flexural release: finite axial stiffness and infinite flexural stiffness of the composite system.



a)



b)

Figure 9: Restraint between axial and flexural effects as a function of a) $n=h_{new}/h_{old}$ and b) $\alpha=h_{new}/(h_{old}+h_{new})$, after Denarié et al. [5].

The range of most cases encountered in practice corresponds to the domain shown on Figure 9a with parameter n on the x-axis. For the chosen set of parameters, the degree of restraint with axial and flexural release varies in a significant way for values of n smaller than 0.3. For values of n larger than 0.3, the overall degree of restraint is almost constant equal to 0.4-0.5.

Silfwerbrand (1997) generalized this observation to different combinations of materials, as shown on Figure 10.

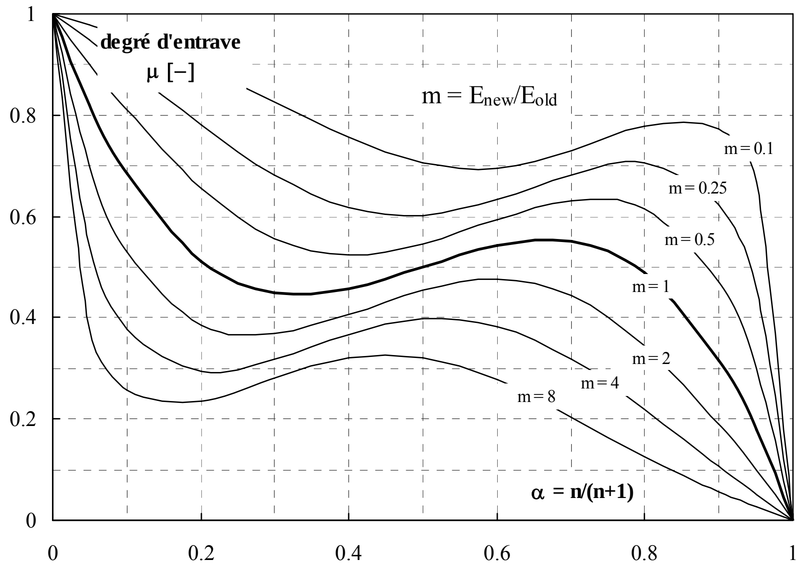


Figure 10: Degree of restraint as a function of relative thickness and relative stiffness, after Silfwerbrand (1986) and Bernard (2000).

In statically indetermined structures, the degree of restraint is increased as the corresponding degree of freedom is progressively limited. If flexural release of stresses is impossible, the release factor μ_M becomes 0, as illustrated on Figure 9 (case "no flexural release"). The same applies for axial release. However, the complete restraint of axial forces is seldom encountered in practice.

Creep has a beneficial effect on the developed stresses due to differential shrinkage. For UHPFRC, a global creep coefficient of 0.8 at long term is mentioned in the litterature, AFGC (2002). At early age (7 first days after casting), the creep is in the order of magnitude of the half of the autogenous shrinkage. It is thus a good estimation to consider an overall creep coefficient of 0.8 for UHPFRC or a creep deformation equal to the half of the imposed shrinkage for simple calculations such as illustrated by the following example.

→ *New UHPFRC overlay of 3 cm applied on an existing concrete slab of 15 cm thickness.*

Geometrical and material data: n=3 cm/15 cm = 0.2, α=0.17, E_{new}/E_{old} = 50000/35000 MPa=1.43, ε_{free} = 0.60 mm/m, ε_{creep} = 0.30 mm/m

Case a) Full restraint $\mu = 1$ → $\sigma_{full} = E_{new}\ \varepsilon_{free}$ = 50000*0.6/1000=**30 MPa**.

Case b) Axial and flexural release available, with neglected creep → m = 1.43, μ = 0.45 and σ = 0.45* 50000*0.6/1000= **13.5 MPa.**

Case c) Axial release only available, with neglected creep → m = 1.43, μ = 0.75 and σ = 0.45* 50000*0.6/1000= **22.5 MPa.**

Case d) Axial and flexural release available, with creep

→ σ= 0.45*50000*(0.6-0.3)/1000=**6.7 MPa**

Case e) Axial release only, with creep

→ σ_1 = 0.75*50000*(0.6-0.3)/1000=**11.3 MPa.**

The maximum normal stress diminishes from 30 to 6.7 or 11.3 MPa. This calculation is however very rough and does not consider the fact that viscoelasticity is significantly higher at early ages, when a large part of the autogenous shrinkage occurs. Finer estimates with comprehensive time-dependent viscoelastic models show that the eigenstresses induced in UHPFRC overlays at long term are approximately 30 % smaller than the values estimated by this simple calculation.

APPENDIX 2 - UNIAXIAL TENSILE TEST

The following instrumented uniaxial tensile test is proposed to determine in perfectly rigid conditions the stress-strain response and the displacement field over a prism of constant cross section of 350 mm length, in the central part of an unnotched dog bone shaped specimen (l= 700 mm, minimum cross section: 50 x 100 mm). The specimen is held in place by means of the "glueing without bonding" technique developed by Helbling and Brühwiler (1987), and applied by Habel (2004) to notched UHPFRC plates of constant cross section. The shape of the proposed specimen is illustrated on Figure 11

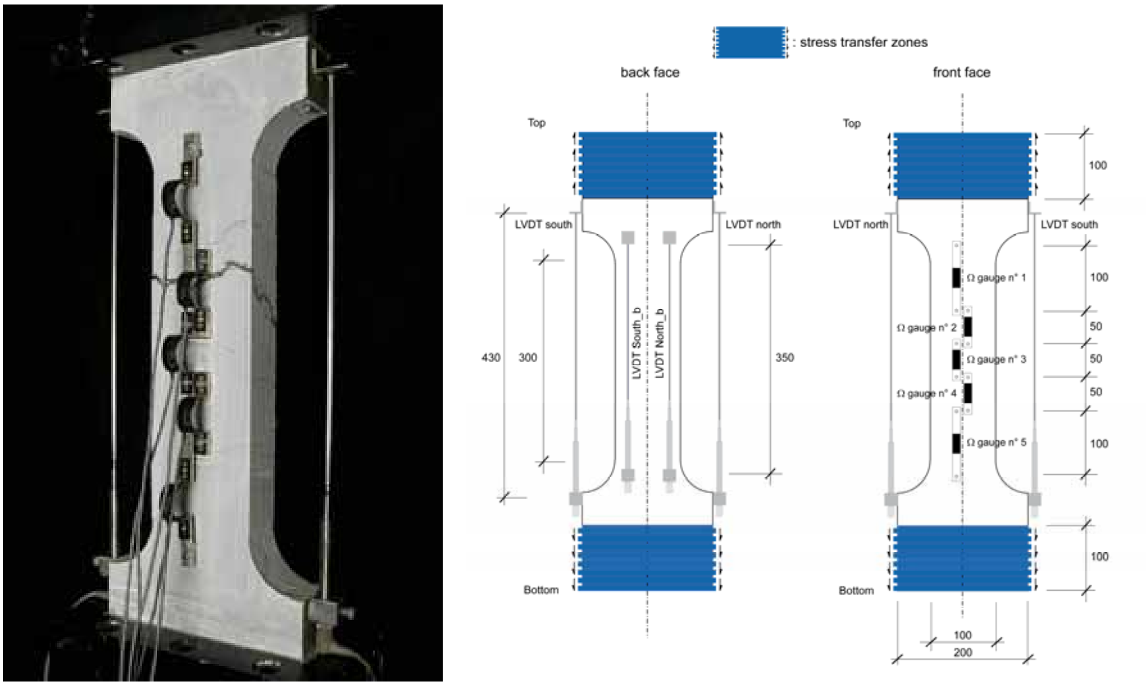


Figure 11: Unnotched tensile test on dog-bone specimens, Denarié et al. (2006), units: mm.

The surface of the specimens is coated with lime to highlight fine cracks. Multiple cracking is to be observed on the specimens, in the tensile hardening domain and correlated with the readings of the Omega gauges distributed over the length of the specimen. More specifically, the distributed character of the deformations and crack has to be characterized in the strain hardening domain. The test is run in a servo controlled hydraulic testing machine with a speed of displacement of 0.02 mm/minute in the hardening domain and 0.2 mm /minute in the softening domain. It is recommended to perform at least 5 tests, at 28 days to characterize both the tensile strength and the tensile hardening behaviour of the material.

APPENDIX 3 – AIR PERMEABILIY TESTS

Torrent et al. (1992), (1995) proposed the Torrent Permeability Tester – TPT, described in Figure 12. This two-chamber device has been validated and used extensively for more than 10 years in Switzerland and other countries. Its application is recommended and described in the most recent Swiss codes for reinforced concrete structures, SIA 262 (2003), SIA 262/1 (2003). Its main advantages are its fully non-destructive character and its ease of operation. The two-chamber design of the permeability cell guarantees an air-intake perpendicular to the concrete surface in the zone of the central chamber. The air permeability index *kT* is calculated automatically by the device, according to the model from Torrent et al. (1995), on the basis of the air flow in the inner chamber, where the pressure measurements are made. The standard duration of a test is 12 minutes. The effect of the degree of moisture saturation of moist concretes is taken into consideration by the subsequent measurement of the electrical resistivity ρ according to Wenner, in the same zone. The very low moisture content of UHPFRC exempts from determining the electrical resistivity and the classification can be done on the basis of the air permeability.

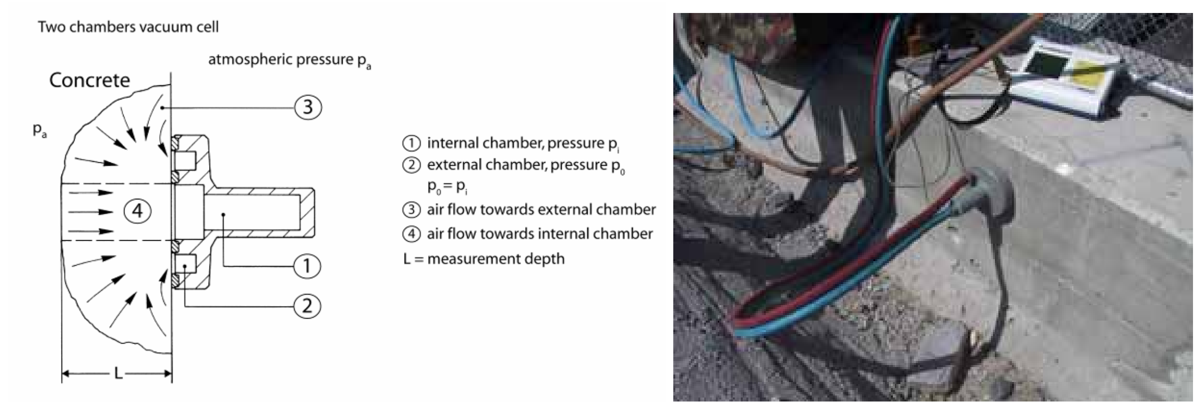


Figure 12: Torrent air permeability tester.

Figure 13 shows the permeability classes and a comparison of the air permeabilities of UHPFRC and two types of concretes. The UHPFRC cast in the laboratory and on site (SAMARIS D22 (2005) exhibit excellent protective properties with a very low permeability.

Following recommendations can be made for the application of the air permeability tests to UHPFRC:

- Target value of air permeability after Torrent at 7 days: 0.005 10^{-16} m^2 for 75 % fractiles, for outstanding protective function.
- Minimum number of measurements on different locations on same element: 6

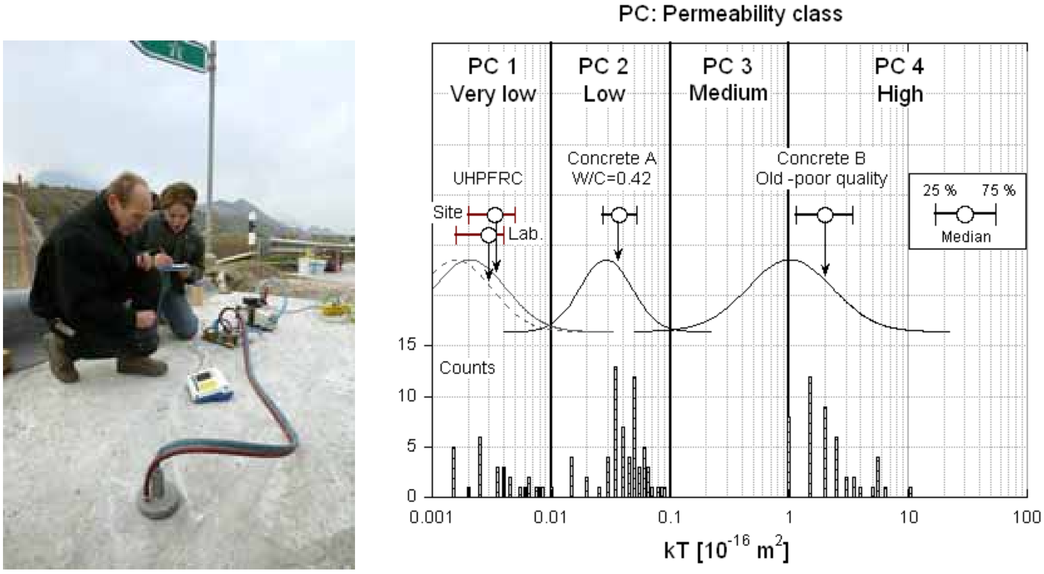


Figure 13: Air permeability measurements on a UHPFRC overlay cast on site and results

APPENDIX 4 – UHPFRC MATERIALS – GENERAL

The mechanical properties of UHPFRC are dramatically improved with respect to normal concrete. Their compressive strength, measured on 11 x 22 cm cylinders at 28 days varies from 160 up to 250 MPa. Their modulus of elasticity varies between 48 and 60 GPa.

Depending on their composition, fibrous reinforcement, and mode of curing, their tensile strength varies from 9 up to 20 MPa, with a strain hardening domain up to 0.2 %.

Three different recipes of the UHPFRC $CEMTEC_{multiscale}$® were used during the project SAMARIS, with similar components (Cement CEM I 52.5, Microsilica, fine sand D_{max}=0.5 mm), with a Microsilica/Cement ratio of 0.26.

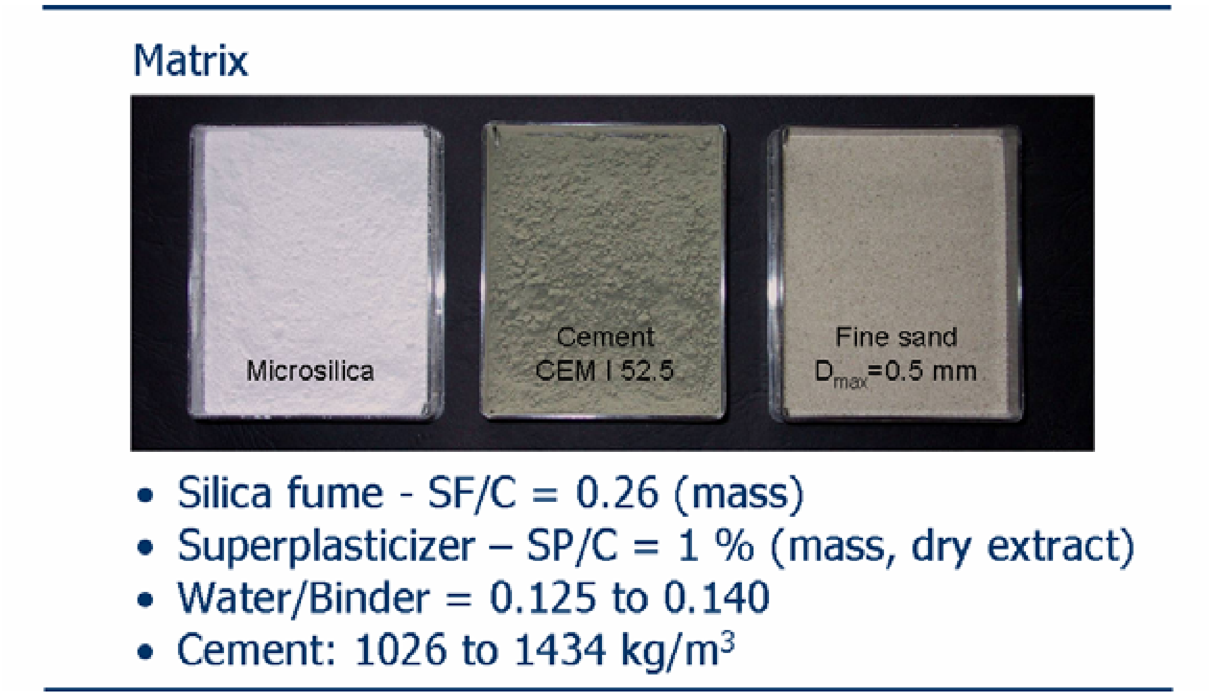


Figure 14: UHPFRC matrix: components and dosages

Various types of UHPFRC exist with different kinds of fibre mixes. With only one type of fibres, a compromise has to be found between the tensile behaviour pre and post peak, with limited strain hardening. On the contrary, the combination of multiple types of fibres with different length, Rossi et al. (2002), Parant (2003), creates a multilevel reinforcement that induces significant tensile strain hardening (up to 0.2 %), and multiple cracking under tension.

The fibrous reinforcement necessary to obtain a strain hardening response in uniaxial tension can be compared to the necessary "minimum reinforcement" in reinforced concrete structures, to control cracking.

The reinforcement of the ultra compact matrices was provided either by a single type of fibres (l_f=10 mm, aspect ratio: 50) with a dosage of 457 kg/m^3, or by a mix of micro (steel wool – 1 mm length) and macrofibres (l_f=10 mm, aspect ratio: 50) with a total dosage of 706 kg/m^3 (9% vol.).

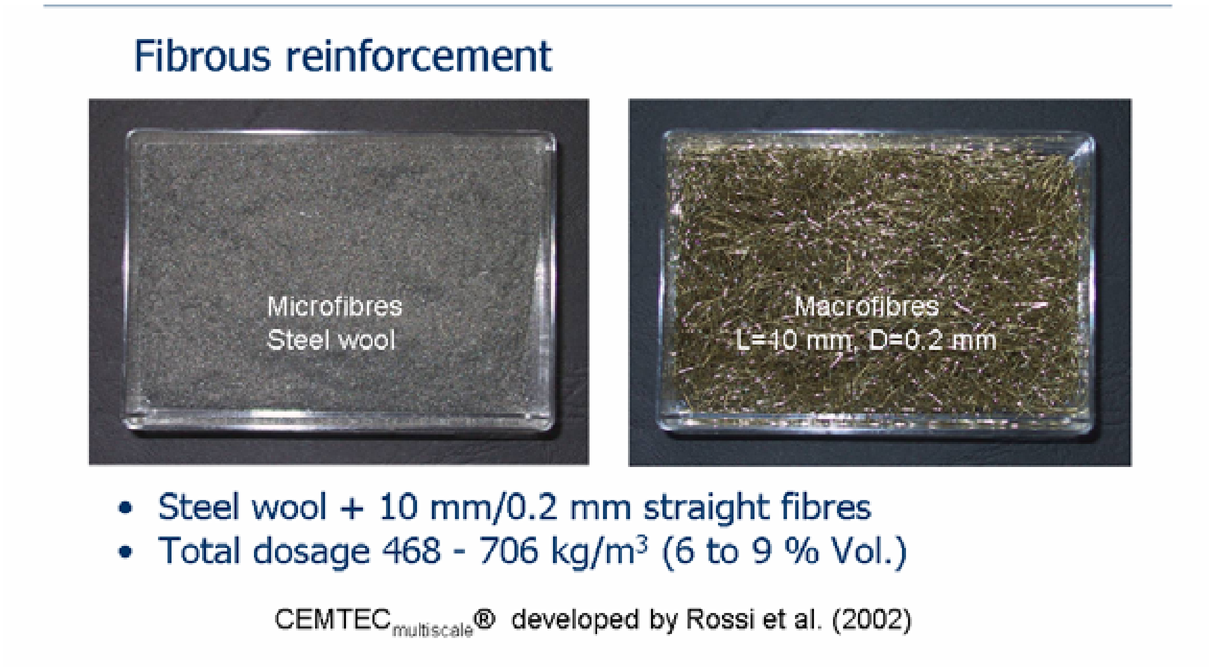


Figure 15: UHPFRC fibrous mix: components and dosages

For the laboratory tests, two different types of UHPFRC were used: mix CM0 (monofibrous reinforcement) and mix CM22 (bi-fibrous reinforcement).

Recipe CM0 is reinforced with a single type of 10 mm long steel fibres with an aspect ratio of 50. It has a water/binder ratio of 0.140, 1041 kg/m^3 cement, a fluid consistency (slump-flow = 700 mm) and is self-compacting and self-levelling.

Recipe CM22 (1410 kg/m^3 cement, Water/Binder ratio of 0.131) had been optimized in the laboratory for its tolerance to a slope of 2.5 %, and used for laboratory tests on structural members. As expected, the size effect on the volume of the batches from laboratory (40 litres) to production plant (300 litres) increased the workability for a similar composition. *Thus, this recipe optimized in the lab, on small batches turned out to be too fluid for tolerating a slope when produced in larger batches (>200 litres). It was used*

A new recipe, less fluid, CM23, was designed and produced in the prefabrication plant, with a lower Water/Binder ratio of 0.125 and 1434 kg/m^3 cement, and tested to guarantee a tolerance to a slope of 2.2 %. *This material was used for the prefabricated downstream kerb and for the watertight overlays on the bridge deck of the first application.*

The uniaxial tensile behaviour (average curves at 28 days, determined on unnotched dog-bone specimens) of the two recipes CM0 and CM23 of the UHPFRC used during the project (CEMTEC$_{multiscale}$®) is presented on Figure 16, showing the range of possible tensile strength and strain hardening responses.

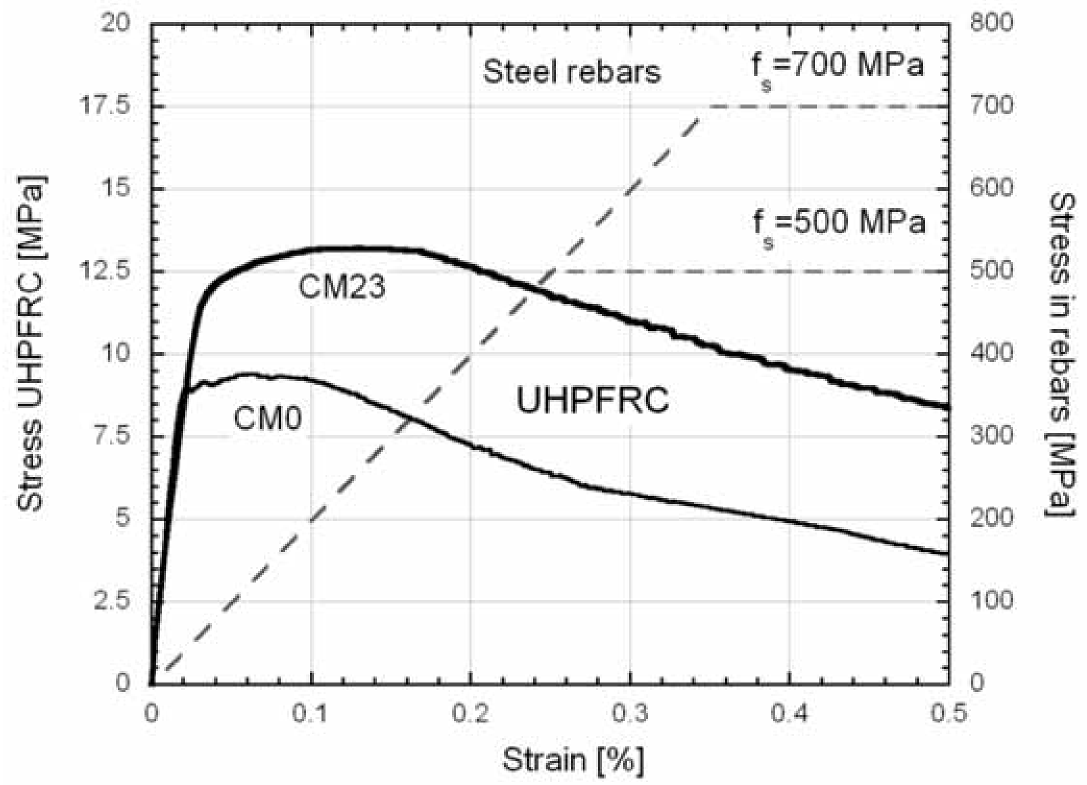


Figure 16: Comparative uniaxial tensile behaviour of UHPFRC (two recipes) and reinforcement bars

The UHPFRC recipes used in this study belong to the family CEMTEC$_{multiscale}$® developed by Dr. P. Rossi – LCPC Paris [5], and modified at MCS-EPFL for the application to rehabilitation. CEMTEC$_{multiscale}$® *recipes are covered by the French patent applications #FR2806403 and #FR2806404 (both published on 9th September 2001) and by the PCT patent application WO0168548 (published on 9th September 2001).*

Other kinds of UHPFRC are of course available on the market or in laboratories, with more or less pronounced strain hardening behaviour. On another hand, basic requirements for the properties of UHPFRC applied to rehabilitation are known at this stage. It is certain that in a near future, optimized UHPFRC will emerge able to provide the necessary protective and mechanical performances with lower costs.

One must also emphasize that UHPFRC applied in thin layers of 2 to 5 cm in composite UHPFRC-concrete constructions are already a competitive solution in terms of costs (see report SAMARIS D22 (2005)).

In terms of prices per m^3, UHPFRC are clearly much more expensive than normal concretes (10 to 15 times). However, for the rehabilitation application the price per m^2 is a much more relevant indicator. In this case, the construction costs of a solution with a thin UHPFRC layer and no waterproofing membrane are equivalent to those of a traditional solution with repair mortar and waterproofing membrane. Further, the UHPFRC solution provides a much longer durability and helps minimize the amount of interventions on the structure during its service life, even beyond 100 years.

APPENDIX 5 – UHPFRC RECIPES - EXAMPLES

Component	Fibres [%]	ρ [kg/m³]	Mass [kg/m³]	Volume [l/m³]
Powders				
Cement		3'140	**1'041**	332
Microsilica (SF)		2'200	**271**	123
(Fine sand + quartz)		2'680	**725**	271
Added water		1'000	**163**	161
Steel fibres 10/0.2 mm	5.9	7'850	**463**	59
Admixture Superplasticiser		1'055	**34.8**	33
Dry extract 30 %			10.4	
Water 70 %			24.3	
Total water		1'000	187	187
Air				20
Total	**5.9**		**2'698**	**1000.0**

Water/(Cement + SF)	**0.140**
Water/Cement	**0.180**
Admixture/Cement	**0.033**
SF/Cement	**0.260**

Table 3: Composition of material CM0

Note: The UHPFRC recipes used in this study belong to the family CEMTEC$_{multiscale}$® developed by Dr. P. Rossi – LCPC Paris, and modified at MCS-EPFL for the application to rehabilitation. CEMTEC$_{multiscale}$® *an recipes are covered by the French patent applications #FR2806403 and #FR2806404 (both published on 9th September 2001) and by the PCT patent application WO0168548 (published on 9th September 2001).*

Component	Fibres [%]	ρ [kg/m³]	Mass [kg/m³]	Volume [l/m³]
Powders				
Cement		3'140	**1'410**	449
Microsilica (SF)		2'200	**367**	167
(Fine sand + quartz)		2'680	**80**	30
Added water		1'000	**200**	200
Steel wool[1]		7'850	**706**	90
Steel fibres 10 mm		7'850		
Admixture Superplasticiser		1'055	**46.5**	44.1
Dry extract 30 %			14.0	
Water 70 %			32.6	32.6
Total water		1'000	232.7	233
Air				20
Total	**9**		**2'810**	**1'000.0**

Water/(Cement + SF)	**0.131**
Water/Cement	**0.165**
Admixture/Cement	**0.033**
SF/Cement	**0.260**

Table 4: Composition of material CM22

Note: The UHPFRC recipes used in this study belong to the family CEMTEC$_{multiscale}$® developed by Dr. P. Rossi – LCPC Paris, and modified at MCS-EPFL for the application to rehabilitation. CEMTEC$_{multiscale}$® *an recipes are covered by the French patent applications #FR2806403 and #FR2806404 (both published on 9th September 2001) and by the PCT patent application WO0168548 (published on 9th September 2001).*

1 The detailed composition of the fibrous mix is patent protected and is available upon request, with a license of exploitation.

Component	Fibres [%]	ρ [kg/m³]	Mass [kg/m³]	Volume [l/m³]
Powders				
Cement		3'140	**1'434**	457
Microsilica (SF)		2'200	**373**	169
(Fine sand + quartz)		2'680	**80**	30
Added water		1'000	**189**	189
Steel wool[2]		7'850	**706**	90
Steel fibres 10 mm		7'850		
Admixture Superplasticiser		1'055	**47.3**	44.8
Dry extract 30 %			14.2	
Water 70 %			33.1	
Total water		1'000	222	222
Air				20.0
Total	**9**		**2'829**	**1'000.0**

Water/(Cement + SF)	**0.123**
Water/Cement	**0.155**
Admixture/Cement	**0.033**
SF/Cement	**0.260**

Table 5: Composition of material CM23

Note: The UHPFRC recipes used in this study belong to the family CEMTEC$_{multiscale}$® developed by Dr. P. Rossi – LCPC Paris, and modified at MCS-EPFL for the application to rehabilitation. CEMTEC$_{multiscale}$® *an recipes are covered by the French patent applications #FR2806403 and #FR2806404 (both published on 9th September 2001) and by the PCT patent application WO0168548 (published on 9th September 2001).*

2 The detailed composition of the fibrous mix is patent protected and is available upon request, with a license of exploitation.

APPENDIX 6 MATERIAL SUPPLIERS (UHPFRC) – (CH)

Component	Type	Supplier
Cement	CEM I 52.5 N HTS CE PM-ES-CP 2, Lafarge, Le Teil	Proz Frères SA, matériaux de construction, CH-1908 Riddes, Switzerland Mr. M.A. Proz **Tel.: +41 27 305 15 15** **Fax. : +41 27 305 15 20** **marc-andre@proz.ch**
Microsilica	SEPR (mean diameter 0.5 µm) Specific surface 12 m^2/g, SiO2 > 93.5 %, white	SEPR, B.P. 40, F-84131 Le Pontet Cedex, France Mr Detalle **Tel.: +33 4 90 32 70 17** **Fax. : +33 4 90 32 71 47** **jean-marie.detalle@saint-gobain.com**
Fine quarz sand	Fontainebleau sand type MN30 (SiO_2>5%), D_{max} < 0.5 mm	Gilbert Gauthier SA, Case Postale 139, CH- 1225 Chêne-Bourg/Genève, Switzer-land Mr. Richard **Tel.: +41 22 348 08 45** **Fax. : +41 22 348 73 25**
Steel fibres	Straight l_f=10 mm, d_f=0.2 mm	Redaelli tecna, Zona Ind. – Localita Pasca-rola, I-80023 Caivano (Napoli, Italy) Mr Mignosi **Tel.: +39 - 081 88 94 246** **Fax. : :+39 -081 83 49 333** **g.mignosi@redaellitecnasud.com**
Steel wool	Crushed steel wool . ref. FbGV2 Code LALACD.BR	Gervois, 1, rue Boucher de Perthes, F-80580 Pont-Remy, France, Mr. Riquiez **Tel.: +33 3 22 27 11 22** **Fax. : +33 3 22 27 14 27** **gervois01@hexanet.fr**
Superplasti-ciser	Chrysofluid OPTIMA 175	Difutec SA, chemin St-Hubert 37, CH-1950 Sion, Switzerland Mr. Joye **Tel.: +41 27 322 58 84** **Fax. : +41 27 322 58 86** **difutec.sa@bluewin.ch**

APPENDIX 7 – TECHNICAL SPECIFICATIONS OF THE CONCRETE MIXER USED FOR THE FIRST APPLICATION

Mixer type: Teka THZ 750 pan mixer (http://www.conspare.com/index.cfm?id=441)

	Teka THZ **750**	
Füllmenge Mischer	Liter	**750**
Füllmenge Zuschlagstoffe	Kg	**1200**
Festbetonausstoß pro Spiel	m^3	**0,5**
Antriebsleistung Mischer	KW	**22**
Drehzahl Rotor	UpM	**29**
Leergewicht Standardmischer	Kg	**2500**
Füllung Beschickerkübel Aufzug 60°	Kg	**1100**
Antriebsleistung Beschicker		
mehrlagige Seiltrommel	KW	**5,5**
einlagige Seiltrommel	KW	**7,5**
Geschwindigkeit Beschickerkübel	m/Sek	**0,4**
Leergewicht Beschicker	Kg	**1000**

APPENDIX 8 - PRECAUTIONS FOR THE PRODUCTION AND USE OF CEMTEC$_{\text{MULTISCALE}}$®

- The compatibility between the cement, the superplasticiser and the silica fume to achieve the target values of workability, mechanical performances and protective function should be tested on small scale batches before realising larger batches.
- The concrete mixer should not be pre-wetted before the filling with the raw components of the UHPFRC.
- The barrel of the concrete truck should not be pre-wetted before the filling with the fresh UHPFRC.
- Safety precautions to be followed are identical to those prescribed for the production of normal concretes with silica fume.
- During all steps of the production and casting of the UHPFRC and after its hardening, special care has to be taken to protect the skin and eyes of the personal from injury by protruding short steel fibres (10 mm long). During the handling of 10 mm long short steel fibres, during the mixing and pouring of the UHPFRC, and during the cleaning of the batching equipments (mixer, etc.) and of the moulds and forms when the UHPFRC has hardened, it is mandatory to protect the eyes of the operators with fully covering glasses from accidental projection of fibres in the face. Further, the aspect ratio of the 10 mm long steel fibres makes them especially prone to penetrate under the skin. For this reason, the use of thick protection gloves is mandatory during all steps of the production process of UHPFRC.
- The duration of mixing of the 10 mm long steel fibres has to be, according to the performances of the mixer, sufficient to insure a uniform dispersion of the fibres in the UHPFRC, but short enough in order to avoid the formation of agglomerates of fibres.
- The presence of protruding steel fibres on the surface can constitute a danger during the handling of hardened UHPFRC specimens (for the personal and for the lifting equipments such as slings). Hardened UHPFRC specimens shall be cautiously examined before manipulation.
- Free surfaces of fresh UHPFRC shall be protected from desiccation as soon as possible. Due to its extremely low W/B ratio, and to the small thickness of the layers applied for rehabilitation applications, UHPFRC overlays are very sensitive to desiccation. A plastic foil shall be applied on the fresh UHPFRC as soon as possible after casting. A moist curing (daily spraying of water) of 8 days shall then be applied as soon as the material is hardened (around 30 hours after contact between binders and water for the UHPFRC recipes described in this report).

APPENDIX 9 - BATCHING SEQUENCE OF CEMTEC$_{\text{MULTISCALE}}$®

- Add cement, microsilica and steel wool (if applicable) in dry mixer.
- Mix for 2 minutes, then stop mixer.
- Add fine quartz sand.
- Mix for one minute.
- Add all water followed by all superplasticiser while mixer runs.
- Let mixer run until getting a homogeneous mix, with liquid consistency (duration around 4 minutes with mixer used for this application – see description in Appendix 4).
- Stop mixer and add half the quantity of short steel fibres (10 mm).
- Mix for 30 seconds until all fibres are properly coated and dispersed.
- Stop mixer and add second half of the fibres.
- Mix for 30 seconds until all fibres are properly coated and dispersed.

Note: the first batch, in the dry mixer, always shows a stiffer consistency than subsequent batches with the same UHPFRC.