Standard

NF P18-470

Juillet 2016

1st issue: -

P18-470

www.afnor.org

Concrete - Ultra-high performance fibre-reinforced concrete - Specifications, performance, production and conformity

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ISSN 0335-3931

French standard

NF P 18-470
29 July 2016

Classification index: **P 18-470**

ICS: 91.100.30

Concrete — Ultra-high performance fibre-reinforced concrete — Specifications, performance, production and conformity

F : Bétons — Bétons fibrés à Ultra Hautes Performances — Spécification, performance, production et conformité
D : Beton — Faserbewehrte Ultrahochleistungsbetone — Festlegung, Eigenschaften, Herstellung und Konformität

French standard approved

by decision of the Director General of AFNOR.

Correspondence

At the date of publication of this document, there does not exist any work dealing with the same subject.

Summary

This document relates to ultra-high performance fibre-reinforced concrete hereafter referred to as "UHPFRC" intended for use in: precast structures and precast structure elements, structures and structure members cast in place, parts of structures fixed by casting in place, particularly in the case of connections, revetments or repairs, for buildings and civil engineering structures.

Descriptors

Technical International Thesaurus: concrete, fibres, steels, polymers, concrete structures, definitions, classifications, designation, specifications, abrasion resistance, consistency, dimensions, heat treatment, compressive strength, density (mass/volume), composition: property, categories, cements, use, aggregates, water, additives, concrete admixtures, exposure, durability, quality control, conformity tests, compression tests, bend tests, tension tests, abrasion tests.

Modifications

Corrections

Published and distributed by Association Française de Normalisation (AFNOR — French standard institute) — 11, rue Francis de Pressensé — 93571 La Plaine Saint-Denis Cedex — Tel.: + 33 (0)1 41 62 80 00 — Fax: + 33 (0)1 49 17 90 00 — www.afnor.org

Version of 2016-07-P

Standards

Standards are designed to serve as a basis in relations between economic, scientific, technical and social partners.

By nature, application of a standard is voluntary. When stipulated in a contract, it is binding on the parties. Legislation may require all or part of a standard to become compulsory.

The standard is a document defined by consensus within a standardisation body involving representatives of all stakeholders. It is submitted for public consultation prior to adoption.

The standard is regularly reviewed to assess its appropriateness over time.

Any standard is considered to be effective as from the date presented on the first page.

Understanding standards

The reader's attention is drawn to the following points:

Only the verbal form **shall** is used to express one or more requirements that shall be satisfied in order to comply with this document. Such requirements may be contained in the body of the standard or in a so-called "normative" annex. For test methods, the use of the imperative corresponds to a requirement.

Expressions involving the verbal form **should** are used to express a possibility that, while preferred, is not actually necessary in order to comply with this document. The verbal form **may** is used to express practical, but not mandatory advice or suggestions, or permission.

Furthermore, this document may provide additional information aimed at making certain elements easier to understand or use, or at clarifying how such elements are applied, but without actually defining a requirement. These elements are presented as **notes or informative annexes**.

Standardisation commission

Acting within a given field of activity, a standardisation commission features the necessary expertise for preparing French standards and defining France's positions in European and international draft standards. The commission may also prepare experimental standards and technical reports.

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Foreword

The Association Française de Génie Civil (AFGC) (*French Association for Civil Engineering)* published recommendations in January 2002 on the design of structures in ultra-high performance fibre-reinforced concrete (UHPFRC) along with the properties, production and control of the UHPFRC itself. These recommendations were revised to include feedback and to make them compatible with design standard NF EN 1992-1-1 (Eurocode 2). A revised edition was published in June 2013 [1].

Ultra-high performance fibre-reinforced concretes have a ductile performance on flexure obtained by the use of fibres in sufficient quantities to enable structures to be designed without the use of reinforcing steel. In addition, the composition of the UHPFRCs, in particular the high binder content and a water/binder ratio typically less than 0.25, reduces capillary porosity which makes them particularly durable with regard to carbonation, chloride penetration, the action of frost and numerous chemical attacks.

The properties of UHPFRCs make them differ from high and very high performance concretes. They therefore do not come under standard NF EN 206/CN:2014, Eurocode 2 is not sufficient for designing structures incorporating them and standard NF EN 13670/CN [2] is not suitable for the execution of structures in UHPFRC. Taking account of the French experience, working together:

— the AFNOR/P 18B "Concrete" Standards Commission decided to draft the present document such that it is independent of standard NF EN 206/CN:2014;

— the BNTRA/CN EC 2 "Design of concrete structures" Standards Commission decided to draft a standard for the design of structures in UHPFRC NF P 18-710:2016 *Design of concrete structures – Specific rules for ultra-high performance fibre-reinforced concretes (UHPFRC)*, which constitutes a national addition to Eurocode 2 (NF EN 1992-1-1 and its national annex NF EN 1992-1-1/NA);

— the BNTEC P 18E "Execution of concrete structures" Standards Commission decided to draft a standard for the execution of structures in UHPFRC NF P 18-451 *Execution of concrete structures – Specific rules for UHPFRCs*, which supplements and adapts standard NF EN 13670/CN [2].

These three documents based on the recommendations by the AFGC are published with the status of an approved French standard and with the purpose of forming a basis for the drafting of European standards covering the same scope.

UHPFRCs whose composition comes out of the present standard due to their mix-proportions or through the use of components which were not envisaged, may whatsoever satisfy the performance targets of the present standard characterising UHPFRCs, in particular with regard to non-brittleness, strength and high durability. These innovative UHPFRCs are not covered by this document but fall under technical assessment procedures and in particular, ATEX.

Introduction

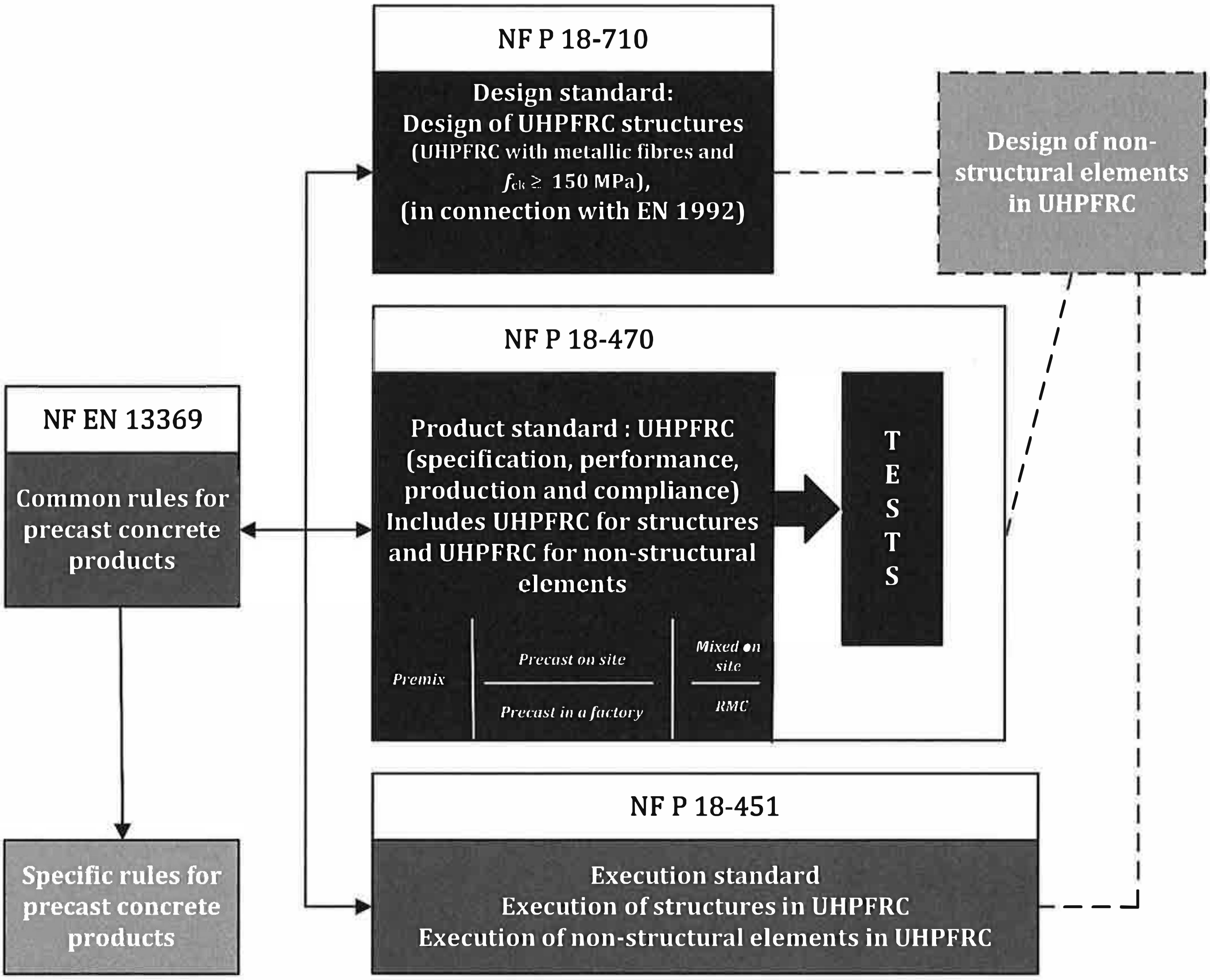
The recommendations of the AFGC on ultra-high performance fibre-reinforced concretes [1] only relate to UHPFRCs intended for structural applications. Taking the French experience into account, these UHPFRCs have a compression strength of at least 150 MPa, expressed in terms of characteristic strength, and their non-brittleness results from the exclusive use of steel fibres although other fibres may also be incorporated in order to obtain a particular performance, for example polypropylene fibres to improve fire resistance.

This standard therefore identifies UHPFRCs of classes 150/165 and above, and containing steel fibres, referred to in design standard NF P 18-710:2016. It also covers UHPFRCs containing other types of fibre or UHPFRCs with a lower strength (130 MPa), not referred to in NF P 18-710:2016. These UHPFRCs may be used in non-structural or architectonic structures. They may also be used in structural applications on condition that they are covered by a technical assessment procedure appropriate to non-traditional installations.

Figure 1 shows the standards architecture making a distinction between:

- on the one hand:
  - this standard which covers and classifies UHPFRCs without prejudging their application domain;
  - standard NF P 18-710:2016 which provides design rules for structures in UHPFRC;
  - standard NF P 18-451[1] which sets out the provisions to be implemented for executing structures in UHPFRC,
- and on the other, the common rules NF EN 13369:2013 and the product standards applying to precast products in UHPFRC,
- and, lastly, documents to be planned and of a status to be specified intended to cover the design and execution of non-structural members in UHPFRC.

1 Being prepared when this standard was published



Key

(black)	Standards published in 2016
(dark grey)	Standard or standard revision to be published end of 2016 or in 2017
(light grey)	Rules not being subject of standard covering UHPFRC at the date of publication of this document

Figure 1 — French normalisation of UHPFRCs - Standards architecture

1 Scope

This standard applies to ultra-high performance fibre-reinforced concretes, hereafter referred to as UHPFRCs, intended for use in:

- precast structures and precast structure elements;
- cast in place structures and structure members;
- parts of structures constituted by cast in place UHPFRC, particularly in the case of connections, overlays or repairs;

for buildings and civil engineering structures.

It also applies to architectonic or non-structural elements whether precast or cast in place.

The UHPFRCs covered by this standard are manufactured and installed in compliance with standard NF P 18-451. They may be manufactured on site or in a ready-mixed concrete plant or even in a precast product manufacturing plant. This standard does not deal with specifications relating to UHPFRCs designed for installation by spraying.

This standard specifies the requirements applicable to the:

- components of the UHPFRCs;
- component premixes if applicable;
- fresh and hardened UHPFRCs and the verification of their properties;
- composition of the UHPFRCs;
- specifications of the UHPFRCs;
- placing and curing of fresh UHPFRC on delivery;
- heat treatment needed to obtain the performance figures, if applicable;
- design trials or the identity card for the UHPFRC;
- suitability tests to be carried out before using a UHPFRC in production;
- production control procedures;
- conformity criteria and the assessment of conformity of the UHPFRC.

This standard is intended to be applied under production conditions covered, for each of the various actors involved, by a quality assurance system dealing with the production of the UHPFRC and related personnel training.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NF P 15-317, *Hydraulic Binders - Sea-water resisting cements*

NF P 15-318, *Hydraulic Binders - Cement with limited sulphides content for use in prestressed concrete*

FD P 18-011, *Concretes - Classification of aggressive environments*[2]

FD P 18-326, *Concrete - Frost zones in France*

NF P 18-451, *Execution of concrete structures – Specific rules for UHPFRC*[3]

NF P 18-459, *Testing hardened concrete - Testing porosity and density*

XP P 18-462, *Testing hardened concrete - Chloride ions migration accelerated test in non-steady-state conditions - Determining the apparent chloride ions diffusion coefficient*

XP P 18-463:2011, *Concrete - Testing gas permeability on hardened concrete*

FD P 18-464, *Concrete - Provisions for the prevention of alkali silica reactions*

FD P 18-503, *Concrete surfaces and facings - Identification elements*

NF P 18-508, *Additions for concrete - Limestone additions - Specifications and conformity criteria*

NF P 18-509, *Additions for concrete - Silicious additions - Specifications and conformity criteria*

NF P 18-513, *Addition for concrete - Metakaolin - Specifications and conformity criteria*

FD P 18-542, *Aggregates - Criteria for qualification natural aggregates for hydraulic concrete with respect to the alkali-reaction*

NF P 18-545, *Aggregates - Defining elements, conformity and coding*

NF P 18-710:2016, *National addition to Eurocode 2 - Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC)*[4]

NF EN 196-1, *Methods of testing cement - Part 1: determination of strength*

NF EN 196-2, *Methods of testing cement - Part 2: chemical analysis of cement*

NF EN 197-1, *Cement - Part 1: Composition, specifications and conformity criteria for common cements*

NF EN 206/CN: 2014, *Concrete - Specification, performance, production and conformity - National addition to the standard NF EN 206*

NF EN 450-1, *Fly ash for concrete - Part 1: Definition, specifications and conformity criteria*

NF EN 933-1, *Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method*

NF EN 934-2+A1, *Admixtures for concretes, mortar and grout - Part 2: Concrete admixtures - Definitions, requirements, conformity, marking and labelling*

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2 Being revised when the present document was published

3 Being prepared when the present document was published

4 Being published when the present document was published

NF EN 1008, *Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete*

NF EN 1770, *Products and systems for the protection and repair of concrete structures - Test methods - Determination of the coefficient of thermal expansion*

NF EN 1990, *Eurocode - Basis of structural design*

NF EN 1992-1-1, *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings*

NF EN 1992-1-1/NA, *Eurocode 2: Design of Concrete Structures - Part 1-1: General rules and rules for buildings – National annex to NF EN 1992-1-1:2005 – General rules and rules for buildings*

NF EN 1992-1-2, *Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design*

NF EN 1992-1-2/NA:2007, *Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design - National annex to NF EN 1992-1-2:2005 - Structural fire design*

NF EN 1992-2:2006, *Eurocode 2 - Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules*

NF EN 12350-5, *Testing fresh concrete - Part 5: Flow table test*

NF EN 12350-7, *Testing fresh concrete - Part 7: Air content - Pressure methods*

NF EN 12350-8, *Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test*

NF EN 12390-1, *Testing hardened concrete - Part 1: Shape, dimensions and other requirements for test specimens and moulds*

NF EN 12390-2, *Testing hardened concrete - Part 2: Making and curing specimens for strength tests*

NF EN 12390-3:2012, *Testing hardened concrete - Part 3: Compressive strength of test specimens*

NF EN 12390-7, *Testing hardened concrete - Part 7: Density of hardened concrete*

NF EN 12390-13:2014, *Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression*

NF EN 12620+A1, *Aggregates for concrete*

NF EN 12878, *Pigments for the colouring of building materials based on cement and/or lime - Specifications and methods of test*

NF EN 13263-1+A1, *Silica fume for concrete - Part 1: Definitions, requirements and conformity criteria*

NF EN 13369:2013, *Common rules for precast concrete products*

NF EN 13501-1+A1, *Fire classification of construction products and building elements - Part 1: Classification using test data from reaction to fire tests*

NF EN 13577, *Chemical attack on concrete - Determination of aggressive carbon dioxide content in water*

NF EN 14889-1, *Fibres for concrete - Part 1: Steel fibres - Definitions, specifications and conformity*

NF EN 14889-2, *Fibres for concrete - Part 2: Polymer fibres - Definitions, specifications and conformity*

NF EN 15167-1, *Ground granulated blast furnace slag for use in concrete, mortar and grout - Part 1: Definitions, specifications and conformity criteria*

NF EN 16502, *Test method for the determination of the degree of soil acidity according to Baumann-Gully*

ISO 4316, *Surface active agents - Determination of pH of aqueous solutions - Potentiometric method*

ISO 7150-2, *Water Quality - Determination of ammonium - Part 2: Automated spectrometric method*

NF EN ISO 7980, *Water Quality - Determination of calcium and magnesium - Atomic absorption spectrometric method*

ASTM C230/C230M, *Standard Specification for Flow Table for Use in Tests of Hydraulic Cement*

3 Terms and definitions

For the purposes of the present document, the following terms and definitions apply.

3.1 Terms and definitions reproduced or adapted from standard NF EN 206/CN:2014

3.1.1 General

3.1.1.1
concrete
material formed by mixing cement, coarse and fine aggregate and water, with or without incorporation of admixtures, additions or fibres, which develops its properties by hydration

Note 1 to entry: The concretes covered by this standard are exclusively ultra-high performance fibre-reinforced concretes, as defined in 3.2.1 in standard NF P18-470, and do not necessarily include gravel.

[SOURCE: NF EN 206/CN:2014, 3.1.1.1, modified – Addition of the note]

3.1.1.2
delivery
process of handing over fresh UHPFRC by the producer

[SOURCE: NF EN 206/CN:2014, 3.1.1.3, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.1.3
designed UHPFRC
UHPFRC for which the required properties and additional characteristics if any are specified to the producer who is responsible for providing a UHPFRC conforming to the required properties and additional characteristics

Note 1 to entry: A UHPFRC is always a designed concrete; it cannot be a prescribed concrete to 3.1.1.10 of standard NF EN 206/CN:2014 as compliance with the composition is not sufficient for ensuring the required performance figures are achived.

[SOURCE: NF EN 206/CN:2014, 3.1.1.4, modified – Replacement of "concrete" with "UHPFRC" in the definition and addition of the note]

3.1.1.4
design working life
assumed period for which a structure or a part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

[SOURCE: NF EN 206/CN:2014, 3.1.1.5]

3.1.1.5
environmental actions
those chemical and physical actions to which the UHPFRC is exposed and which result in effects on the UHPFRC or reinforcement or embedded metal that are not considered as loads in structural design

[SOURCE: NF EN 206/CN:2014, 3.1.1.7, modified – Replacement of "concrete" with "UHPFRC" - Addition of "its components" in the definition]

3.1.1.6
precast element
UHPFRC element cast and cured in a place other than the final location of use (factory produced or site manufactured)

[SOURCE: NF EN 206/CN:2014, 3.1.1.8, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.1.7
producer
person or body producing fresh UHPFRC

[SOURCE: NF EN 206/CN:2014, 3.1.1.11, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.1.8
ready-mixed UHPFRC
UHPFRC delivered in a fresh state to the user by a person or body who is not the user; in the sense of this standard it is also:

— UHPFRC produced off site by the user;

— UHPFRC produced on site, but not by the user

[SOURCE: NF EN 206/CN:2014, 3.1.1.13, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.1.9
site-mixed UHPFRC
UHPFRC produced on the construction site by the user of UHPFRC for his own use

[SOURCE: NF EN 206/CN:2014, 3.1.1.15, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.1.10
site (construction site)
area where the construction work is undertaken

3.1.1.11
specification of the UHPFRC
final compilation of documented technical requirements given to the producer in terms of performance, possibly resulting from a number of additional specifications from several specifiers

[SOURCE: NF EN 206/CN:2014, 3.1.1.17, modified – Replacement of "concrete" with "UHPFRC" in the title]

3.1.1.12
specifier
person or body establishing the specification for fresh and hardened UHPFRC

Note 1 to entry: The specifier may be one or more of the following: prime contractor, project owner, contractor or precast manufacturer, according to the terms and conditions of the contract.

[SOURCE: NF EN 206/CN:2014, 3.1.1.18, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2 Constituents

3.1.2.1
addition
finely-divided-inorganic constituent used in the UHPFRC in order to improve certain properties or to achieve special properties

[SOURCE: NF EN 206/CN:2014, 3.1.2.1, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2.2
admixture
constituent added during the mixing process in small quantities related to the mass of cement to modify the properties of fresh or hardened UHPFRC

[SOURCE: NF EN 206/CN:2014, 3.1.2.4, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2.3
aggregate
natural, artificial, reclaimed or recycled granular mineral constituent suitable for use in UHPFRC

[SOURCE: NF EN 206/CN:2014, 3.1.2.5, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2.4
cement
finely ground inorganic material which, when mixed with water, forms a paste that sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water

[SOURCE: NF EN 206/CN:2014, 3.1.2.8]

3.1.2.5
polymer fibres
straight or deformed pieces of extruded, orientated and cut material, which are suitable to be homogenously mixed into UHPFRC

[SOURCE: NF EN 206/CN:2014, 3.1.2.13, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2.6
steel fibres
straight or deformed pieces of cold-drawn steel wire, straight or deformed cut sheet fibres, melt extracted fibres, shaved cold drawn wire fibres or fibres milled from steel blocks, which are suitable to be homogeneously mixed into UHPFRC

[SOURCE: NF EN 206/CN:2014, 3.1.2.17, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.2.7
additives
all products which are incorporated in the UHPFRC other than the cement, aggregates, mixing water, admixtures, mineral additions, pigments or fibres (for example, a product increasing the viscosity or thixotropy of the UHPFRC other than an admixture)

[SOURCE: NF EN 206/CN:2014, 3.1.2.18, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.3 Fresh UHPFRC

3.1.3.1
agitating equipment
equipment generally mounted on a self-propelled chassis and capable of maintaining fresh UHPFRC in a homogeneous state during transport

[SOURCE: NF EN 206/CN:2014, 3.1.3.1, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.3.2
batch
quantity of fresh UHPFRC produced in one cycle of operations of a mixer

[SOURCE: NF EN 206/CN:2014, 3.1.3.2, modified – Replacement of "concrete" with "UHPFRC" in the definition - Removal of ", or quantity poured during 1 min by a continuous mixer"]

3.1.3.3
cubic metre of UHPFRC
quantity of fresh UHPFRC which, when compacted in accordance with this standard, occupies a volume of 1 m^3

[SOURCE: NF EN 206/CN:2014, 3.1.3.3, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.3.4
entrapped air
air voids in UHPFRC which are not purposely entrained

[SOURCE: NF EN 206/CN:2014, 3.1.3.6, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.3.5
fresh UHPFRC
UHPFRC which is fully mixed and still in a condition that is capable of being placed by the chosen method

[SOURCE: NF EN 206/CN:2014, 3.1.3.7, modified – Replacement of "concrete" with "UHPFRC" in the title and the definition]

3.1.3.6
load
quantity of UHPFRC transported at one time and including a batch, a fraction of a batch or several batches

[SOURCE: NF EN 206/CN:2014, 3.1.3.8, modified – Replacement of "concrete" with "UHPFRC", "in a vehicle" by "at one time" and "one or more mixes" by "a mix, a fraction of a mix or several mixes" in the definition]

3.1.3.7
non-agitating equipment
equipment used for transporting UHPFRC without agitation (3.1.3.1)

EXAMPLE A transport hopper.

[SOURCE: NF EN 206/CN:2014, 3.1.3.9, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.3.8
segregation resistance
ability of fresh UHPFRC to remain homogeneous in composition while in its fresh state

[SOURCE: NF EN 206/CN:2014, 3.1.3.11, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.4 Hardened UHPFRC

3.1.4.1
hardened UHPFRC
UHPFRC that is in a solid state and which has developed a certain strength

[SOURCE: NF EN 206/CN:2014, 3.1.4.2, modified – Replacement of "concrete" with "UHPFRC" in the definition]

3.1.4.2
characteristic strength
value of strength above which 95 % of the population of all possible strength determinations of the volume of UHPFRC under consideration, are expected to fall

Note 1 to entry: In standard NF P 18-470, the characteristic strength is estimated from a sample of experimental values assuming a normal distribution.

[SOURCE: NF EN 206/CN:2014, 3.1.5.4, modified – Reformulation of the definition for UHPFRC]

3.1.5 Achievement of performance

3.1.5.1
conformity test
test performed by the producer or user of the fresh UHPFRC according to the provisions of standard NF P 18-470 to assess the conformity of the UHPFRC as part of a suitability test (3.2.2.5) or during a production period

[SOURCE: NF EN 206/CN:2014, 3.1.5.6, modified – Reformulation of the definition for UHPFRC]

3.1.5.2
evaluation of conformity
evaluation of the results of analyses and tests obtained for a UHPFRC as part of a suitability test or during a production period or a fraction of the production period (control period) intended to check the conformity of a UHPFRC with standard NF P 18-470 according to the specifications of the contract

[SOURCE: NF EN 206/CN:2014, 3.1.5.7, modified – Reformulation of the definition for UHPFRC]

3.2 Terms and definitions specific to the present document

3.2.1 General

3.2.1.1
ultra-high performance fibre-reinforced concrete (UHPFRC)
concrete characterised by a high compressive strength, greater than 130 MPa, beyond the scope of NF EN 206/CN:2014, high post-cracking tensile strength giving ductile behaviour under tension and whose lack of brittleness makes it possible to design and produce structures and structure members without using reinforcing steel

Note 1 to entry: To produce certain structures, the UHPFRC may nevertheless contain reinforcing steel (this is then called reinforced UHPFRC) or prestressing steel (prestressed UHPFRC).

3.2.1.2
binder
as envisaged in this document, all components excluding fibres, sand, gravel if any and pigments if any

3.2.1.3
premix of constituents
uniform mix of constituents, of determined and constant composition, produced in the plant, intended for the production of UHPFRC and placed on the market with an identity card (see 3.2.2.1)

Note 1 to entry: These pre-mixtures of constituents are usually called "premixes".

3.2.1.4
total water
sum of added water, including in the form of ice, water already contained in and on the surface of the aggregates, the water in the admixtures, water in additives and additions used in the form of suspensions, appearing in the nominal recipe of the UHPFRC (5.2.1)

3.2.1.5
working time
specified duration, counted from the introduction of water during mixing, for which the UHPFRC keeps the required workability

3.2.1.6
equivalent age
age of the UHPFRC relating to the time during which the UHPFRC shall be kept at the reference temperature of 20°C in order to obtain the same maturity value (characterised by its compression strength) as under real curing and thermal history conditions

3.2.1.7
thin member
member with thickness less than or equal to three times the length of the longest fibres contributing to non-brittleness

3.2.2 Achievement of performance

3.2.2.1
identity card
document associated with the nominal recipe of UHPFRC, its manufacturing principle and treatments which may be carried out after it has been placed, showing all the characteristics of the material to which the producer commits in terms of performance achieved by the UHPFRC when the provisions set out in the identity card are rigorously applied

Note 1 to entry: When it exists and is available before the project suitability test is carried out, the identity card, substitutes in whole or in part to the results of the design tests. It makes it possible to assume that the material will comply with the specified requirements for the project and will save time on detailed studies.

Note 2 to entry: UHPFRCs obtained from a premix of constituents have an identity card.

3.2.2.2
premix producer
person or body producing a premix of constituents (3.2.1.3) intended for marketing accompanied by an identity card (3.2.2.1)

3.2.2.3
user
person or body using fresh UHPFRC, placing it and applying to it any subsequent treatments required in order to obtain the specified performance, in the execution of a construction or an element

3.2.2.4
design test
procedure implemented by the UHPFRC producer comprising the analyses and tests needed to show the ability of a UHPFRC mix to comply with the requirements of the present standard and those of the product, structure or structure member specification mentioned in a given contract

Note 1 to entry: The design test uses, if available, on an identity card of the UHPFRC (3.2.2.1).

3.2.2.5
suitability test
implementation procedure by the producer and user of UHPFRC comprising the analyses and tests, including on a control mock-up, intended to demonstrate the conformity of a UHPFRC to the present standard and to the specifications of the contract under the conditions of execution of the project, product or structure component, with validation of the incidence of the placement.

3.3 Symbols and abbreviations

X0	Exposure class where there is no risk of corrosion or attack
XC1 to XC4	Exposure classes for the risk of corrosion induced by carbonation
XD1 to XD3	Exposure classes for the risk of corrosion induced by chlorides other than those from seawater
XS1 to XS3	Exposure classes for the risk of corrosion induced by chlorides from seawater
XF1 to XF4	Exposure classes for the risk of freeze/thaw attack
XA1 to XA3	Exposure classes for the risk of chemical attack
XH1 to XH3	Classes associated with the prevention of risks due to delayed ettringite formation
Dp+	Improved porosity class defined in 4.2.2
Dc+	Class associated to an improved resistance to the diffusion of chloride ions defined in 4.2.2
Dg+	Classes associated to an improved resistance to the gaseous transfers defined in 4.2.2
XM1 to XM3	Abrasion exposure classes
RM1 to RM3	Abrasion resistance classes associated with the hydraulic flows defined in 4.2.3
Ca, Cv, Ct	Consistence classes defined in 4.3.1
D_{upper}	Largest value of *D* for the largest aggregates actually used in the UHPFRC (present in the UHPFRC and authorised by the specification of the UHPFRC), *D* being the upper sieve size in an aggregate categorised as d/D (NF EN 12620+A1) NOTE For simplicity, in this document, we shall call D_{upper} the upper nominal size of the largest aggregate
STT, TT1, TT2, TT1+2	Heat treatment classes defined in 4.3.3
UHPFRC.../...	Compressive strength classes for the UHPFRCs defined in 4.4.1, the first number equating to $f_{ck,cyl}$ and the second to $f_{ck,cube}$
T1, T2, T3	Tensile behaviour classes defined in 4.4.3
L_f	Length of the longest fibres contributing to non-brittleness
f_{ck}	Characteristic compressive strength of the UHPFRC NOTE When this symbol is used in this standard, it applies either to $f_{ck,cyl}$ or to $f_{ck,cube}$ depending on the case
$f_{ck,cyl}$	Characteristic compressive strength of the UHPFRC determined by tests on cylindrical test specimens
$f_{ck,req}$	Required characteristic value of the compressive strength

$f_{c,cyl}$	Compressive strength of the UHPFRC determined by tests on cylindrical test specimens
$f_{ck,cube}$	Characteristic compressive strength of the UHPFRC determined by tests on cubic test specimens
$f_{c,cube}$	Compressive strength of the UHPFRC determined by tests on cubic test specimens
f_{cm}	Mean compressive strength of the UHPFRC NOTE When this symbol is used in this standard, it applies either to $f_{cm,cyl}$ or to $f_{cm,cube}$ depending on the case
f_{ci}	Result of an individual compressive strength test on the concrete
$f_{ctm,el}$	Mean value of the limit of elasticity under tension
$f_{ctk,el}$	Characteristic value of the limit of elasticity under tension
$f_{ctk,el,req}$	Required characteristic value of the limit of elasticity under tension
$f_{cti,el}$	Individual result of the limit of elasticity under tension
$M_{max,i}$	Individual result of the maximum bending moment during a characterisation by bending test
$M_{m,max}$	Mean result of the maximum bending moment during a characterisation by bending test
M_{ref}	Value of the maximum bending moment calculated using the required constitutive curve under tension
f_{ctf}	Post-cracking tensile strength
f_{ctfm}	Mean value of the post-cracking strength
f_{ctfk}	Characteristic value of the post-cracking strength
f_{ctf}^*	Maximum post-cracking stress according to a simplified law
ε_{el}	Limit of elastic strain under tension
ε_{lim}	Limit of elastic strain under tension taken into account in the response
S_c	Standard deviation
ϕ	Diameter of the test cylinder
K	Orientation factor expressing the mechanical effect of the orientation of the fibres on the post-cracking behaviour under tension
K_{global}	Orientation factor associated with global effects
K_{local}	Orientation factor associated with local effects
γ_{cf}	Partial factor relating to the UHPFRC under tension
γ_c	Partial factor relating to the UHPFRC when compressed
E_{cm}	Mean value of Young's modulus
E	Bending modulus of elasticity defined in E.4.1

4 Classification, designation and coding

4.1 Classes associated with the type of fibres contributing to non-brittleness

The UHPFRC is classified according to the nature of the fibres involved in strain hardening under flexure according to 4.4.3.

The UHPFRC is said to be of type M (metallic) when these are metallic fibres.

The UHPFRC is said to be of type A (other) when these are other fibres, in particular organic fibres.

4.2 Classification according to environmental actions

4.2.1 Exposure classes

4.2.1.1 General

The environmental actions are classified by exposure classes in accordance with Table 1 from standard NF EN 206/CN:2014. The given examples are informative.

The exposure classes explained below result in regulations dealing with the concrete cover and control of cracking detailed in standard NF P 18-710:2016, which supplements standard NF EN 1992-1-1 and its national annex NF EN 1992-1-1/NA for application to structures in UHPFRC, and specifications on the UHPFRC material detailed in 5.3.

Table 1 — Exposure classes related to environmental conditions

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack. For concrete with reinforcement or embedded metal: very dry.	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
Where the reinforced concrete or concrete with embedded metallic parts is exposed to air and humidity, the exposure classes shall be defined as follows:		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity ; concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
Where the reinforced concrete or concrete with embedded metallic parts is subject to contact with water containing chlorides other than from marine sources, including ice clearance salts, the exposure classes shall be defined as follows:		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides. Pavements; car park slabs
4 Corrosion induced by chlorides from sea water		
Where the reinforced concrete or concrete with embedded metallic parts is subject to contact with seawater chlorides or the action of air carrying sea salt, the exposure classes shall be defined as follows:		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5 Freeze/thaw attack		
When the concrete is subject to a significant attack due to freeze/thaw cycles while it is damp, the exposure classes shall be defined as follows:		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation with de-icing agents or seawater	Road and bridge decks exposed to de-icing agents Concrete surfaces directly exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing
6 Chemical attack		
When the concrete is subject to chemical attack by soils and natural groundwater, the exposure classes shall be defined as follows:		
XA1	Slightly aggressive chemical environment	Concrete exposed to natural soils and ground water in accordance with Table 3
XA2	Moderately aggressive chemical environment	Concrete exposed to natural soils and ground water in accordance with Table 3
XA3	Highly aggressive chemical environment	Concrete exposed to natural soils and ground water in accordance with Table 3

The following details are added:

a) type M UHPFRCs cannot come under exposure class X0;

b) in the absence of special specifications, are classified as:

1) XC1: parts of buildings sheltered from the rain, with the exception of parts classified as XC3,

2) XC2: parts of buildings in long term contact with water ,

3) XC3: parts of buildings sheltered from rain but not enclosed, or exposed to high levels of condensation both with regard to frequency and duration,

4) XC4: above ground parts of civil engineering structures and of buildings not protected from the rain, including adjacent zones to these parts concerned by water routing and/or splashing;

c) in the absence of special specifications, are classified as:

1) XD1: moderately wet surfaces exposed to airborne chlorides,

2) XD2: swimming pools or parts exposed to industrial waters and containing chlorides,

3) XD3: parts of structures subject to frequent and very frequent splashing and containing chlorides, and where a sealing coating ensuring the protection of the UHPFRC is absent;

d) in the absence of special specifications, are classified as:

1) XS1: structure members which are neither in contact with seawater nor exposed to spray, but which are directly exposed to saline air, namely those located beyond the XS3 classification area and at least 1 km from the coast, sometimes more, up to 5 km depending on the particular topography,

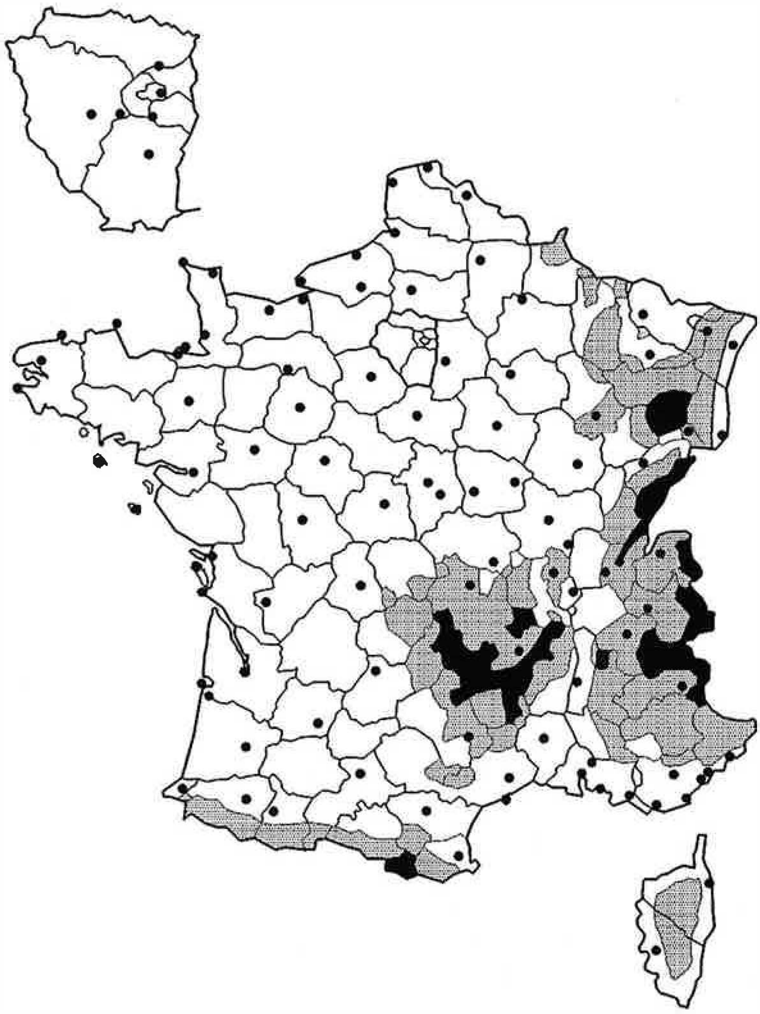
2) XS2: permanently submerged marine structures members,

3) XS3: marine structure members in tidal zone and/or exposed to spray when they are located at least 100 m from the coast, sometimes more, up to 500 m depending on the particular topography;

e) in the case of freeze/thaw attack and unless special specification otherwise particularly based on the state of saturation by long-term contact with liquid water (for example horizontal surface or otherwise), the exposure classes XF1, XF2, XF3 and XF4 are indicated in the map giving the areas subject to frost (Figure 2) and in Table 2 with additional details from document FD P 18-326. Salting is considered "infrequent" when the annual average of the number of days when salting takes place estimated over the last 10 years is less than 10, "very frequent" when it is greater than or equal to 30 and "frequent" between these two cases.

Table 2 — Classes of exposure to freeze/thaw attack with or without de-icing agents

Salting / Freezing	None	Infrequent	Frequent	Very frequent
Low or moderate	XF1	XF1	XF2	XF2[a]
Severe	XF3	XF3	XF4	XF4
[a] With the exception of concrete roadways and members of civil engineering structures which are very exposed and which will be classified as XF4.				



Key

Low or moderate freezing:	XF1 (without de-icing agent) 1) XF2 (with de-icing agent) 2)
Severe freezing:	XF3 (without de-icing agent) 3) XF4 (with de-icing agent) 4)
Moderate or severe freezing:	Depending on the altitude
Weather station	

1) No salting or infrequent salting
2) Frequent or very frequent salting
3) No salting or infrequent salting
4) Frequent or very frequent salting

NOTE Saint-Pierre et Miquelon and the French Southern and Antartic Territories are classified in severe freezing zone.

Figure 2 — Map of areas in France subject to frost (Figure NA2 of standard NF EN 206/CN:2014)

f) Additional classes XH1, XH2 and XH3 from the "Recommandations pour la prévention des désordres dus à la reaction sulfatique interne" published by the LCPC in August 2007 [3] are introduced to describe the characteristic more or less water saturated of the immediate environment around the parts of the structure.

NOTE Selection of exposure classes should be based on the guides [4] prepared by the Ecole Française du Béton:

— "Guides for selecting exposure classes of cast in place or precast building structures"
— "Guide for selecting exposure classes of concrete bridges"
— "Guide for selecting exposure classes of maritime and fluvial structures"
— "Guide for selecting exposure classes of road equipment structures"
— "Guide for selecting exposure classes of excavated road tunnels"
— "Guide for selecting exposure classes of covered trenches, galleries, caps and submerged caissons"
— "Guide for selecting exposure classes of varied civil engineering structures"

4.2.1.2 Special case of chemical attacks

Limiting values for exposure classes for chemical attack from natural soil and ground water are given in Table 3.

Table 3 — Limiting values for exposure classes for chemical attack from natural soil and ground water

Chemical characteristic	Reference test method	XA1	XA2	XA3
Groundwater				
SO_4^{2-}, in mg/l	NF EN 196-2	≥ 200 and ≤ 600	> 600 and ≤ 3000	> 3000 and ≤ 6000
pH	ISO 4316	≤ 6,5 and ≥ 5,5	< 5,5 and ≥ 4,5	< 4,5 and ≥ 4,0
Aggressive CO_2, in mg/l	NF EN 13577	≥ 15 and ≤ 40	> 40 and ≤ 100	> 100 to saturation
NH_4^+, in mg/l	ISO 7150-2	≥ 15 and ≤ 30	> 30 and ≤ 60	> 60 and ≤ 100
Mg^{2+}, in mg/l	NF EN ISO 7980	≥ 300 and ≤ 1 000	> 1 000 and ≤ 3 000	> 3 000 to saturation
Soils				
SO_4^{2-} total, in mg/kg [a]	NF EN 196-2 [b]	≥ 2 000 and ≤ 3 000 [c]	> 3 000 [c] and ≤ 12 000	> 12 000 and ≤ 24 000
Acidity according to Baumann-Gully, in ml/kg	NF EN 16502	> 200	Not encountered in practice	

a Clay soils with a permeability below 10^{-5} m/s may be moved into a lower class.

b The test method prescribes extraction of SO_4^{2-} by hydrochloric acid; alternatively, water extraction may be used, if experience is available in the place of use of the concrete.

c The 3 000 mg/kg limit shall be reduced to 2 000 mg/kg, where there is a risk of accumulation of sulfate ions in the concrete due to drying and wetting cycles or capillary absorption.

In addition to Table 3, reference should be made to document FD P 18-011 in the case of risk of attack by slightly mineralised waters or by gaseous environments. Failing a special study, this document acts as a reference for selecting the binder (cement and addition) depending on the environment.

In addition to Table 3, a special study may be needed to establish the relevant exposure condition where there is:

a) limits outside of Table 3;

b) other aggressive chemicals;

c) chemically polluted ground or water;

d) aggressive industrial environment;

e) high water velocity in combination with chemical species of Table 3.

The aggressive chemical environments classified in Table 3 are based on natural soil and ground water at water/-soil temperatures between 5°C and 25°C and a water velocity sufficiently slow to approximate to static conditions. The most onerous value for any single chemical characteristic determines the class. Where two or more aggressive characteristics lead to the same class, the environment shall be classified into the next higher class, unless a special study for this specific case proves that it is not necessary.

4.2.2 Transfer resistance classes

4.2.2.1 Basic thresholds

The UHPFRCs shall satisfy the following three requirements:

a) water porosity at 90 days ≤ 9,0% (according to NF P 18-459);

b) coefficient of diffusion of chloride ions at 90 days ≤ 0,5 x10^{-12} m^2/s according to standard XP P 18-462 adapted according to the provisions of clause A.1;

c) apparent permeability to gases at 90 days ≤ 9 x10^{-19} m^2 according to standard XP P 18-463:2011 adapted according to the provisions of A.2.1.

NOTE These criteria locate UHPFRCs within the range of cementitious materials with very high potential durability for exposure classes XC, XS, XD and XF, according to the AFGC guidance document [5].

4.2.2.2 Improved potential durability classes

UHPFRCs may belong to one or other of the following improved potential durability classes according to whether the following thresholds are achieved:

a) Dp+: improved porosity:

water porosity at 90 days ≤ 6,0 % (according to NF P 18-459);

b) Dc+: improved resistance to the diffusion of chloride ions:

coefficient of diffusion of chloride ions at 90 days ≤ 0,1 x 10^{-12} m^2/s according to standard XP P 18-462 adapted according to the provisions of clause A.1;

NOTE 1 While awaiting endorsement of standard XP P 18-462, values between 0,1 x 10^{-12} m^2/s and 0,2 x 10^{12} m^2/s may be accepted if the measurement uncertainty makes a value ≤ 0,1 x 10^{-12} m^2/s not significant.

c) Dg+: improved resistance to gaseous transfers:

apparent permeability to gases at 90 days ≤ 1 x 10^{-19} m^2 according to standard XP P 18-463:2011 adapted according to the provisions of A.2.2.

NOTE 2 These improved potential durability classes are worth used in particular when justified by a particularly severe exposure or a particularly long design working life, as specified in 5.3.3.

4.2.3 Abrasion exposure and abrasion resistance classes

The severity of exposure to abrasion of a structure or part of a structure is described by classes XM1, XM2 and XM3 in accordance with standard NF P 18-710:2016.

With regard to abrasion associated with hydraulic flows, the UHPFRC is classified by its performance based on its abrasion index determined in accordance with Annex I, consisting of comparing the imprint formed in the material subject to a sandblast with that which forms on glass:

a) class RM1: 1 ≤ abrasion index < 1,5 (material resistant to "hydraulic" abrasion);

b) class RM2: 0,7 ≤ abrasion index < 1 (material highly resistant to "hydraulic" abrasion);

c) class RM3: abrasion index < 0,7 (material ultra-resistant to "hydraulic" abrasion).

4.3 Classes relating to fresh and maturing UHPFRCs

4.3.1 Consistence classes

In fresh state, the UHPFRC shall remain homogeneous and there shall be no segregation of fibres or a solid fraction of the constituents taking account of the means used for UHPFRC placing.

The consistence of the UHPFRC in fresh state is normally subject to a specification associated with a target value.

Otherwise, the UHPFRC shall be classified according to its consistence in fresh state. It therefore belongs to one of the following three consistence classes:

a) Ca: UHPFRC which may be self-compacting, i.e. generally able to be placed without vibration or use of a mechanical flow aid;

b) Cv: viscous UHPFRC, i.e. generally able to be placed without vibration but which requires use of a mechanical flow aid;

c) Ct: UHPFRC exhibiting a flow threshold, i.e. generally able to flow under the effect of dynamic shearing but whose free surface at rest may keep sloping.

The consistence class selected shall be associated with the workability retention time during which the preservation of this consistence is requested.

For the Ct classes, the ability to be placed should be ensured under the conditions of the project and characterised by a performance measured according to a procedure covered by an agreement between the producer, the specifier and the user.

The consistence areas relating to these classes are characterised by one of the following tests appropriate to the size of the fibres and the aggregates comprising the UHPFRC.

The classification is determined as set out in Table 4.

Table 4 – Consistence classes for UHPFRCs

Class	**Flow table test** (in accordance with standard NF EN12350-5) mm	**Flow table test with ASTM conical mould without shock** (adapted from standard ASTM C230/C230M) mm	**Slump-flow test** (by reference to standard NF EN 12350-8) mm
Ca	Without shock: ≥ 560	≥ 270	≥ 760 (SF3)
Cv	Without shock: 420 to 560 After 15 shocks: > 560	230 to 270	660 to 760 (SF2)
Ct	Without shock: < 420 After 15 shocks: > 560	< 230	< 660 (SF1)

NOTE The choice of the test is determined by mutual agreement between the specifier, the user and the supplier of the UHPFRC. For a UHPFRC, it should be noted that the measurement uncertainty associated with these tests is such that the result is rounded to the centimetre (10 mm).

4.3.2 Classes depending on the maximum dimension of the aggregates

When the UHPFRC is classified according to the maximum size of the aggregates, the classification shall be made from the nominal size greater than the largest aggregate present in the UHPFRC (D_{upper}) in compliance with standard NF EN 12620+A1. D_{upper} is less than or equal to 10 mm.

NOTE D_{upper} is the maximum dimension of the sieve by means of which the size of the aggregates is determined in accordance with standard NF EN 12620+A1.

4.3.3 Heat treatment classes

The UHPFRC is classified according to the heat treatment which is possibly applied to in order to reach its properties in mature hardened state.

The UHPFRC is classified as STT when it has not undergone any heat treatment.

The UHPFRC is classified as TT1 when it has undergone a "heat curing" or "acceleration of hydration by heat treatment" or "heating" which aims to bring forward the start of setting and to accelerate setting and initial hardening in the mould by application of moderate heating. The average compression strength measured at 28 days after the application of such a heat treatment shall not be less than 88% of the mean compressive strength at 28 days of the same UHPFRC produced and kept at 20°C ± 2°C and which had not undergone any heat treatment (active or passive).

The UHPFRC is classified as TT2 when, several hours after it has set, it undergoes heat treatment at a relatively high temperature (of the order of 90°C) at a degree of humidity greater than 90% for several tens of hours. The mean compressive strength measured at 28 days after the application of such a heat treatment shall not be less than the average compressive strength at 28 days of the same UHPFRC produced and kept at 20°C ± 2°C and which had not undergone any heat treatment (active or passive).

The UHPFRC is classified as TT1+2 when it has undergone both the heat treatments described above successively. The mean compressive strength measured at 28 days after the application of such a heat treatment shall not be less than the mean compressive strength at 28 days of the same UHPFRC produced and kept at 20°C ± 2°C and which had not undergone any heat treatment (active or passive).

NOTE The cooling management of a structure or a member in UHPFRC does not constitute a heat treatment class and comes under standard NF P 18-451.

4.4 Classes corresponding to the properties of hardened UHPFRCs

4.4.1 Compressive strength classes

The UHPFRC is classified with respect to its compressive strength by reference to its characteristic strength at 28 days $f_{ck\text{-}cyl}$ measured on cylinders of nominal dimensions 110 mm/220 mm, commonly called "11/22", according to standard NF EN 12390-3:2012, the test specimens satisfying standards NF EN 12390-1 and NF EN 12390-2, and in accordance with the details of Annexes B and C of this document. The classification is given in Table 5. Moreover, it is possible to use intermediate strength levels rounded to the nearest 5 MPa.

If checks on the strength of the UHPFRC in the production phase are envisaged on cubic test specimens, the compressive strength of the UHPFRC shall be measured on cubes with 10 cm edges and the characteristic value $f_{ck\text{-}cube}$ may be determined. However, in this case, in design tests, double determination of the strength both on cylinders and on cubes with a sufficient number of samples is needed to ensure the validity of the value used for the project, and determination on cylinders takes precedence for classifying the UHPFRC. In the control phase, as an alternative to the direct comparison of the value $f_{ck\text{-}cube}$ relative to the class limits in Table 5 or the intermediate levels used, determination on cubes may be weighted by the transfer coefficient determined in the design phase to estimate $f_{ck\text{-}cyl}$ and verify compliance with the class.

NOTE These provisions take into account the difficulty of identifying a single relationship between $f_{ck\text{-}cyl}$ and $f_{ck\text{-}cube}$.

Table 5 – Compressive strength classes for UHPFRCs

Compressive strength class	Minimum characteristic cylinder strength	Minimum characteristic cube strength
	$f_{ck\text{-}cyl}$ MPa	$f_{ck\text{-}cube}$ MPa
UHPFRC 130 / 145	130	145
UHPFRC 150 / 165	150	165
UHPFRC 175 / 190	175	190
UHPFRC 200 / 215	200	215
UHPFRC 225 / 240	225	240
UHPFRC 250 / 265	250	265

4.4.2 Density classes

The UHPFRCs covered by the present standard shall have a dry density (including the fibres of course) of between 2200 kg/m³ and 2800 kg/m³. They are deemed to be of normal density, the structure design taking account as and when required of the effective value of the density according to the UHPFRC used.

This standard does not make provision for light or heavy UHPFRCs under or beyond this density range.

4.4.3 Tensile behaviour classes

The tensile behaviour of UHPFRCs used as a reference in designing the structure and in specifying the material, shall be determined by inverse analysis of the bending test results according to the procedure described in Annex D (tests on prisms) or in Annex E (tests on thin plates), according to the geometry of the project members, and taking into account for the post cracking phase the orientation factor K which expresses the effect of the placement of the UHPFRC in the structure, product or structure component according to the part of the structure concerned and the direction considered. The orientation factors K shall be determined during the suitability test for the structure or member considered in accordance with Annex F.

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The characteristic value of the limit of elasticity under tension at 28 days for the UHPFRCs covered by the present standard $f_{ctk,el}$ shall be greater than 6,0 MPa.

The UHPFRCs covered by this standard shall have a sufficient strain hardening behaviour under flexure such that they satisfy the following inequality (1):

$$\frac{1}{w_{0,3}}\int^{w_{\lim}}\frac{\sigma(w)}{1,25}dw \geq \max(0,4 f_{ctm,el};3\text{MPa}) \qquad (1)$$

where

$w_{0.3}$ = 0,3 mm;

$f_{ctm,el}$ is the mean value of the limit of elasticity under tension in MPa;

$\sigma(w)$ is the characteristic post-cracking stress according to the crack opening w, in MPa.

The tensile behaviour class of the UHPFRC is obtained by comparison with the limit of elasticity $f_{ct,el}$ and the post-cracking strength f_{ctf}, for the mean curve and the characteristic curve. It is determined in principle by including the orientation factor K_{global} in the post-cracking phase expressing the effect of the placement of the UHPFRC in the structure, the product or structure component, in accordance with Annex F, using a fixed postulated value of 1,25 for this factor.

The UHPFRC is of class T1 (strain softening under direct tension) when $f_{ctf}/1,25 < f_{ct,el}$ both for the mean curve and for the characteristic curve, i.e. $f_{ctfm}/1,25 < f_{ctm,el}$ and $f_{ctfk}/1,25 < f_{ctk,el}$.

The UHPFRC is of class T2 (limited strain hardening) when $f_{ctf}/1,25 \geq f_{ct,el}$ for the average curve and $f_{ctf}/1,25 < f_{ct,el}$ for the characteristic curve, i.e. $f_{ctfm}/1,25 \geq f_{ctm,el}$ and $f_{ctfk}/1,25 < f_{ctk,el}$.

The UHPFRC is of class T3 (significant strain hardening) when $f_{ctf}/1,25 \geq f_{ct,el}$ both for the mean curve and for the characteristic curve, i.e. $f_{ctfm}/1,25 \geq f_{ctm,el}$ and $f_{ctfk}/1,25 \geq f_{ctk,el}$.

4.5 Description

UHPFRCs of type M whose characteristic compressive strength is at least 150 MPa are graded UHPFRC-S.

UHPFRCs of type M whose characteristic compressive strength is greater than 130 MPa and strictly less than 150 MPa are graded UHPFRC-Z.

NOTE UHPFRC-S concretes are deemed usable for designing structures, precast products and precast elements of structures in accordance with standard NF P 18-710:2016.

5 Requirements

5.1 Requirements related to constituents

5.1.1 General

The constituents shall not contain harmful substances in quantities which could have a detrimental effect on the durability of the UHPFRC or cause corrosion of reinforcing or prestressing steels if applicable. They shall be appropriate to the use envisaged for the UHPFRC.

Although the suitability for use of a constituent may have been established, this does not necessarily mean it can be used in all cases or for whichever composition of the UHPFRC.

Only constituents whose suitability for the prescribed use has been established shall be used in UHPFRCs in accordance with this standard. This may require a reduction in the tolerances on all or some of their properties relative to the requirements given in the standards which cover them, to ensure that the properties of the UHPFRC are met. Establishing these tolerances and the precision in the dosage forms part of the mix-design study of the UHPFRC (see 5.2).

5.1.2 Cement

For use in the UHPFRC, the cement shall comply with standard NF EN 197-1. General suitability for use has been established for cements CEM I 52,5 or CEM II/A 52,5. Suitability for use of other types or classes of cement requires a validation based on a special study which takes into account potential variations in the characteristics, nature and content of the components.

In the absence of a special study, for a design working life greater than or equal to 100 years, the cements shall conform to NF P 15-317 to be suitable for use in the particular environment of seawater (classes XS2 and XS3). Moreover, the composition of the UHPFRC binder constituents when exposed to this environment (sulphide, sulphate content, etc.) shall be such that the binder also conforms to NF P 15-317.

In the absence of a special study, for a design working life greater than or equal to 100 years, the cements intended for use in the particular environment of contact with salty waters or soils containing sulphates (classes XA2 or XA3) shall be selected according to the provisions set out in FD P 18-011.

In the absence of a particular study, cements intended for use in the particular environment of contact with pure waters, or acid waters or acid soils (in classes XA2 and XA3, and for a design working life greater than or equal to 100 years in class XA1) shall be:

a) selected in accordance with FD P 18-011;

b) CEM II/A-D or CEM II/A-Q cements;

c) CEM I or CEM II/A cements with the addition of at least 6% silica fume or at least 6% metakaolin (as a percentage of the total mass of cement and additions).

In the absence of a particular study, in other chemical attack situations, the UHPFRC binder should be chosen by reference to FD P 18-011 when the corresponding attack, associated to a class XA1, XA2 or XA3 is provided for therein, except for class XA1 associated with a design working life of 50 years.

For UHPFRC members prestressed by pre-tensioning or post-tensioning for which the design working life is greater than or equal to 100 years, in the absence of a particular study, the cement shall be CP2 in accordance with the specifications of NF P 15-318. However, for UHPFRC members prestressed by post-tensioning for which the design working life is greater than or equal to 100 years, the cement may be CP1 in accordance with the specifications of NF P 15-318.

5.1.3 Aggregates

General suitability for use is established for aggregates with normal density and heavy aggregates in accordance with NF EN 12620+A1 and NF P 18-545. The characteristics of the aggregates shall be indexed A in accordance with NF P 18-545. In particular, the water absorption coefficient of the aggregates shall be less than or equal to 2,5%, except in case of a particular study mainly focused on the stability of the working time.

In the absence of a particular study, the aggregates shall be classified NR with regard to the alkali-aggregate reaction risk according to FD P 18-464 and FD P 18-542.

5.1.4 Mixing water

General suitability for use is established for potable water and groundwater compliant with to NF EN 1008.

5.1.5 Admixtures

Suitability for use is established for admixtures compliant with to NF EN 934-2+A1.

5.1.6 Mineral additions and pigments

General suitability for use as an addition is established for:

a) fillers in accordance with NF EN 12620+A1;

b) pigments in accordance with NF EN 12878;

c) limestone additions in accordance with NF P 18-508;

d) siliceous additions in accordance with NF P 18-509;

e) fly ash in accordance with NF EN 450-1;

f) silica fumes in accordance with NF EN 13263-1+A1;

g) ground granulated blast furnace slags in accordance with NF EN 15167-1 if they also are class A according to NF EN 206/CN:2014;

h) metakaolins of type A in accordance with NF P 18-513.

5.1.7 Fibres contributing to non-brittleness

Fibres contributing to non-brittleness of the UHPFRC according to 4.4.3 are suitable for use if they comply with one of the following concrete fibre standards:

— NF EN 14889-1 (steel fibres) for type M UHPFRCs (several categories of steel fibres may be combined);

— NF EN 14889-2 (polymer fibres) for type A UHPFRCs, when these are polyvinyl alcohol (PVA) fibres. The suitability for use of other types of polymer fibres in accordance with this standard requires a validation based on a special study which verifies in particular that the mechanical performance of the UHPFRC incorporating these fibres is kept over time at sufficiently high levels above the design values (resistances, ductility), in particular under the effect of temperature, immersion/drying cycles, freezing/thawing cycles and loading cycles likely to produce fatigue effects.

Other fibres may be used to help give the UHPFRC strain hardening properties under flexure according to 4.4.3 as long as they are covered by a standard or a technical approval which considers their use in a UHPFRC in accordance with this standard and sets out specifically in which type of UHPFRC they may be incorporated along with any restrictions related to the terms and conditions of application of this standard. The stability of the mechanical performance of the UHPFRC over time sufficiently above the design values (resistances, ductility) especially shall have been verified, particularly under the effect of temperature, immersion/drying cycles, freeze/thaw cycles and loading cycles likely to produce fatigue effects.

5.1.8 Other fibres providing additional characteristics

Other fibres may be used to help give the UHPFRC additional characteristics as long as these fibres are covered by a standard or a technical approval which considers their use in a UHPFRC in accordance with this standard and sets out specifically in which type of UHPFRC they may be incorporated.

Polypropylene fibres in accordance with standard NF EN 14889-2 are deemed suitable for use insofar as they help prevent the risk of spalling in M or A type UHPFRCs in the event of a fire.

5.1.9 Additives

Additives may be incorporated in the UHPFRC to improve some of its properties or provide it with specific properties, subject to a particular study which checks that any secondary effects are under control. All additives taken together shall not exceed 5% of the volume of the concrete. Where additives are used, the composition of the UHPFRC with and without additives shall be considered as different and then a new design test should be carried out.

5.1.10 Premix of constituents

UHPFRCs may be prepared from pre-dosed and premixed constituents comprising:

a) cement and additions;

b) possibly, all or part of the aggregates;

c) possibly, admixtures in solid form;

d) possibly, pigments in solid form;

e) possibly, additives;

f) possibly, some or all of the fibres.

The suitability for use of each of these constituents taken separately shall be established under 5.1.1, 5.1.2, 5.1.3, 5.1.5, 5.1.6, 5.1.7, 5.1.8 and 5.1.9 depending on the nature of the constituent considered.

For the premix, the regularity of the constituents, their compatibility and precision of dosage shall have been checked in order that the required performances are met in order to produce UHPFRCs which then have an identity card (see 5.6). The dosing facilities and the manufacturing procedure shall make it possible to meet a tolerance of ± 2 % on the dosage of each component of the premix, with the exception of fibres for which the tolerance is (– 2%; +4%). The history of automatically-recorded raw material weightings of quantities which are fed into the mixer shall be provided so as to make it possible to check whether this tolerance has been complied with. Records shall be kept for at least 12 months.

A label identifying the premix and its production references and certifying that production checks have been carried out shall accompany each lot delivered. The detail of these checks is given in Annex G.

5.2 Requirements for the composition of UHPFRCs

5.2.1 General

The constituents of the UHPFRC and their proportions shall be selected at the design test stage so as to satisfy the specified requirements with regard to durability, properties in fresh state and characteristics in hardened state, taking into account the material production process and the considered execution method of the structure including the treatments possibly applied after placing which enable these properties to be attained.

The producer shall especially select the types and classes of constituents from among those whose suitability for use has been established for the specified environmental conditions.

The composition of the UHPFRC shall minimise the segregation, bleeding and non-uniformity of distribution of the fibres within the structure. To this aim, special attention shall be paid to the quantities of water added to the UHPFRCs by the various constituents (added water, water absorbed by the aggregates, water in admixtures). Whether the UHPFRC constituents are used in the form of premixed constituents or otherwise, special care shall be taken in monitoring their regularity.

The nominal recipe needed to obtain a cubic metre of the UHPFRC in use shall be fixed at the design stage or by reference to an identity card. It shall be proposed by the producer who commits to reach the performance-based specifications determined by the prescriber. This recipe shall be confirmed by the suitability test aimed to check whether the performance specified are met when the UHPFRC is produced under the planned production, placing conditions and is submitted to the planned treatment.

The nominal recipe, which is being part of the contract, shall be defined by the quantity of each constituent added separately and, if applicable, by the quantity of the premix(es) of constituents.

For constituents added separately, the nominal recipe shall give:

a) the denomination and weight of the various aggregate categories (dry materials);

b) the denomination and weight of the cement (with an indication of quantity of silica fume for a cement containing silica fume);

c) the denomination and dry weight of each addition, pigment or additives if applicable;

d) the total volume of water (added water plus volume brought by the various constituents);

e) the denomination and weight of solid content of admixture;

f) the denomination and weight of each type of fibre.

For constituents added in the form of a premix, the nominal recipe shall give the denomination and weight of the "composite" constituent corresponding to the premix with reference to the demonstration of its suitability for use (see 5.1.10).

The dosing facilities and manufacturing procedure shall allow meeting a tolerance of −2% and +4% for fibres and ± 2% for every other weighed constituent. The prescriber shall be able to make sure that this requirement is met and checked by the producer's quality assurance system, particularly by an adaptation of measuring balance according to the capacity of the mixer and the quantities manufactured. Traceability shall be ensured of the quantities of constituents weighed then mixed along with the mixing sequence.

A variation in the quantity of at least one of the constituents by more than the above weighing tolerances results in the composition of the UHPFRC being considered as different and therefore a new design test needs to be carried out (except in the case of adjustment of admixtures covered in 5.2.6).

NOTE More critically than for the concretes covered by NF EN 206/CN:2014, the properties of the UHPFRC required for its use in the structure can only be obtained by strict compliance with the execution procedures related to the material in the fresh state and during the hardening phase. In addition, requirements related to transport, placing, curing and subsequent treatment should be taken into account when specifying the UHPFRC.

5.2.2 Choice of the cement

The cement shall be selected from among those whose suitability for use has been established and taking into consideration:

a) the execution of the structure;

b) the end use of the UHPFRC and the structure including requirements associated with the facings;

c) any curing and heat treatment conditions;

d) the dimensions of the structure (development of heat);

e) the prevention of any cracking linked to restrained thermal deformations and any delayed ettringite formation;

f) environmental attacks to which the structure is exposed (see 4.1);

g) the potential reactivity of the aggregates to the alkalis of the constituents;

h) compatibility with the admixtures.

5.2.3 Use of aggregates

The nature, type, dimension and categories of the aggregates shall be selected taking into account:

a) the execution of the structure;

b) the end use of the UHPFRC (specified properties) and of the structure;

c) environmental attacks to which the structure is exposed;

d) prevention of all alkali-aggregate reactions (in the absence of a particular study, the aggregates shall be classified NR with regard to the alkali-aggregate reaction risk according to FD P 18-464 and FD P 18-542);

e) requirements associated with facings.

The greatest nominal size of the largest aggregate present in the UHPFRC (D_{upper}) shall be selected taking into account the minimal dimensions of the sections and the concrete cover of any reinforcing or prestressing steel.

5.2.4 Use of recycled water

Water retrieved from concrete manufacturing or UHPFRC shall not be used.

5.2.5 Use of additions

The use of additions helps to obtain a high level of compactness of the UHPFRC cement matrix, and a high compressive strength. Several types of addition may generally be used including ultra-fine additions with pozzolanic properties, in optimised proportions. The composition of the UHPFRC finally summarized in the identity card of the UHPFRC (see 5.5) and validated during the design and suitability test shall include all additions used, wherein the substitution of one addition by another or the substitution to the cement is excluded.

For prestressed UHPFRC members where the design working life is greater than or equal to 100 years, the composition of the additions and their dosage shall be such that the sulphide content of the binder does not exceed 0,2%.

5.2.6 Use of admixtures

The total quantity of admixtures used shall not exceed the maximum dosage recommended by the manufacturer of each admixture, except if the effect of higher dosage on the performance of the UHPFRC is agreed upon and taken into account.

When multiple admixtures are used, their compatibility shall be checked prior to the design and suitability tests.

The method of feeding the admixtures (possible dispersion in mixing water, possible feeding in several phases, etc.) shall have been studied prior to the design test. If there is a significant climatic variation leading to a modification in the addition of admixtures, this modification shall induce an additional check in the suitability test.

5.2.7 Use of fibres contributing to ensure non-brittleness

The type, dimension and quantity of fibres contributing to non-brittleness of the UHPFRC according to 4.4.3 shall be selected taking into account:

a) the end use of the UHPFRC (specified properties, particularly mechanical performance) and of the structure;

b) environmental attacks to which the structure is exposed;

c) the method of placing the UHPFRC and execution of the structure;

d) requirements associated to facings.

Fibres complying with the type and the specified quantity shall be added to the mixture according to a feeding method which ensures that their distribution is uniform throughout the mix.

5.2.8 Use of fibres providing additional characteristics

The type, dimension and quantity of fibres providing additional characteristics shall be selected taking into account:

a) the end use of the UHPFRC and of the structure;

b) environmental attacks to which the structure is exposed;

c) the method of placing the UHPFRC and execution of the structure;

d) requirements associated to facings.

Indeed one or more of these aspects corresponding to the additional characteristics brought by the fibres are sought and shall be assessed.

Fibres complying with the type and quantity specified shall be added to the mixture according to a feeding method which ensures that their distribution is uniform throughout the mix.

5.2.9 Use of premixes of constituents

The use and possible selection of a premix of constituents to produce a UHPFRC shall take account of:

a) the nature of the structure and its parts and their method of execution, in particular the curing and any heat treatment operations;

b) the end use of the UHPFRC and the structure, and the required properties, including requirements associated to the facings;

c) the attacks to which the structure is exposed and durability requirements.

The usage of a premix of constituents allows to rely on the documented industrial experience regarding UHPFRCs produced with the same premix and also having an identity card (see 5.1.10).

The addition of additional constituents to the premix of constituents and the rest of the UHPFRC production sequence shall comply with the recommendations of the premix producer.

5.2.10 Temperature of fresh UHPFRC

The temperature of fresh UHPFRC when it is delivered and placed (whatever the production phase, in the design test or the suitability test) shall not be lower than 10°C or greater than 35°C, unless specified otherwise as a result of a particular study or data in the identity card of the UHPFRC and jointly accepted by the parties concerned.

5.2.11 Chloride content

The chloride content of a UHPFRC expressed as percentage by mass of chloride ions relative to the mass of cement shall not exceed:

a) 0,20% for a non-reinforced UHPFRC of type M, unless specially justified due to the proven resistance of the fibres to corrosion, or for a UHPFRC containing post-tensioning steels;

b) 0,15% for a UHPFRC of type A or M used in members containing prestressing steels;

c) 0,40% in all other cases.

5.2.12 Mixing protocol

The general principles dealing with the order of feeding of the constituents and, if appropriate, the target values of physical characteristics to be met at the end of the various mixing phases shall be given in the identity card of the UHPFRC or shall be determined by the design test.

NOTE In general, the mixing of UHPFRCs comprises, in the first phase, a homogenisation of the powders and aggregates, in the second phase, the introduction of water and all or part of the admixtures until a sufficiently fluid consistence is obtained, and in the third phase, the introduction of the fibres.

A mixing protocol associated with the UHPFRC nominal recipe and appropriate to actual production conditions shall then be defined in accordance with the provisions of NF P 18-451 and confirmed by the suitability test.

It is then fixed for the rest of the production, and aims in particular to ensure uniformity of the granular composition in the volume of manufactured UHPFRC, uniformity of the distribution of fibres in the mix, absence of fibres ball-up and of agglomerates deprived of fibres, and the consistence properties required for transporting and placing the UHPFRC. The ability to meet these properties shall be regularly verified by tests on fresh and/or hardened UHPFRC under the execution specifications described in NF P 18-451.

5.3 Requirements associated with exposure classes (durability and abrasion)

5.3.1 General

In order for the structure in UHPFRC to be resistant to environmental attacks, it shall have been designed in accordance with the requirements of NF P 18-710:2016 (in particular clauses 4 and 7) and comply with the requirements related to the material defined in this standard in terms of limiting values for the composition of the UHPFRC (see 5.3.2) and performance-based requirements on certain properties of the material (see 5.3.3 and 5.3.4). These requirements shall take into account the required design working life of the UHPFRC structure.

5.3.2 Requirements for the composition of the UHPFRC

The cement shall satisfy the requirements of 5.1.2, as shall the binder, when the structure is located in an environment described by exposure classes XA1, XA2 or XA3.

When the risk of spalling shall be avoided in a fire situation to be considered in the project, the UHPFRC shall include an appropriate content of polypropylene fibres confirmed by a representative test.

5.3.3 Performance-based requirements associated with durability

In addition to the requirements of 5.3.2, and in the absence of a specific justification of durability, Table 6 summarises the performance-based requirements which apply to UHPFRCs in order to ensure that the structures are durable according to their exposure and the required design working life of the project ("DWL" in the table, whose values are defined by reference to NF EN 1990).

Table 6 — Performance-based requirements associated with durability

Exposure class	DWL(a)	Requirement	Comments
XC1, XC2, XC3, XC4	50 years	-	Basic thresholds of 4.2.2
	100 years	-	Basic thresholds of 4.2.2
	150 years	Dp+, Dg+	
XS1, XS2, XD1, XD2, XF2	50 years	-	Basic thresholds of 4.2.2
	100 years	-	Basic thresholds of 4.2.2
	150 years	Dp+, Dc+, Dg+	
XF1, XF3	50 years	-	Basic thresholds of 4.2.2
	100 years	-	Basic thresholds of 4.2.2
	150 years	-	Basic thresholds of 4.2.2
XS3, XD3	50 years	-	Basic thresholds of 4.2.2
	100 years	Dp+, Dc+	
	150 years	Dp+, Dc+, Dg+	
XF4	50 years	-	Basic thresholds of 4.2.2
	100 years	Dp+, Dc+, Dg+	
	150 years	Dp+, Dc+, Dg+ and specific study	
XA1	50 years	-	Basic thresholds of 4.2.2
	100 years	-	Basic thresholds of 4.2.2 and specific requirements of 5.1.2
	150 years	Dp+, Dc+, Dg+	And specific requirements of 5.1.2
XA2, XA3	50 years	-	Basic thresholds of 4.2.2 and specific requirements of 5.1.2
	100 years	Dc+	And specific requirements of 5.1.2
	150 years	Dp+, Dc+, Dg+	And specific requirements of 5.1.2 to be supplemented by a specific study in the XA3 case with non-static conditions
Additional requirements (b) for the prevention of delayed ettringite formation (see 4.2.1) when the geometry or destination of the member, or the heat treatment associated with the manufacturing protocol and maturation of the UHPFRC, do not make it possible to eliminate the risk of exposure to a temperature greater than 65°C maintained for more than 4 hours during manufacture or during the service life of the member.			
XH1	50 years	-	Basic thresholds of 4.2.2
	100 years	-	Basic thresholds of 4.2.2
	150 years	Dp+	
XH2	50 years	-	Basic thresholds of 4.2.2
	100 years	(c)	Basic thresholds of 4.2.2 and (b)
	150 years	Dp+ and (c)	
XH3	50 years	(c)	Basic thresholds of 4.2.2 and (b)
	100 years	Dp+ and (c)	
	150 years	Dp+, Dc+, Dg+ and (c)	

[a] The requirements indicated for a DWL of 150 years applies for outstanding projects where the DWL is strictly greater than 100 years. Above 200 years, a special study is required.

[b] It is not necessary to apply these additional requirements if a temperature of 65°C is only exceeded in an accidental fire situation.

[c] The risk of delayed ettringite formation shall be eliminated based on a performance verification using the LPC66 test method [6].

5.3.4 Requirements associated with the abrasion risk

In the event of exposure to the abrasion risk associated with a hydraulic flow at varying degrees of severity, reference is made to the corresponding classification of the UHPFRC (see 4.2.3) to specify the requirements according to Table 7:

Table 7 — Requirements for resistance to hydraulic abrasion

Environment	Class
XM1	RM1, RM2 or RM3
XM2	RM2 or RM3
XM3	RM3

NOTE This classification is not appropriate for describing the resistance to an abrasion risk by shocks and attrition not involving water or a fluid flow. In this case, the use of a sufficiently strong UHPFRC to dispense with a sacrificial thickness can be covered by a requirement defined by the prescriber.

5.4 Requirements for fresh UHPFRC

5.4.1 Consistence

The consistence of fresh UHPFRC is normally covered by a specification associated with a target value which shall be within a specified interval whose range shall normally not exceed 15% of the target value, this specification taking into account the resources used for placing the fresh UHPFRC. This specification is coupled with retention specified working time rounded to a quarter of an hour. It shall be expressed by reference to one of the following tests, depending on the size of the fibres and the aggregates comprised in the UHPFRC:

a) flow table test (according to standard NF EN 12350-5);

b) slump flow test using the ASTM cone (adapted from standard ASTM C230/C230M);

c) slump flow test using the slump cone (by reference to standard NF EN 12350-8).

NOTE 1 The choice of test should be determined by mutual agreement between the prescriber, user and supplier of the UHPFRC.

NOTE 2 For a UHPFRC, it should be noted that the measurement uncertainty associated with these tests is such that the result is rounded to the nearest centimetre (10 mm).

In case a target value is not specified, the consistence of the UHPFRC shall be specified by reference to a consistence class Ca, Cv or Ct (see 4.3.1) and shall be combined with retention prescribed working time rounded to a quarter of an hour.

The consistence shall be checked at the instant the UHPFRC is used, after pumping if relevant, and before it is placed.

It can also be determined immediately after discharging from the mixer, after transport to the site where it is to be used, or during the placing so that contradictory measurements can be taken by the various parties.

5.4.2 Air content

When the air content of a UHPFRC needs to be determined, it shall be measured in accordance with EN 12350-7.

NOTE The resistance of a UHPFRC to freezing-thawing, with or without de-icing salts, does not require special requirements regarding air content, see 5.3.3.

5.4.3 Maximum size of aggregates

When the maximum aggregate size (D_{upper}) is to be determined, it shall be measured in accordance with standard NF EN 933-1.

NOTE When D_{upper} needs to be determined for fresh UHPFRC, a sieving procedure adapted from standard NF EN 933-1 and performed after extracting the aggregates by washing the fresh UHPFRC, should be adopted with the agreement of the parties concerned.

The maximum aggregate size (D_{upper}) as defined in standard NF EN 12620+A1 shall not be greater than the specified one.

5.4.4 Uniformity of fresh UHPFRC before placing

The UHPFRC producer shall ensure that the transportation and handling of the UHPFRC from the mixer to the location where it is to be used are carried out so as to avoid segregation, entrapping of air or ingress of foreign materials. He shall also ensure that the elapsed time between the UHPFRC being manufactured and the end of the placing operation remains compatible with the specified working time.

NOTE 1 The provisions applicable to the transportation and handling of fresh UHPFRC before placing which aim to ensure accordance with these requirements, are given in NF P 18-451.

If applicable, the addition of an admixture or admixture supplement after the UHPFRC gets discharged from the mixer shall be justified at the design test and suitability test stages. Incorporation of these constituents then forms part of the fresh UHPFRC production process and the control samples shall be taken after they have been fed. Apart from this case, no addition with respect to the nominal recipe of any component whatever it is shall be made after the UHPFRC has got discharged from the mixer.

In parallel with the systematic checking of consistence, the uniformity of the fresh UHPFRC shall be checked immediately before it is placed. To achieve this, samples shall be taken to characterise the uniformity of the granular distribution, the uniformity in the distribution of fibres, absence of fibres ball-up and absence of agglomerates with no fibres. These checks, based on qualitative or quantitative analyses of these samples shall be carried out during the suitability test where they are used in validating the transport and handling conditions of the UHPFRC which are part of the execution specifications detailed in NF P 18-451.

The objectives to be reached in terms of uniformity of the UHPFRC shall be determined for the suitability test. The checks to be carried out during production are described in standard NF P 18-451.

NOTE 2 The detection of fibres ball-up and agglomerates with no fibres is normally carried out by visual inspection. For type M UHPFRCs, fibre uniformity and distribution may be verified by weighing measures after washing of the samples.

5.4.5 Placement of fresh UHPFRC and finishing

UHPFRC shall be placed in accordance with NF P 18-451. The placing process shall enable the material to keep its uniformity and in particular reach the specified dimensional, appearance and mechanical performance requirements.

The process for placing fresh UHPFRC shall be fixed in a manner to avoid segregation, unnecessary air entrapment, upsetting the volumetric uniformity of the fibre distribution and producing fibre orientation during pouring the fresh material which may not have been evaluated quantitatively on the control mock-up in the suitability test.

The process used for placing fresh UHPFRC shall be reproducible. It shall be covered by a protocol agreed between the parties concerned, validated after the suitability test which explains the methods and resources deployed for attaining the required performance.

5.4.6 Placing temperature

The conformity of a UHPFRC to this standard implies that it has been produced, transported and placed when the ambient temperature is greater than -5°C and, in the absence of specific detailed provisions in accordance with NF P 18-451, less than 40°C.

The ambient temperature ranges for which the production, transport and placing of the UHPFRC require specific provisions, are fixed, along with these provisions, in NF P 18-451. Compliance with these by all parties involved forms an integral part of the conformity of the UHPFRC to this standard.

5.4.7 Curing

Curing shall be performed. It shall be applied as soon as possible after placing the material until the mean compressive strength of the UHPFRC in the most critical area reaches at least 30% of the specified f_{ck} value, unless a specific study shows there are no disadvantageous effects of using a different target value on the performance and durability properties. The provisions for reaching this target shall be validated by the suitability test.

NOTE Checks on the effectiveness of these provisions may be carried out on informative test specimens or by a maturity monitoring method appropriate to the UHPFRC.

Standard NF P 18-451 describes the methods used for curing. Unless specific proof is provided, methods for preventing the effects of intense and early self-desiccation do not dispense from surface curing.

Reproducibility with regard to curing requires the description of the applicable provisions to be incorporated in the placement protocol for the UHPFRC mentioned in 5.4.5, validated at the end of the suitability test and covered by an agreement between the UHPFRC user and the prescriber. Besides reaching a sufficient compressive strength, the characterisation of the efficiency of curing on the control mock-up fabricated during the suitability test, in order to validate this aspect of the protocol, may be based on qualitative criteria (appearance, compatibility with colour and appearance specifications of the facings, absence of cracking) and/or quantitative criteria (in situ measurement of the transfer properties such as water absorption).

During production, the effectiveness of the curing provisions applied according to the protocol shall be checked in accordance with standard NF P 18-451.

The possible adaptations to the provisions to ensure the effectiveness of the curing process in the event of a variation in the ambient hydric and thermal conditions during production and placing of the UHPFRC shall be covered by an agreement between the user and the prescriber on the basis of measures updating those of the initial suitability test, meanwhile it will not be necessary to carry out a new suitability test.

5.4.8 Heat treatments

In this standard, the heat treatment applied to fresh UHPFRC of types TT1 and TT1+2, is considered to contribute in significantly changing the final properties in the hardened state, when the average compressive strength measured after application of this heat treatment differs by more than 7% from the mean compressive strength measured at the same time step on the same UHPFRC but which has not undergone heat treatment before setting had started.

The heat treatment applied to the UHPFRC whether fresh or hardened and significantly changing its final properties in hardened state, for certain UHPFRCs of type TT1 and for UHPFRCs of type TT2 or TT1+2, shall be fine-tuned during the design study and characterised by the design test, or shall have been characterised beforehand in the identity card of the material, by the time-curve of temperature and hydric conditions to which the UHPFRC member is subjected to during this treatment. In particular, it shall be checked at this stage that the effect of such a heat treatment enables the requirements in 4.3.3 to be complied with.

The heat treatment applied to the UHPFRC from the initial hours before the material sets for UHPFRCs of type TT1 or TT1+2 whose only significant effect is to accelerate setting and hardening without changing the final properties of the material, shall have been determined by a generic study beforehand allowing equivalent time adjustment for the material being considered. Treatment appropriate to the members of the project shall undergo specific fine-tuning and be validated by the suitability test. It shall be characterised by the time function of the temperature and hydric conditions to which the UHPFRC member is subjected during this treatment.

In all cases, the characterisation of the heat treatment, which relates to the environmental conditions applied to the member, shall include the age (or equivalent age) of the material at the start of the application of the treatment, the rising rate of temperature until a stable stage is reached (temperature, duration of application, tolerance on these variables) and the rate of cooling down to ambient temperature for each type of treatment if necessary. Characterisation shall also include the relative humidity conditions during each treatment. Ages shall be expressed to the nearest 15 min when they are less than 24 h then to the nearest hour. Temperatures shall be expressed to the nearest °C and the relative humidity values rounded to 5%.

Heat treatment(s) applied during the suitability test contribute to validating the choice of UHPFRC, since it shall be checked that the specified performances are attained on the treated UHPFRC. It shall also be checked at this stage that the effect of the heat treatment makes it possible to comply with the requirements in 4.3.3.

When the UHPFRC undergoes heat treatment of moderate amplitude applied in order to anticipate the start of setting and accelerate setting and initial hardening (sometimes described as "heat curing", "curing" or "acceleration of hydration by heat treatment") which only modifies the properties of the material at early age, in particular the strength, shrinkage and creep, by changing the time variation of these properties as a function of the equivalent age of the material, but still keeps their final values, it shall be ensured that the properties at early age are attained in accordance with the calculation.

NOTE 1 The maturity monitoring may make it possible to ensure compliance with this requirement from the single initial calibration of the increase in strength.

Unless specific proof is provided, the heat treatment of this type corresponding to type TT1 and TT1+2 UHPFRCs before treatment on mature concrete, shall be limited to a total duration of 12 h and to a maximum concrete temperature of 60°C.

On the other hand, when the heat treatment significantly modifies certain properties, in particular the strength and its evolution, the properties associated with durability, shrinkage and creep which develop after this heat treatment, corresponding to some type TT1 UHPFRCs and type TT2, and TT1+2 UHPFRCs after treatment on mature concrete, this effect shall have been characterised at the design stage (or in the identity card for the material) so as to be taken into account appropriately in the project.

Compliance with the heat treatment protocol shall be covered by the provisions of the internal check carried out by the UHPFRC user, and shall be subject to an external check by the prescriber. The check that the treatment protocol has been applied shall be shown by a record of the temperature and humidity throughout the treatment period.

Any provisions for adapting the methods used to carry out treatment applicable before setting and hardening at ambient temperature conditions shall have been envisaged by the UHPFRC user.

When envisaged in the production process, the cooling of a structure or a member in UHPFRC does not constitute a heat treatment class and comes under standard NF P 18-451. The fine tuning is validated by the suitability test.

NOTE 2 The characterisation and compliance of the application of the cooling process is subjected to the provisions detailed in standard NF P18-451.

5.5 Requirements for hardened UHPFRCs (structural use)

5.5.1 General

Unless specified otherwise, the properties required for hardened UHPFRCs, including properties associated with fire resistance and control of spalling under the action of fire, shall be measured on test specimens tested at 28 days for type STT or TT1 UHPFRCs or after application of heat treatment for type TT2 or TT1+2 UHPFRCs. For special uses, it may prove to be necessary to specify certain properties at different time steps which shall then be given in the specification. It may involve in particular, for type TT2 or TT1+2 UHPFRCs, the properties needed to justify the execution phases before heat treatment.

5.5.2 Compressive strength

The compressive strength of the UHPFRC shall be determined in accordance with NF EN 12390-3:2012 by tests carried out on standardised cylinders of 110 mm diameter and slenderness ratio 2, the test specimens complying with standards NF EN 12390-1 and NF EN 12390-2. Additional indications are given in Annex C, in particular for the use of test specimens of other shapes or dimensions.

The mean strength, used in the standard determination of design ultimate strain under compression and for the design constitutive behaviour for non-linear structural analysis according to the indications given in NF P 18-710:2016, shall come from the design test or the identity card of the material.

The experimental determination of the characteristic strength shall be carried out in accordance with Annex B.

The characteristic strength of the UHPFRC shall be greater than or equal to the minimum characteristic strength value for the class specified for the project (see Table 5). It shall in addition be greater than or equal to the minimum characteristic strength of the strength class to which the UHPFRC belongs (see Table 5) without exceeding this minimum characteristic strength plus 40 MPa.

NOTE The minimum characteristic value specified for the project is to be distinguished from the minimum characteristic strength of the chosen UHPFRC.

5.5.3 Density

The dry density of the UHPFRC shall be determined in accordance with standard NF EN 12390-7 after oven drying with the following clarifications:

a) grinded test specimens may be used;

b) the minimum volume of the sample is reduced to 0,5 litres;

c) the result is the average value obtained over a minimum of 3 test specimens.

The average value of the density shall comply strictly with the class limiting values given in 4.4.2. A tolerance of – 100 kg/m^3 relative to the lower limiting value and of + 100 kg/m^3 relative to the upper limiting value is allowed for each individual result. When, in special cases, the density is specified in terms of a target value, a tolerance of ± 100 kg/m^3 is applied on individual results and a tolerance of ± 50 kg/m^3 is applied to the average value. However, the average of the experimental results for determining the density of a UHPFRC shall neither be strictly less than 2200 kg/m^3 nor strictly exceed 2800 kg/m^3 to comply with the normal density class (see 4.4.2).

For some UHPFRCs comprising organic fibres, the drying conditions may need to be adapted, they shall then be described in the test report. Moreover, the density may be subject to measurements under different humidity control conditions. These conditions shall then be specified and recorded in the test report.

5.5.4 Behaviour under tension

The behaviour of the UHPFRC under tension shall be measured and analysed in accordance with Annex D (tests on prisms) or Annex E (tests on thin plates) depending on the geometry of the project members. The orientation factors K that express the effect of the distribution and orientation of the fibres, in the part of the structure and the direction considered, shall be determined in accordance with Annex F.

The required behaviour of the UHPFRC under tension shall be detailed by a specification which comprises the following three items:

a) tensile behaviour class (see 4.4.3);

b) a characteristic constitutive curve of the material under tension, with which the experimental estimate of the characteristic constitutive curve determined on moulded test specimens will be compared, corresponding to specified stress values rounded to the nearest 0,1 MPa. The characteristic values of the limit of elasticity and the post-cracking strength shall be given explicitly;

NOTE If the conventional laws described in 3.1.7.3.2 and 3.1.7.3.3 of NF P18-710:2016 are used, the specification consists in giving the parameters mentioned in these paragraphs (limit of elasticity, post-cracking strength, crack width corresponding to the local peak or to 0,3 mm if there is no peak and corresponding stress, crack width equal to 1% of the height of the test prism and corresponding stress, etc.) describing the characteristic features of the UHPFRC constitutive behaviour under tension. In the case where conventional laws are not used, the specifications correspond to a set of maximum characteristic stress values and values describing the characteristic tensile behaviour.

c) a set of orientation factors K_{global} and K_{local}, in the various parts of the structures and directions being subjected to a design verification relying on the contribution of the UHPFRC under tension. The curves obtained by applying these orientation factors to the above constitutive tensile response curve in accordance with Annex F represent the behaviour under tension used as a reference for the design of the structure in accordance with NF P 18-710:2016, before application of the partial factor corresponding to the tensioned UHPFRC γ_{cf}, where relevant.

The average value of the post-cracking strength, used in particular for the conventional determination of anchor length and minimum lap splice length and in the compressive constitutive design law for non-linear analysis according to the indications given in NF P 18-710:2016, shall come from the design test or the identity card of the material. It shall be determined in accordance with Annex D (tests on prisms) or Annex E (tests on thin plates) depending on the geometry of the project members.

5.5.5 Reaction to fire

UHPFRCs conform to this standard are classified A1 according to NF EN 13501-1+A1 and do not require tests[5] if they contain less than 1% by weight or volume (according to the lowest value) of organic material distributed uniformly. Otherwise, their classification may be carried out on the basis of tests in accordance with NF EN 13501-1+A1.

[5] According to the order dated November 21, 2002 related to the fire reaction of construction products, reflecting the decision of the European Commission of 09 September 1994 (94/611/EC) published in the Official Journal of the European Communities No. L 241/25, of 09 September 1994

5.5.6 Physical and mechanical properties at high temperature

Standard NF P 18-710:2016 describes the justifications needed to ensure the fire resistance of a structure in UHPFRC by a full-scale test or by thermomechanical modelling.

Justification by calculation requires the knowledge of the temperature-dependent physical and mechanical properties: thermal conductivity, specific heat, density, thermal expansion, Young's modulus, tensile strength and compressive strength, and if necessary transient thermal deformation.

The evolution in density, specific heat and thermal conductivity with temperature shall be derived from NF EN 1992-1-2 with the following precisions:

a) change in density by reference to 3.3.2 (3) of this standard;

b) specific heat by reference to 3.3.2 (1) of this standard;

c) thermal conductivity by reference to 6.3.1 (1) of standard NF EN 1992-1-2/NA:2007.

For the considered UHPFRC, the thermal expansion and the evolution with temperature of Young's modulus, behaviour under tension and compressive strength shall be determined experimentally in the design test or in the identity card of the material. Determination shall be carried out on test specimens not protected from desiccation up to the maximum temperature reached in the structure during the considered scenario, and at least up to 600°C.

The methods to be used, mainly deriving from the recommendations of the RILEM technical committee "*Test methods for mechanical properties of concrete at high temperatures*", and introduced as a whole by RILEM Recommendation Part 1 [7], are as follows:

a) temperature-evolution of compressive strength: RILEM Recommendation part 3 [8] with determination under heat on at least 3 test specimens, compliant with Annex C with the exception of the slenderness ratio equal to 3, brought to temperature before applying the load. The result from each of the test specimens shall not differ by more than 10% from the average; the selected value shall be the smallest of the individual strengths;

b) evolution of Young's modulus: RILEM Recommendation Part 5 [9] with determination under heat on at least 3 test specimens, in accordance with Annex C with the exception of the slenderness ratio equal to 3, brought to temperature before applying the load. The result from each of the test specimens shall not differ by more than 20 % from the average; the selected value shall be the average of the determinations;

c) thermal expansion: determination according to RILEM Recommendation Part 6 [10] on test specimens in accordance with Annex C, the result is the average curve from 2 test specimens. The mean square root deviation relative to the average curve shall be less than 20%;

d) behaviour under tension: determination under heat of the behaviour by a bending test carried out on 3 test specimens, brought to temperature (in accordance with the provisions of 6.3.2 of recommendation [8]) before application of load, the test and the analysis being carried out in accordance with Annex D or Annex E according to the thickness of the member. Maximum moment of each of the 3 test specimens shall not differ by more than 20% from the average; the selected curve shall be the one corresponding to the lowest resisting moment.

If this data is necessary as part of an advanced fire calculation model, the transient thermal strain shall be determined under compression in accordance with RILEM Recommendation Part 7 [11] on test specimens conforming to Annex C, not protected from desiccation, subjected to a compressive stress equal to 30% of the characteristic strength up to the maximum temperature attained in the structure during the scenario considered and at least up to 600°C. The result is obtained as the average curve from 2 test specimens. The difference between the two curves shall be less than 4 mm/m for temperatures less than or equal to 300°C.

5.5.7 Control of spalling under the action of fire

When the action of fire is to be taken into account in the project according to a given scenario, the control of the risk of the UHPFRC spalling in the structures or exposed components shall be checked in accordance with standard NF P 18-710:2016.

The sensitivity to spalling of the UHPFRCs under the action of fire is governed by the composition of the UHPFRC but does not constitute an intrinsic property of the material. It shall be quantified experimentally on a representative (with regard to geometry and load) member or component of the actual structure regarding the fire scenario considered.

The incorporation of a sufficient polypropylene fibre content generally reduces or even eliminates the sensitivity of the UHPFRC to spalling when subjected to fire.

5.5.8 Young's modulus

Young's modulus of UHPFRCs cannot be inferred simply from their compressive strength. Standard NF P 18-710:2016 gives clarifications on the value of Young's modulus to be used for the design.

When Young's modulus of UHPFRC is to be determined, it shall be measured in accordance with Annex C. The derived value is the average of the results of at least 3 test specimens rounded to the GPa unit.

When specified, the value of Young's modulus shall take the form of a target value. The average experimental value obtained shall comply with this target value with a tolerance of ± 5 % and the relative tolerance on each individual result is ± 10 % relative to the target value.

5.5.9 Strain at failure under uniaxial compression

For the design, the strain at failure under uniaxial compression of the UHPFRC is normally obtained according to the indications of 3.1.7.2 of NF P 18-710:2016 and is not determined by a specified requirement.

For the design, the compressive constitutive behaviour for the non-linear structural analysis is normally obtained according to the indications of 3.1.7.2 of NF P 18-710:2016 and is not determined by a specified requirement.

5.5.10 Shrinkage

5.5.10.1 General

The shrinkage of UHPFRCs is not simply inferred from the compressive strength, it develops quickly from the start of setting and its amplitude generally requires precautions to be taken in terms of constructive methods. When UHFRC is submitted to adequate curing after the end of the placing phase and during setting, the shrinkage of UHPFRC is mainly autogenous. For type TT1 or TT1+2 UHPFRCs, part of the shrinkage occurs during drying. For a UHPFRC of type TT2 or TT1+2, it may be assumed that all shrinkage has taken place at the end of the heat treatment.

5.5.10.2 Total shrinkage amplitude

The total shrinkage amplitude occurring between the start of setting and 90 days of age is a synthetic data, part of the UHPFRC identity card if relevant. The reference conditions for determining it are as follows:

— curing for 24 h except when heat treatments are applied;

— subsequent storage at (20 ± 2)°C and (50 ± 5)% relative humidity;

— measurement of the deformations of the test specimen along its greatest dimension on a gauge length at least twice as long as the largest transverse dimension;

— correction of measured deformations to deduct any thermal shrinkage/expansion;

— triggering of measurements no later than when setting starts, as measured according to standard NF EN 480-2 on the non-modified UHPFRC, or when the speed of ultrasonic waves does not exceed 2500 m/s.

The total shrinkage amplitude occurring between the start of setting and 90 days of age may constitute a specified requirement. In this case, in the absence of a standardised method available or adapted, the additional details of the procedure for its determination and the acceptance criteria shall be defined by mutual agreement between the producer, the prescriber and the user. It is recommended to specify this requirement in the form of a target value and to associate a tolerance on the experimental value obtained, typically of ±10 % of this target value.

NOTE The experimental determination of the evolution of UHPFRC shrinkage may provide a useful information for controlling the effects of restrained deformations at early age, and apply if necessary 2.3.3 and V.1 of standard NF P 18-710:2016. To be more representative or for use in the design, the test conditions may be adapted by mutual agreement between the parties involved.

5.5.10.3 Determination for calculation

When the question is relevant for the considered member in UHPFRC, standard NF P 18-710:2016 provides clarifications on the shrinkage time-law to be used for the calculation and the control of any of shrinkage effects combined with other prescribed deformations and loads.

The time-evolution of shrinkage may then be described using the models in Annex B of NF EN 1992-2:2006, through a calibration of the amplitudes and coefficients linked to the kinetics according to B.104 of NF EN 1992-2:2006. For type TT1 or TT1+2 type UHPFRCs, this evolution shall be expressed in terms of equivalent time especially at early age during heat treatment. The calibration consists of adjusting the coefficients by minimising the quadratic error relative to the average experimental result. The amplitude coefficient is rounded to the nearest 10 µm/m.

5.5.10.4 Controlling shrinkage effects

Depending on the project, other procedures may be determined by mutual agreement between the producer, prescriber and user allowing the shrinkage or its effects to be characterised without a necessary computational verification. These procedures shall in particular specify the geometry of the test specimens to be used, the duration and the test conditions along with the operating conditions of the test and interpretation of the results in conjunction with the associated requirements.

5.5.11 Creep

5.5.11.1 General

The creep of UHPFRCs cannot be deduced simply from their compressive strength. For loads applied to a UHPFRC of sufficient maturity, the desiccation creep is very low and the specific creep is less than that of high performance concretes. For a UHPFRC of type TT2 or TT1+2, it may be assumed that the creep is almost non-existent for the load applied after heat treatment.

5.5.11.2 Determination for calculation

When the question is relevant for the UHPFRC member under consideration, standard NF P 18-710:2016 provides clarifications on the creep law to be used for the calculation and the control of any of creep effects combined with other prescribed deformations and loads.

The development of the creep should be described using the models in Annex B of NF EN 1992-2:2006, through a calibration of the amplitudes and coefficients linked to the kinetics under B.104 of NF EN 1992-2:2006. For this calibration, the reference conditions are (20 ± 2)°C for the experimental determination of the creep evolution (basic creep or total creep), and (50 ± 5)% relative humidity to determine drying creep. For type TT1 or TT1+2 type UHPFRCs, this evolution shall be expressed in equivalent time, in particular at early age during heat treatment. The calibration consists of adjusting the coefficients by minimising the quadratic error relative to the average experimental result. The amplitude coefficient of specific creep is rounded to the nearest 1 µm/m/MPa.

When the creep of the UHPFRC needs to be determined experimentally, appropriate precautions shall be adopted, both for the conduct of the test as well as its interpretation, when the loading takes place while the UHPFRC is still in a phase of rapid strength acquisition.

Depending on the project, the creep factors of the UHPFRC at representative ages of the application of the loads may constitute a specified requirement. In the absence of a standardised method available or adapted, the details of the procedure for its determination and the acceptance conditions shall be defined by a mutual agreement between the producer, the prescriber and the user. It is recommended to specify this requirement in the form of a target value and to adopt a tolerance on the experimental value obtained of ± 0,1.

5.5.11.3 Controlling creep effects

Depending on the project, other procedures may be determined by mutual agreement between the producer, prescriber and user allowing the creep or its effects to be characterised without a necessary computational justification. The procedures shall in particular specify the geometry of the test specimens used, the duration and the test conditions along with the operating conditions of the test and interpretation of the results in conjunction with the associated requirements. In particular, if the control of creep effects in the UHPFRC has not been demonstrated by a calculation performed according to NF P 18-710:2016, for instance because the UHPFRC used was not covered by this standard, this shall be proved experimentally for members or structures made of prestressed UHPFRC.

5.5.12 Coefficient of thermal expansion

The coefficient of thermal expansion of UHPFRCs varies according to the material used. Standard NF P 18-710:2016 gives clarifications on the value of the coefficient of thermal expansion to be used for the calculation.

When the coefficient of thermal expansion needs to be determined for the UHPFRC, it shall be measured in accordance with NF EN 1770. It is expressed to the nearest 0,5 µm/m/°C.

The value of the coefficient of thermal expansion may be specified, given that it could typically vary depending on the UHPFRC used from 8 µm/m/°C to 14 µm/m/°C. The tolerance on the experimental value obtained is ± 1 µm/m/°C.

5.6 Identity card

5.6.1 Information associated with the description

The identity card shall include an unambiguous description corresponding to all the requirements and resources enabling the established properties to be obtained in a reproducible way (requirements specified or likely to be specified):

a) nominal recipe of the UHPFRC (constituents description, mix-proportions, tolerances, D_{upper}), including if applicable, a premix of constituents;

b) general principles of the mixing process;

c) application of a heat treatment and description of this treatment when it significantly influences the properties in the hardened state (some TT1 UHPFRCs, type TT2 or TT1+2 UHPFRCs);

d) in accordance with this standard, classification (linked in particular with the type of fibres contributing to non-brittleness) and designation.

5.6.2 Minimal requirements

The identity card shall include at least the following requirements as defined in 5.3, 5.4 and 5.5 which shall have been measured or checked less than 2 years ago except for shrinkage and porosity (less than 5 years) and the coefficient of thermal expansion (less than 10 years):

a) consistence and working time ;

b) characteristic compressive strength (at 28 days for type STT and TT1 UHPFRCs, before and after post-setting heat treatment for type TT2 and TT1+2 UHPFRCs);

c) maximum stress and values describing the characteristic behaviour under tension (at 28 days for type STT and TT1 UHPFRCs, before and after post-setting heat treatment for type TT2 and TT1+2 UHPFRCs) and tensile behaviour class, by reference to a given use associated with a placing process and a *K*-factor;

d) Young's modulus;

e) density;

f) air content;

g) water porosity measured at 90 days;

h) apparent diffusion coefficient of chloride ions;

i) gas permeability;

j) coefficient of thermal expansion;

k) total shrinkage amplitude as defined in 5.5.10.

5.6.3 Additional properties

The identity card of a UHPFRC may include additional properties which form part of the requirements described in 5.3, 5.4 and 5.5, or which provide calculation data for a justification in accordance with NF P 18-710:2016, at the producer's initiative, in particular to meet a more complete set of specified requirements, especially:

a) maximum stress and values describing the characteristic behaviour under tension (at 28 days for type STT and TT1 UHPFRCs, before and after post-setting heat treatment for type TT2 and TT1+2 UHPFRCs) and tensile behaviour class, (by reference to other given uses, especially different thicknesses, coupled with the adopted placing processes and to the K-factors obtained);

b) characteristics associated with shrinkage (5.5.10) and creep (5.5.11);

c) class associated to reaction to fire, if applicable, data characterising resistance to thermal instability, parameters associated with the fire resistance calculation

d) abrasion resistance;

e) average compressive strength;

f) average maximum post-cracking stress;

g) characteristics describing constitutive behaviour at high loading rate.

The producer shall provide to the prescriber, on request, details of the determination of the values given in the identity card for the UHPFRC (test reports, internal control data, scatter, etc.).

6 Specification of the UHPFRC

6.1 General

To carry out a given project, the UHPFRC prescriber shall ensure that all relevant requirements corresponding to the required properties of the UHPFRC are included in the specification given to the producer. The prescriber shall also specify all the requirements corresponding to the properties of the UHPFRC necessary for transporting it (before and after delivery), for placing it, or for any other subsequent treatment, and the special requirements associated for example with the expected appearance of the facings.

To achieve this, the prescriber shall take into account:

a) the use of the UHPFRC both when fresh and hardened;

b) curing and further storage conditions;

c) dimensions of the structure (development of heat);

d) environmental attacks and service conditions to which the structure will be exposed in connection with the expected durability;

e) any requirements regarding the appearance of the facings and surface finishes;

f) any requirements associated to the thickness of the sections, the concrete cover of any reinforcing or prestressing steels, and the placing conditions of the UHPFRC.

The UHPFRC is specified as a “designed UHPFRC” (see 3.1.1.3), the specified properties being obtained by the choice of a given UHPFRC from consolidated experimental data in the identity card of the material, or resulting from a design test. A suitability test is used to check that the properties are met under project conditions.

6.2 Basic specifications

The specification of the UHPFRC for a given project shall include:

a) conformity to this standard;

b) compressive strength class;

c) class associated with the type of fibres contributing to non-brittleness;

d) the target value for consistence, otherwise, the consistence class (this consistence indication being in all cases associated with the specified working time);

e) the heat treatment class and the control parameters associated with the treatment(s) if applicable;

f) the tensile behaviour described in accordance with 5.5.4 by the tensile behaviour class of the UHPFRC, the tensile performance curve for the material, and the set of orientation factors appropriate to the structure considered;

g) the indication of the exposure classes applicable to the parts of the structure involved;

h) the design working life of the project.

6.3 Additional requirements

Depending on the nature and requirements of the project, the specification of the UHPFRC may need to include the following additional data associated with the material or the structural member considered:

a) in case of XA1, XA2 or XA3 exposure, the data associated with chemical attacks so that durability-related requirements can be complied with;

b) the characterisation of exposure to fire to be taken into account in the project, the resistance duration and the fire behaviour type expected for the member in UHPFRC;

c) the abrasion resistance class;

d) if necessary, taking into account the design working life of the project, the transfer resistance classes;

e) if relevant, the maximum aggregate size.

Depending on the project requirements, the following properties may be covered by specifications in the form of performance associated with attaining the threshold or target values according to the measuring processes or by application of specified test methods. The conditions for checking whether these requirements have been attained, and in particular the frequency of the control tests, shall be set out in the specifications according the nature and requirements of the project:

a) additional characteristics associated with the consistence of the fresh UHPFRC (if necessary to define the specification by classes or target value);

b) characteristics associated with the development of strength, for example, strength at early age time steps (associated with formwork removal or application of prestressing);

c) density;

d) coefficient of thermal expansion;

e) Young's modulus;

f) Poisson's ratio;

g) shrinkage characteristics (see 5.5.10);

h) creep-related characteristics (see 5.5.11);

i) characterisation of the dynamic behaviour, impact strength;

j) temperature of fresh UHPFRC;

k) air content of the fresh UHPFRC;

l) performance-based requirements pertaining to the UHPFRC material associated with the facings appearance according to FD P 18-503;

m) water porosity;

n) diffusion coefficient of chloride ions;

o) gas permeability;

p) capillary absorption;

q) characterisation of the resistance to chemical attacks (leaching, acid attack, etc.).

Depending on the project requirements, other requirements may be specified in the form of performance associated with attaining the threshold or target values according to measuring processes or by application of test methods which will have to be specified.

Although the performance based expression of the requirements shall preferably be given in the specification of UHPFRCs, additional specifications may be based on the exclusion or mandatory use of a source or a particular type of constituent. In this case, the prescriber shall ensure that its use is compatible with the specification of the UHPFRC.

Additional requirements regarding resources or performance, again based on the material or its constituents, may be associated with the manufacturing process, transport, placing and treatment during the maturation of the UHPFRC in order to obtain the required properties. Additional requirements based on the material may, for example, also be associated with the prevention of corrosion of the fibres emerging at the surface, to the application of surface treatments or to obtaining a finished facing. In all these cases, the prescriber shall ensure that the specified conditions are compatible with the specification of the UHPFRC.

Articles 7 to 10 specify the conditions for checking that the requirements of 6.2 and 6.3 have been met during the design test, suitability test and in the control tests during production.

7 Design and suitability tests

7.1 General

The design test, performed by the UHPFRC producer or under his responsibility, consists in checking that the UHPFRC formula enable to satisfy the specifications of the project taking account of the manufacturing tolerances. As such, the producer may, if applicable, rely on the existence of an identity card for meeting all or some of the specifications. In the absence of an identity card or suitable information in the identity card, he shall carry out a design test which includes the determination of the specified properties which had not been studied beforehand.

The UHPFRC producer shall then carry out a suitability test in order for the specifier to approve the use of the proposed UHPFRC formula taking into account the resources used for manufacturing, transport, placing, curing and carrying out any treatments provided for in the production procedures. The suitability test shall also include production of a control member under the responsibility of the user of the fresh UHPFRC in order to validate all the production procedures and in particular the conditions for placing, curing and carrying out any treatments, by reaching the specified performance figures.

7.2 Design test

7.2.1 Content of the design test

The design test shall be based on all the properties of the UHPFRC specified for a given project as detailed in clause 6. It consists in validating that the performance figures have been attained by the nominal recipe and in checking that this nominal recipe remains robust if the proportions of the constituents reach the tolerated boundary values, robustness being assessed with regard to compressive and tensile strength, and consistence. Validation shall include the application of any planned heat treatments.

As such, the design test shall be based on the following mixes:

a) a mix according to the nominal recipe;

b) a mix relating to the solid derivative whereby a quantity of binder equal to once the weighted tolerance is added and a quantity of added water equal to once the weighted tolerance is removed;

c) a mix relating to the liquid derivative whereby a quantity of added water equal to once the weighted tolerance is added and a quantity of binder equal to once the weighted tolerance is removed.

A sample shall be taken from each mix on which the tests relating to the basic specifications are carried out:

a) a consistence test appropriate to the workability of the concrete combined with a measurement of the temperature of the fresh concrete;

b) a determination of the practical period of use of the UHPFRC by taking regular measurements of the consistence over time using the test appropriate to the workability of the concrete, supplemented if necessary by measurements at a temperature representative of the likely placing conditions;

c) a test to determine the compression strength (measured over at least three test specimens) in accordance with Annex C;

d) a test to determine the tensile behaviour according to Annex D or Annex E.

The mix corresponding to the nominal recipe shall enable samples required for the following additional tests to be taken:

— those relating to checking conformity to this standard (water porosity, diffusion coefficient of chloride ions, apparent permeability to gases, density, compliance with the requirements of 4.3.3 regarding any heat treatment applied),

— those relating to the additional requirements with reference to 6.3 and the determination of the activation energy of the UHPFRC allowing subsequent recalibration in equivalent time.

7.2.2 Acceptance criteria of the design test

7.2.2.1 General

The design test is considered probative if the following conditions are all fulfilled:

a) the results of the water porosity, diffusion coefficient of chloride ions, apparent permeability to gases and density tests are all compliant with the requirements given in 4.2.2 and 4.4.2;

b) where a heat treatment is applied, the requirements of 4.3.3 are satisfied;

c) the results of tests relating to the additional requirements are all compliant with the specifications;

d) all the consistence results (measured in the interval corresponding to the practical period of use) comply with the specified class, or are within the specified range relative to the target consistence value, under temperature conditions compliant with 5.2.10 for the nominal recipe and its derivatives;

e) the results of the compressive and tensile tests for the nominal recipe and the derivatives satisfy the requirements given in 7.2.2.2 and 7.2.2.3.

7.2.2.2 Acceptance criteria for the results of the compressive strength tests

On the one hand:

The arithmetic mean ($f_{cm,n}$) of the results of the mix corresponding to the nominal recipe shall satisfy the following inequalities (2) and (3):

$$f_{cm,n} \geq f_{ck,req} + C_E - (C_{moy} - 3S_c) + 3 \text{ (MPa)} \qquad (2)$$

$$f_{cm,n} \geq 1{,}1\, f_{ck,req} \qquad (3)$$

On the other hand:

For each of the derivative mixes, the average of the compressive strength results shall satisfy the following inequalities (4) and (5):

$$f_{cm,d} \geq f_{ck,req} + C_E - (C_{moy} - S_c) \quad (4)$$

$$f_{cm,d} \geq 1{,}05\, f_{ck,req} \quad (5)$$

In these inequalities, with values expressed in MPa:

- $f_{cm,n}$ is the arithmetic mean of the compressive strength results obtained from the mix associated to the nominal recipe;
- $f_{cm,d}$ is the average compressive strength result on a derived mix;
- $f_{ck,req}$ is the required characteristic value of the compressive strength;
- C_E is the compressive strength at 28 days of the cement used for the design test, determined in accordance with NF EN 196-1;
- C_{moy} is the average value of the compression strength of the cement at 28 days, determined in accordance with NF EN 196-1, observed by the supplier during the six months preceding the design test;
- S_c is the standard deviation of the values used to determine C_{moy}.

7.2.2.3 Acceptance criteria for the results of the tensile tests

For each of the derivative mixes and for the mix using the nominal recipe, the estimate of the characteristic value of the limit of elasticity $f_{ctk,el}$ from the 4-point bending tests shall be greater than or equal to the required value $f_{ctk,el,req}$.

For each of the derivative mixes and for the mix corresponding to the nominal recipe, the estimate of the characteristic curve of the tensile behaviour determined in accordance with Annex D or Annex E shall be greater than or equal at all points to the law required by reference to 6.2.

For each of the derivative mixes and for the mix corresponding to the nominal recipe, the UHPFRC shall belong to the specified tensile behaviour class, or to a higher class.

7.3 Suitability test

7.3.1 Content of the suitability test

7.3.1.1 Properties to be verified

The suitability test shall in all cases include checking of the following properties of the UHPFRC:

a) the consistence, determined according to the test appropriate to the workability of the UHPFRC combined with a measurement of the temperature of the fresh UHPFRC;

b) the practical period of use of the UHPFRC determined by taking regular measurements of the consistence over time using the test appropriate to the workability of the concrete, supplemented if necessary by measurements at a temperature representative of the likely placing conditions;

c) the compressive strength (determined by application of Annex C);

d) the tensile behaviour (determined by application of Annex D or Annex E).

When the following properties are specified for the given project, the suitability test shall in addition include checking of:

a) the air content of the fresh UHPFRC;

b) any additional characteristics associated with the consistence of the fresh UHPFRC in conjunction with the placing conditions;

c) Young's modulus;

d) the strength development (characterised, for example, by values at early ages with reference to the requirements associated with removal of formwork, handling, prestressing or heat treatment).

The samples used to confirm that the specified performance figures are reached by the nominal recipe, shall be taken from a representative load of UHPFRC produced under the set out conditions and according to the production procedures to be validated (mixing, production of a representative volume, transport, placing and any treatments if applicable). A sample shall be taken when placing of the load starts and ends. Each sample shall enable the properties specified for fresh UHPFRC to be determined and half of the test specimens required on hardened UHPFRC to be produced.

The minimum number of test specimens produced in total for checking the properties to be measured systematically shall be:

— 6 test specimens to determine the compressive strength according to Annex C;

— 12 prisms for determining the tensile behaviour according to Annex D, or 4 plates for determining tensile behaviour according to Annex E. The producer's quality assurance system shall provide for a check on uniformity of the distribution of fibres after the tests on prisms have been completed.

Where a heat treatment as described in 5.4.8 is applied, the suitability test also includes the manufacture and storage of test specimens for checking compliance with the requirements of 4.3.3.

7.3.1.2 Control mock-up

The suitability test shall also include production of a control mock-up representative of the actual structure and its production conditions. This mock-up, certain dimensions of which may be reduced, shall be full-scale in the directions of least thickness, in areas where concentrated forces are applied, and shall enable any difficulties in casting the UHPFRC and restrained deformations to be identified. It shall enable the following to be validated:

a) the methodology for placing the UHPFRC, its effectiveness and its effect on the orientation of the fibres (characterised by the determination of the orientation factors *K*), incorporating, if relevant, specific provisions in case of placing successive loads;

b) provisions for curing the concrete;

c) provisions for preparing any areas for resumption of concreting;

d) if applicable, the compliance of facings with the required quality;

e) achievement of dimensional tolerances and concrete cover if necessary;

f) if applicable, the ability to carry out heat treatment(s) in a controlled way;

g) if necessary, the formwork removal kinetic in conjunction with the strength development.

The detail definition of the control member and of the suitability test programme associated with this member including the sampling plan for determining the K orientation factors shall be the subject of an agreement between the specifier, the UHPFRC producer and (except for a prefabricated product in UHPFRC covered by a product standard) the prime contractor. The determination of the K orientation factors shall be carried out in accordance with Annex F.

7.3.2 Acceptance criteria of the suitability test

7.3.2.1 General

The suitability test is considered probative if the following conditions are all fulfilled:

a) all the consistence results (measured in the interval corresponding to the practical period of use) comply with the specified class, or are within the specified range relative to the target consistence value, under temperature conditions conforming to 5.2.10 or under temperature conditions representative of the envisaged production process;

b) the results of the compressive strength and tensile behaviour tests satisfy the following requirements;

c) when a heat treatment as described in 5.4.8 is applied, the requirements of 4.3.3 are met;

d) when these properties are specified for the project, the results obtained in terms of air content of the fresh UHPFRC, of any additional characteristics associated with the consistence of the fresh UHPFRC in conjunction with its placing conditions, in terms of Young's modulus or strength development, are all included in the range specified around the target value;

e) the values of K_{global} and K_{local} are smaller than or equal to the specified values for all parts of the structure and directions considered;

f) the placing and treatment procedures for the UHPFRC applied during the manufacture of the control member are validated by the achievement of the specified performance figures on this control member.

7.3.2.2 Acceptance criteria for the compressive strength tests

The results of the compressive tests are deemed satisfactory if inequalities (6) and (7) are satisfied:

- $f_{cm} \geq f_{ck,req} + C_E - (C_{moy} - 3S_c)$ (6)

- $f_{cm} \geq 1,1\, f_{ck,req}$ (7)

In these inequalities, with values expressed in MPa:

— f_{cm} is the arithmetic mean of the compressive strength results;

— $f_{ck,req}$ is the characteristic value required for the compressive strength;

— for UHPFRCs produced without use of premixes of constituents:

  — C_E is the compressive strength at 28 days of the cement used for the design test, determined in accordance with NF EN 196-1,

  — C_{moy} is the average value of the compressive strength of the cement at 28 days, determined in accordance with NF EN 196-1, observed by the supplier during the six months preceding the design test,

  — S_c is the standard deviation of the values used to determine C_{moy};

— for UHPFRCs produced from a premix of constituents:

— C_E is the compressive strength of the control material obtained with the premix used for the design test, determined in accordance with Annex G;

— C_{moy} is the average value of the compression strength of the control material determined in accordance with Annex G, observed by the supplier during the six months preceding the suitability test;

— S_c is the standard deviation of the values used to determine C_{moy}.

7.3.2.3 Acceptance criteria for the tensile tests

The results of tensile behaviour tests on moulded test specimens (produced and analysed according to Annex D or Annex E) are deemed satisfactory if all the following conditions are satisfied:

a) each individual value of the limit of elasticity from the tests $f_{cti,el}$ is greater than 1,0 time the required characteristic value $f_{ctk,el,req}$;

b) the average of the values of limit of elasticity $f_{cti,el}$, denoted as $f_{ctm,el}$, is greater than 1,05 times the required value $f_{ctk,el,req}$;

c) the estimate of the characteristic curve of the tensile behaviour determined in accordance with Annex D or Annex E shall be at all points greater than or equal to the law required by reference to 6.2;

d) the estimate of the average curve of the tensile behaviour determined in accordance with Annex D or Annex E shall, beyond the limit of elasticity, be at all points greater than or equal to1,1 times the law required by reference to 6.2.

8 Production control of UHPFRC

8.1 Control of production and transportation of fresh UHPFRC

The production and transportation of the UHPFRC to the location where it is to be placed shall be carried out under quality assurance provisions and be subject to an internal control by the UHPFRC producer. The UHPFRC producer should have information on the duration and conditions of storage of the constituents used compatible with achieving the expected performance figures, and take account of this in his organisation. In particular, if he uses a premix, he should comply with the recommendations for reaching the performance figures mentioned in the identity card associated with the premix used.

The associated procedure shall include all execution requirements given in NF P 18-451. It shall moreover include the following production controls:

a) control of the constituents forming part of the composition of the UHPFRC, based on the regularly-updated product technical data sheets, periodically supplemented by results of acceptance testing to enable compliance with the requirements listed in 5.1 and 5.2 to be verified;

b) control of the storage duration and conditions for the constituents;

c) control of the compliance with the composition tolerances, in compliance with the objectives set out in 5.2.1;

d) control of compliance with the mixing procedure described in 5.2.12;

e) control of the homogeneity of the fresh UHPFRC after transportation by reference to 5.4.4;

f) control of the temperature of the fresh UHPFRC immediately before placing (see 5.2.10 and 5.4.6);

g) the definition of corrective actions in the event of a deviation.

Controls listed in this sub-clause shall in particular be based on:

a) the recording of weighings and of the characteristics describing the mixing sequence;

b) the measurements of consistence carried out if necessary at the point of release from the mixer and compulsorily, for each load, at the point of delivery and after transportation for placing according to the requirements of NF P 18-451;

c) the measurement of additional characteristics associated with the consistence of the fresh UHPFRC when such properties are prescribed;

d) the recording of the temperature of the fresh UHPFRC;

e) samples of the fresh UHPFRC taken and tested in accordance with the requirements of 5.4.4.

The quality system of the UHPFRC producer shall enable a load which does not comply with the target values of this system to be isolated, either at the weighing stage or at the control stage of samples of UHPFRC from the mixer or after transportation.

The records associated with UHPFRC production and transportation control shall be kept for a minimum of 36 months as part of the UHPFRC producer's internal control system and shall be passed on to the UHPFRC user on request. They may be shown on the delivery note with the review of the UHPFRC specification when delivery of the fresh UHPFRC corresponds to transfer of ownership.

The internal control associated with UHPFRC production may be supplemented by a contradictory testing based on the tests on fresh UHPFRC mentioned above, or by an external testing by a third party. The provisions of such testing do not form part of the present standard and come under special contract documents.

8.2 Control of the installation of fresh UHPFRC

Placing fresh UHPFRC shall be carried out under quality assurance provisions. The quality assurance provisions implemented by the user and the corresponding requirements are described in NF P18-451.

The records associated with UHPFRC placing control shall be kept for a minimum of 36 months and passed on to the specifier on request.

8.3 Control of setting and curing of UHPFRC

The quality assurance provisions regarding control of the setting and maturation of the UHPFRC are described in NF P 18-451.

The checks shall include at least the following:

a) a check that the requirements of 5.4.7 have been met, the conditions and frequency of which were determined in the corresponding protocol;

b) a check on the application of the heat treatment protocol, if applicable, by a continuous recording of the temperature and relative humidity values associated with these operations;

c) a check that the specifications in terms of compressive strength and tensile behaviour have been fulfilled, this check needing to be carried out at a frequency subject to an agreement between the producer, the UHPFRC user and the specifier, the frequency needing to be at least one sample for each volume of UHPFRC produced under 10 m³, plus one sample per additional fraction of 10 m³ produced or the remaining fraction. Each sample shall enable 3 compressive tests to be carried out in accordance with Annex C and, depending on the thickness of the member concerned, 6 bending tests on un-notched prisms in accordance with Annex D or 6 bending tests on thin plates in the most critical direction in accordance with Annex E.

When the following properties are specified for the given project, the checks may in addition include measurements for checking that the associated specifications have been fulfilled according to the conditions and at a frequency covered by an agreement between the specifier, the UHPFRC producer and the user. These measurements on hardened UHPFRC may for example be based on:

a) characteristics associated with the strength development, for example, strength at an early age (associated with removal of formworks or application of prestressing);

b) density;

c) Young's modulus;

d) shrinkage characteristics;

e) creep-related characteristics;

f) performance-based requirements applicable to the UHPFRC material associated with facings appearance;

g) water porosity;

h) diffusion coefficient of chloride ions;

i) gas permeability;

j) capillary absorption;

k) characterisation of the resistance to chemical attacks (leaching. acid attack, etc.);

l) characterisation of the abrasion resistance.

The checks associated with the specified properties shall be carried out both by the UHPFRC producer and by the user, as well as for external control requirements. Provisions for such checks do not form part of the present standard and come under special contract documents.

The records associated with checking the UHPFRC when placed and with the performance of the UHPFRC when hardened shall be kept for a minimum of 36 months under the UHPFRC user's internal control system and passed on to the specifier when the structure or manufactured members are delivered.

9 Production control and compliance with requirements

9.1 Criteria applicable to the production and delivery of UHPFRC in fresh state

The conformity of UHPFRC produced and delivered may be declared if the following conditions are all fulfilled:

a) records of weighing operations and checking of material sources enable to declare compliance with the nominal recipe within the limits of – 2% and + 4% for the fibres and ± 2% for all other constituents weighed;

b) records of the sequence of mixing operations enable to declare compliance of the mixing procedure within a limit of ± 1 % throughout each phase;

c) the temperature of the fresh concrete and the ambient temperature during placing rounded to the nearest °C are within the specified ranges;

d) the consistence measured if necessary at the point of release from the mixer and compulsorily, for each load, after transportation for placing is within the specified range (see 5.4.1);

e) when the mix or the volume of UHPFRC delivered is subject to analysis, the result of samples of fresh UHPFRC subject to qualitative testing (e.g. absence of clusters) or to quantitative testing (e.g. air content, fibre content) as indicated in 5.4.4 fulfil the criteria defined in the appropriate procedure.

If one of the aforementioned conditions is not satisfied, the mixes or corresponding batches or loads which are likely to have been affected shall be identified and removed wherever possible. If this cannot be done, the producer shall inform the user without delay. The user shall carry out suitable curative measures in compliance with the provisions given in NF P 18-451 and, if applicable, those of NF P 18-710:2016. The next batches and loads shall be subject to the full set of recordings and control measures. If one of the aforementioned conditions is still not satisfied, concreting shall be stopped until the causes of the non-conformity are determined and settings changed to reach all specifications.

9.2 Criteria applicable to hardened UHPFRCs

9.2.1 General

The conformity of placed and hardened UHPFRC may be declared if the following conditions are all fulfilled:

a) the checks and records relating to UHPFRC placing operations comply with the requirements in 8.2;

b) the temperature and relative humidity records associated with any heat treatment operations on the UHPFRC enable to declare compliance with the protocol associated with these operations, mentioned in 5.4.8; to this end, the temperature measured shall not differ by more than 2°C from the specified value, the relative humidity shall not differ by more than 5% from the specified value, and the age of the material at the start of each of these treatment phases (incorporating retiming in equivalent time) shall not differ by more than 1 h from the specified value;

c) the results of the compressive strength and tensile behaviour tests, carried out on tests specimens which have followed the same protocol as the structure in terms of curing and heat treatment if applicable, satisfy the requirements described below;

d) all measurements of additional properties subject to a check satisfy the specified inequality or are included in the specified range around the target value.

9.2.2 Acceptance criteria for the compressive strength tests

The results of compressive strength tests are deemed satisfactory if:

a) on the one hand, for the project considered, whenever a control test sample is taken, inequalities (8), (9) or (10), and (11) are satisfied simultaneously:

$$S_c \leq 10\ \%\ f_{ck,req} \quad (8)$$

$$f_{cm} \geq f_{ck,req} + 1{,}3\ S_c \text{ if } n \geq 15 \quad (9)$$

or

$$f_{cm} \geq f_{ck,req} + \alpha\ S_c \text{ if } 3 \leq n < 15 \qquad \text{where } \alpha = [(n\text{-}3).1{,}3+(15\text{-}n).1]/12 \quad (10)$$

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$$f_{ci} \geq f_{ck,req} - 7{,}5 \qquad (11)$$

In these inequalities, with values expressed in MPa:

— f_{cm} is the arithmetic mean of n control test results for compressive strength if $n \leq 15$, and the average of the last 15 results if $n > 15$,

— $f_{ck,req}$ is the required value of the characteristic compressive strength,

— f_{ci} is the value of the compressive strength given by test i,

— S_c is the standard deviation of the aforementioned last fifteen results;

b) on the other hand, when the production of a given composition of fresh UHPFRC is intended for a number of structures, the aforementioned inequalities are still satisfied by considering the results of fifteen consecutive samples, whatever structure the UHPFRC is intended for

If one of the three conditions is not fulfilled, production shall be suspended until the causes of the non-conformity are determined and corrective action undertaken until the inequalities are satisfied.

9.2.3 Acceptance criteria for the tensile tests

The results of the 4-point bending tests on un-notched test specimens (see 8.3c) are deemed satisfactory if:

a) on the one hand, for each test sample (moulded), the maximum moment $M_{max,i}$ is greater than 0,95 times the maximum moment M_{ref}, calculated with the specified tensile response curve (calculation law without taking into account the partial coefficient γ_{cf} relating to the tensioned UHPFRC or the orientation factor K, as set out in 5.5.4 and 6.2);

b) on the other hand, the average of the maximum moments, $M_{m,max}$, is greater than 1,05 times M_{ref}.

10 Conformity evaluation

10.1 Conformity evaluation steps for a UHPFRC

Conformity evaluation of a UHPFRC with this standard comprises a number of steps which may or may not represent transfers of responsibility:

a) conformity evaluation of the premix, when the UHPFRC is produced from this premix of constituents (evaluation is based on a potential compliance with the identity card for the UHPFRC);

b) initial evaluation of conformity of the UHPFRC by acceptance of the design test including if appropriate the data from the identity card for this UHPFRC (the evaluation is based on compliance with the specification, without incorporating all the specificities of the production process);

c) initial evaluation of conformity by acceptance of the suitability test (the evaluation is based on full compliance with the specification incorporating both the UHPFRC formula and the mixing, transportation, placing and treatment processes);

d) conformity evaluation in the production phase based on the results of the control tests associated with the supply of fresh UHPFRC;

e) conformity evaluation in the production phase based on the control tests associated with placing the UHPFRC, to the treatments applied to it, and to meeting the specified performances for hardened concrete.

Conformity of the UHPFRC to this standard is only established when compliance with each of these steps has been verified, whether or not transfer of ownership is involved.

10.2 Tasks and responsibilities

The producer of a premix of constituents intended for use in UHPFRCs is responsible for assessing and declaring conformity to the properties specified according to the conditions defined in Annex G.

The UHPFRC producer is responsible for evaluating conformity at the stage of the design test, the results of which are submitted to the specifier for acceptance.

The UHPFRC producer is responsible for evaluating conformity at the stage of the suitability test, for what derives from checks on consistence, compressive strength, tensile behaviour determined on moulded test specimens, along with the air content, Young's modulus and strength development if applicable. The UHPFRC user is responsible for evaluating conformity at the stage of the suitability test for what concerns the orientation factors K_{global} and K_{local} and the placing and treatment procedures of the UHPFRC, as applied when manufacturing the control mock-up in order to validate them. With the exception of UHPFRCs used for prefabricated products covered by product standards, the results of the suitability test shall be submitted to the client for acceptance.

The fresh UHPFRC producer is responsible for evaluating and declaring the conformity of the UHPFRC according to the conditions defined in 9.1 with regard to compliance with the production protocol and the properties determined in fresh state, and according to the conditions defined in 9.2 for properties defined in hardened state for the purposes of the potential conformity of the UHPFRC delivered: compressive strength, tensile behaviour, any additional properties specified.

The fresh UHPFRC user, producer of a product, element or structure in hardened UHPFRC is responsible for evaluating and declaring the conformity of the UHPFRC according to the conditions in 9.2 with regard to compliance with the placing, curing and any heat treatment protocols, and with regard to compliance with the properties determined for UHPFRC in hardened state: compressive strength, tensile behaviour, any additional properties specified or subject to checks.

For prefabricated products, requirements and specific provisions associated to the conformity evaluation of the UHPFRC may be specified in the relevant technical specifications (NF EN 13369:2013, product standards and technical approvals).

The internal checks carried out for conformity evaluation described above may be supplemented by a third party evaluation. This is not covered by the present standard and comes under the special documents for the contract.

NOTE Acceptance of a structure or structure parts in UHPFRC should be governed by the submission of these results to the prime contractor.

Annex A
(normative)

Adaptation of procedures for determining transfer resistance classes

A.1 Measurement of the diffusion coefficient of chloride ions

Carry out a measurement at 90 days in accordance with XP P 18-462 taking into account the following additional instructions:

a) the diameter D of the test body shall be at least equal to 3 L_f and their thickness may be reduced to 30 mm;

b) as far as possible, choose the current intensity I and test duration Δt in order to fulfil, as for other concretes, the following condition: 3.105 A.s.m-2 ≤ I × $\Delta t/S$ ≤ 9.105 A.s.m-2, where S is the exposed surface area of the test body, in m². This results in a penetration depth Xd of the order of 10 mm to 20 mm and enables a comparable relative uncertainty of the test to be maintained;

c) if it is not possible to accurately measure the current intensity, apply a voltage of 60V and adopt a duration Δt for the test of between 96 h and 500 h.

A.2 Measurement of the apparent gas permeability

A.2.1 Verification of the threshold relating to the scope of this standard

Carry out a measurement at 90 days in accordance with XP P 18-463:2011 taking the following modifications into account:

a) only carry out the measurement after drying at 105°C, drying being stopped when the determination criterion of M_{sec} is reached in accordance with 7.2.2 of XP P 18-463:2011;

b) the flow rate can be determined by measuring the transit time on a reduced portion of the flowmeter tube (not necessarily between the two maximum volume graduations);

c) the transit time of the soap bubble on the portion of flowmeter chosen shall be between 20 s and 180 s;

d) according to the Note in 5.3 of XP P 18-463:2011 it is also possible to use a mass flowmeter.

A.2.2 Verification of the threshold relating to class Dg+ (see 4.2.2)

Carry out a measurement at 90 days in accordance with XP P 18-463:2011 taking the following modifications into account:

a) only carry out the measurement after drying at 105°C, drying being stopped when the determination criterion of M_{sec} is reached in accordance with 7.2.2 of XP P 18-463:2011;

b) the thickness of the test body crossed by the gas flow may be reduced to 30 mm;

c) according to the Note in 5.3 of XP P 18-463:2011 carry out the measurement using a mass flowmeter;

d) it is possible to increase the exposure time of the sample to the gas pressure gradient so as to reach steady state operating conditions, without exceeding 120 min. It is also possible to increase the time t over which the flow rate is measured without however exceeding 30 min.

Annex B
(normative)

Estimation of characteristic values

The characteristic value of a strength equates to an overrun probability of 95% in this standard, according to NF EN 1990 (Eurocode 0). However, in this standard, it shall be estimated from a population of experimental values assuming a normal distribution and using Student's law with a non-execution probability of less than 5%.

The estimate of the characteristic value is then equal to the experimental mean value reduced by the product of Student coefficient (reproduced in Table B.1) by experimental estimation of the standard deviation.

Table B.1 — Student coefficients

Number of experimental results	Student coefficient
3	2,920
4	2,353
5	2,132
6	2,015
7	1,943
8	1,895
9	1,860
10	1,833
11	1,812
12	1,796
....	...
> 30	1,7
....	...
∝	1,645

To obtain estimates of the characteristic curves, the above analysis shall be carried out stepwise and not on the integral of the curve.

Annex C
(normative)

Compressive test and derived mechanical properties

C.1 Characteristics of test specimens

The test specimens used for the compressive tests (evaluation of the strength or of the modulus) shall comply with the following criteria:

a) the reference specimen is the moulded cylinder of nominal dimensions Ø110 mm x 220 mm when the length of the longest fibres is less than 22 mm, or the moulded cylinder of nominal dimensions Ø160 mm x 320 mm for longer fibres. The tests may be carried out on cylinders with other dimensions, or on cubes, subject to prior determination at the design stage or in the identity card of the correspondence coefficient to the value determined on the reference specimen; in all cases, the smallest dimension Ø of the test specimens shall satisfy $Ø \geq 5\ L_f$ and $Ø \geq 6\ D_{upper}$ (Lf being the length of the longest fibres and D_{upper} the upper nominal dimension of the coarsest aggregate);

b) the test specimens shall satisfy the requirements of NF EN 12390-1, NF EN 12390-2 and NF EN 12390--:2012, noting that for test specimens with dimensions outside the reference values of NF EN 12390-1, Annex B of NF EN 12390-3:2012, applies;

c) in order to apply NF EN 12390-2, the filling of the moulds and compacting shall be adapted to the consistence of the UHPFRC. For UHPFRCs of class Ca, placing is by gravity, for UHPFRCs of class Cv, compacting may be improved by the use of a tamping rod, for UHPFRCs of class Ct, external vibration may be used if it is representative of the placing process used in the structure. In all cases, the use of a vibrating needle is prohibited;

d) taking account of the high strengths expected, surfacing shall be carried out with particular care using a disc grinder.

C.2 Determination of the compressive strength

The tests shall be carried out in accordance with NF EN 12390-3:2012 with the following clarifications:

a) the compressive testing machine shall be controlled for the load with a loading rate of between 0,4 MPa/s and 0,8 MPa/s;

b) for sampling, the determination of a mean strength value shall be obtained as the average of a minimum of 3 test specimens;

c) the estimate of the characteristic value of the compressive strength for the population of results considered shall be obtained following Annex B of this standard.

C.3 Determining Young's modulus

Before the test to determine Young's modulus, the average strength of the concrete considered should be determined through three tests up to failure.

The tests for determining Young's modulus shall be carried out in accordance with NF EN 12390-13:2014, amended by the indications in C.1 in terms of test specimen shapes and dimensions. Method B of this standard is applied in order to determine Young's modulus, assessed as a stabilised secant modulus.

The following additional indications apply:

— the strain measurements shall be performed using three or more strain gauges arranged symmetrically on the test specimen;

— the accuracy and calibration of the strain gauges shall be such as to ensure an absolute error of less than 5 µm/m.

C.4 Determination of Poisson's coefficient

Poisson's coefficient for the UHPFRCs shall be determined on the test specimens identical to those for measuring Young's modulus, tested in accordance with the same protocol (NF EN 12390-13:2014 adapted according to C.3), the measurements from the strain gauges arranged in the transverse direction being processed similarly.

Annex D
(normative)

Bending tests on prisms and method of data processing

D.1 Introduction

This annex describes the experimental and results analysis procedures for characterising the tensile performance of UHPFRCs through bending tests, when (unlike for thin members for which Annex E is applied), the orientation of the fibres is not influenced by a reduced member thickness relative to the dimension of the fibres.

Two types of test are described:

— four-point bending tests on un-notched prisms which enable the limit of linear behaviour to be ascertained;

— three-point bending tests on notched prisms which enable the contribution of the fibres as reinforcement of a cracked section to be ascertained and the tensile behaviour class determined (see 4.4.3).

The annex describes the method of using these tests to determine an equivalent response curve for the material under direct tension by inverse analysis.

The tests shall be performed and used in series of at least 6 specimens of the same type. The determination of the tensile limit of elasticity and the inverse analyses to determine the post-peak tensile behaviour shall be applied to the average curve and the characteristic curve from the series of test results.

D.2 Dimensions and preparation of test specimens

The test specimens shall be prisms of square section $a \times a$ and length $4\,a$. The dimension a, between 7 cm and 20 cm, shall be between 5 and 7 times the length of the longest fibres.

These dimensional criteria apply in general for both moulded prisms and prisms sampled by sawing (in particular during the suitability test for determining the K factor). For the sawn prisms, taking account of the geometry of the original structure, the prism length criterion may be relaxed (provided that the span equal to 3 times the height rule is not modified), along with the width criterion (which may vary between one half of the height of the prisms and one-and-a-half times the height).

For prisms poured in UHPFRC of consistence class Ca and Cv, the test sample shall be produced by leaving the UHPFRC to flow from one end of the mould, the flow being encouraged by rodding only for UHPFRCs of consistence class Cv, reloading being carried out systematically behind the flow front. For these consistence classes, vibration is prohibited.

For prisms poured in UHPFRC with consistence class Ct, a repeatable installation method derived from that used for the structure shall be defined.

In all cases, filling the mould using heaps placed side-by-side is prohibited.

For prisms which are to be notched, a notch shall be sawn in the central section of the tensioned face during the bending test. This face shall be one of the side faces which was against the formwork when the prism was poured. The depth of the notch is equal to half the length of the longest fibres. The width of the notch shall be less than 3 mm.

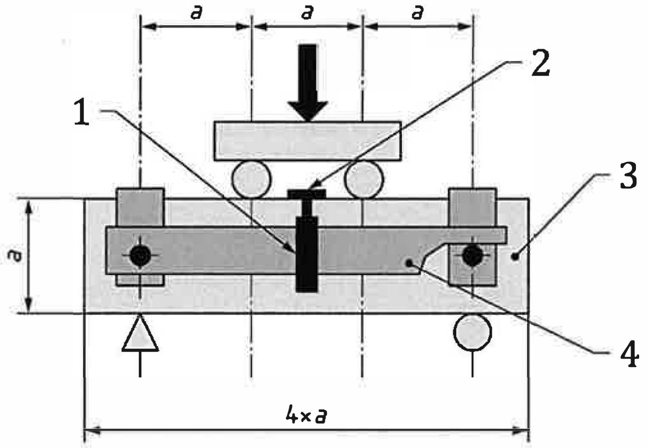
D.3 Conducting the tests

The specimens are tested using three-point flexure (centred flexure) for notched prisms, and four point flexure (circular flexure) for un-notched prisms, with moulded prisms being supported on the two side faces. For sawn prisms, the test specimens shall be orientated so that the side faces have the same edge effect with regard to the fibres during the test. This orientation shall be identical for all prisms of a given series and mentioned in the test report.

The length between the lower supports is equal to three times the height of the prism.

The test machine is a universal testing machine which can be servo-controlled with respect to the actuator load or displacement, or to an external sensor. The support and load application system shall be made up of a fixed point and moving points (for example supports on rollers), to limit the spurious axial force.

For four-point bending tests, a displacement sensor shall be fixed by a specific device to the sample in order to measure its deflection during the test (Figure D.1). The average deformation of the lower fibre may also be measured using one or more extensometers arranged around the lower fibre of the prism. This or these sensor(s) may be fixed using bonded studs.



Key

1 Displacement sensor

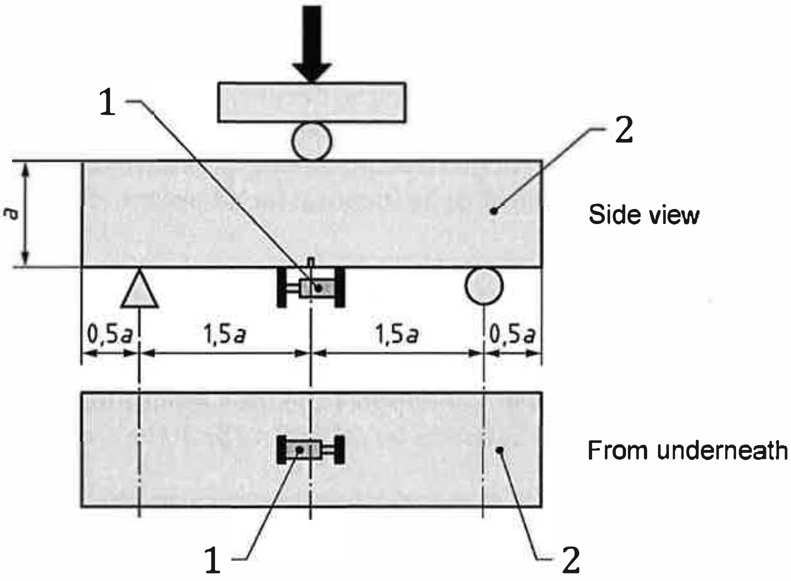
2 Glued idler plate, e.g. made of aluminium

3 Specimen

4 Yoke for measuring the central deflection

Figure D.1 — Deflection measuring principle in a four-point bending test

For three-point bending tests, a sensor spanning the notch is fixed to the prism around the lower tensioned fibre of the prism (Figure D.2). The distance between the fixing studs shall be the same between one test and another and less than 5 cm. The sensor range shall be less than 2 mm. The accuracy of the displacement measurement shall be better than 0,5% of the range full scale.



Key

1 Extensometer

2 Speciment

Figure D.2 — Measuring principle of the opening of a crack in a three-point bending test

A pre-load is applied to the test specimen of as low an intensity as possible, which shall be taken into account in the rest of the test.

NOTE The application of the pre-load may be controlled by the actuator displacement or by controlling the force.

After the pre-load has been applied, the servo-control is activated either on the crack opening sensor or on the deflection sensor, or on the actuator displacement sensor.

Depending on the sensor chosen for controlling the test, the loading rate shall be adapted as follows:

— by actuator displacement control: (0,25 ± 0,1) mm/min;

— by control on deflection: (0,1 ± 0,05) mm/min;

— by control on sensor measuring the extension of the lower fibre or bridging the crack: (0,025 ± 0,01) mm/min.

The test is continued until at least one of the following criteria is fulfilled:

— deflection measured directly on the sample attaining 0,015 x a (a being the height of the prism);

— extension of the lower fibre attaining 0,015 x a (a being the height of the prism).

Data shall be recorded during the test at a frequency of at least 5 recordings per second. The signals to be recorded are:

— the time;

— opening of the crack or extension of the lower fibre;

— the deflection;

— the force;

— if relevant, the displacement of the actuator.

D.4 Use of the 4-point bending test on un-notched prisms

D.4.1 Determination of the limit of elasticity under tension

The curve derived from the force– deflection or force – extension curves from the 4-point bending tests enable the value of the force (F_{nl}) corresponding to the loss of linearity of the behaviour to be determined. The corresponding stress, called the limit of elasticity in bending, is calculated by the following formula (D.1):

$$f_{ct,fl} = 3\ F_{nl} / b.a \qquad \text{(D.1)}$$

where F_{nl} is in N, *a and b* are in mm, and $f_{ct,fl}$ is in MPa

where *a* is the height of the prism in mm and *b* is the width of the prism in mm.

To obtain an estimated considered as intrinsic, the tensile limit of elasticity $f_{ct,el}$ is calculated by applying the formula (D.2) following:

$$f_{ct,el} = f_{ct,fl}\ \frac{\kappa\ a^{0,7}}{1+\kappa\ a^{0,7}} \qquad \text{(D.2)}$$

where κ = *0,08*

and where *a* is the height of the prism in mm.

NOTE The coefficient κ may be recalibrated for UHPFRCs of class T3, it will be in general greater than 0,08 which will increase the limit $f_{ct,el}$ calculated.

The average limit of elasticity $f_{ctm,el}$ shall be determined by applying the method to the average curve from the tests.

The characteristic limit of elasticity $f_{ctk,el}$ shall be determined by applying the same method to the characteristic curve from the tests.

D.4.2 Data processing in the case of class T3 UHPFRCs

In the case of class T3 UHPFRCs, for which a stress-deformation analysis shall be carried out in accordance with NF P 18-710:2016, the tensile law σ-ε shall be inferred from the 4-point bending tests by using the step-by-step inverse analysis method described in Annex E of this standard.

D.5 Data processing of the 3-point bending test on notched prisms

D.5.1 Determination of the crack opening

To take account on each of the test curves of the elastic deformation averaged over the gauge length of the sensor bridging the notch, the crack opening shall be determined by removing the value of the crack opening w_0 measured at the end of the elastic region (loss of linearity) from the crack opening values measured subsequently. This operation is simply carried out by changing reference point and placing the new origin of the curves at the assumed time step when the crack was located.

In the case where the crack opening was not recorded, this shall be estimated from the measurement *f* of the deflection. Given the deflection f_0 which corresponds to the end of the elastic region, the opening of the crack (w) is determined by the following relationship (D.3):

$$w = 4/3 \times 0,9 \times (f - f_0) \qquad \text{(D.3)}$$

D.5.2 Data filtering

Data shall be filtered on each of the force-crack opening test curves in order to reduce the noise of experimental data to facilitate implementation of the inverse method. This consists, beyond the first point corresponding to the end of the elastic region, of a null crack opening, in adopting a discrete representation of the curve with a step of 20 µm and producing a moving average of the forces recorded at intervals of 40 µm by allocating this value to the central point of the interval.

At the end of this operation, the curves relating to the various test specimens have the same x-axis basis with a view to processing.

D.5.3 Determination of the tensile post-cracking law by inverse method

The analysis of the test by inverse method makes it possible to obtain the expression for the tensile stress as a function of crack opening from experimental results linking the moment applied to the crack opening. The method shall be applied to the filtered data in order to obtain a stable numeric convergence by considering the average curve and the characteristic curve from the series of test results.

D.5.3.1 Mechanical balance of the cracked section

Figure D.3 illustrates a cracked section of a prism under flexure.

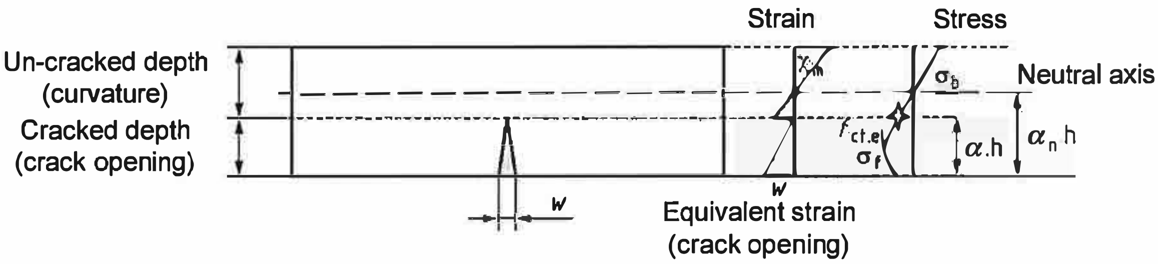


Figure D.3 — Distribution of deformations and stresses over the cracked and non-cracked parts of the section depth

A distinction is made between the non-cracked depth where the stress distribution corresponds to a linear elastic behaviour, and the cracked part of the section where the stress distribution depends directly on the efficiency of the fibres. It is the latter distribution which is sought and which results from use of the inverse method. The mechanical balance of the section leads to equations (D.4) to (D.7) following, where the contribution of the non-cracked part is designated by the index b and that of the cracked part by the index f:

$$N_b = \frac{E_{cm} \cdot \chi_m . b . h^2}{2} \left[(1-\alpha_n)^2 - (\alpha - \alpha_n)^2 \right] \tag{D.4}$$

$$N_f = \frac{\alpha . h . b}{w} \int_0^w \sigma_f . d\omega \tag{D.5}$$

$$M_f = \alpha h . N_f - \frac{(\alpha . h)^2 . b}{w^2} \int_0^w \sigma_f . \omega . d\omega \tag{D.6}$$

$$M_b = \frac{E_{cm} \cdot \chi_m . b . h^3}{3} \left[(1-\alpha_n)^3 - (\alpha - \alpha_n)^3 \right] + h . \alpha_n . N_b \tag{D.7}$$

$$M = M_b + M_f \tag{D.8}$$

$$N = N_b + N_f = 0 \tag{D.9}$$

where

M is the resisting moment, M, M_b and M_f being in MN·m;

N is the normal force, equal to 0, N_b and N_f being in MN;

α is the relative depth of the crack (see Figure D.3);

α_n is the relative depth of the neutral axis given by: $\sigma_t = E_{cm}.\chi_m.h.(\alpha - \alpha_n)$;

χ_m is the curvature of the non-cracked part in m^{-1} ;

$f_{ct,el}$ is the tensile limit of elasticity (average value $f_{ctm,el}$ or characteristic value $f_{ctk,el}$ depending on the curve processed, determined according to C.4 above), in MPa;

E_{cm} is the average value of Young's modulus, in MPa;

b is the width of the section, in m;

h is the height of the section (after deducting the depth of the notch), in m.

The crack opening is linked to the curvature for the non-cracked part through the following kinematic relationship (D.10):

$$w = [\chi_m + 2.\chi_e]\frac{2.(\alpha h)^2}{3} \qquad \text{(D.10)}$$

where χ_e is the equivalent elastic curvature in m^{-1}, given by: $\chi_e = M / (E_{cm}.I)$ where I is the inertia of the rectangular cross-section.

The relationship between the height of the crack and the depth of the neutral axis is inferred through the following expression (D.11):

$$(\alpha_n - \alpha).h.\chi_m.E_{cm} = f_{ct,el} \qquad \text{(D.11)}$$

For practical reasons, the sensor bridging the crack is in general slightly offset by a distance e from the base of the notch. The inverse analysis shall take into account the effect of this difference by correcting the result of the measurement w_{mes} by applying the following equation (D.12):

$$w = w_{mes}\,[\alpha.h / (\alpha.h + e)] \qquad \text{(D.12)}$$

D.5.3.2 Iterative resolution

The stress-crack opening curve sought is determined discretely by pairs of points (w_i, σ_{fi}). The discretisation of the x-axis relating to the crack openings (20 µm steps) is sufficiently fine to express all the stresses according to (D.13) by a trapezoidal approximation, namely:

$$\int_0^{w_{i+1}} \sigma_f.dw = \int_0^{w_i} \sigma_f.dw + \left(\frac{\sigma_{f_i} + \sigma_{f_{i+1}}}{2}\right)(w_{i+1} - w_i) \qquad \text{(D.13)}$$

The expressions of the normal force N_{fi+1} and the moment M_{fi+1} of the cracked part may then be written incrementally according to expressions (D.14) and (D.15):

$$N_{f_{i+1}} = N_{f_i} \cdot \frac{\alpha_{i+1}}{\alpha_i} \cdot \frac{w_i}{w_{i+1}} + \alpha_{i+1} \cdot b \cdot h \cdot \left(\frac{\sigma_{f_i} + \sigma_{f_{i+1}}}{2}\right)\left(1 - \frac{w_i}{w_{i+1}}\right) \qquad \text{(D.14)}$$

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$$M_{f_{i+1}} = M_{f_i} \cdot \left(\frac{\alpha_{i+1}}{\alpha_i} \cdot \frac{w_i}{w_{i+1}} \right)^2 + \alpha_{i+1} \cdot h \cdot N_{f_{i+1}} \cdot \left(1 - \frac{w_i}{w_{i+1}} \right) - \frac{(\alpha_{i+1} \cdot h)^2 \cdot b}{2} \cdot \left(1 - \frac{w_i}{w_{i+1}} \right)^2 \cdot \sigma_{f_{i+1}} \tag{D.15}$$

Thus, considering that the crack opening-stress relationship is known up to iteration i, we obtain the two unknowns of stress and relative depth of the crack at iteration i+1, respectively $\sigma_{f\,i+1}$ and α_{i+1} by solving the equations above, expressing the nullity of the axial force and the equality of the resistant bending moment of the section with the experimental moment.

In order to start the incremental process, it is simply a question of taking as initial values the point defined as the cracking moment (end of elastic region), with a null crack opening in compliance with relationship (D.16):

$$M_b^0 = M_{ext} = \frac{-bh^2 \cdot \sigma_f^0}{6} \tag{D.16}$$

with $M_f^0 = 0 ; N_b^0 = 0 ; N_f^0 = 0$

At the end of each increment, a correction is carried out on the value of iteration i after having calculated iteration i+1. This smoothing relates to the following moving average (D.17):

$$\sigma_{fi} = (2\,\sigma_{fi} + \sigma_{f\,i+1}) / 3 \tag{D.17}$$

D.6 Correction of edge effects due to casting, sawing and notching

The result of the post-cracking part of the previous analyses is weighted according to the variations in local orientation or local fibre anchoring conditions, by reference to a theoretical perfect anchoring situation relating to the assumed intrinsic behaviour of the UHPFRC at the core of a "massive" member.

D.6.1 Moulded edges

When the prisms are moulded, the orientation of the fibres tends to become 2D near the formwork walls. A factor of 1,2 is therefore applied over a width $L_f/2$ to provide the equivalent of the 3D efficiency, except if this edge is located at the side of the area compressed during the bending test.

D.6.2 Sawn edges

When near a sawn edge, account shall be taken of the fact that the fibres have also been sawn. We consider that half of the fibres are no longer anchored over a width $L_f/2$. A factor of 1/2 is therefore applied over a width $L_f/2$ except if this edge is located at the side of the area compressed during the bending test.

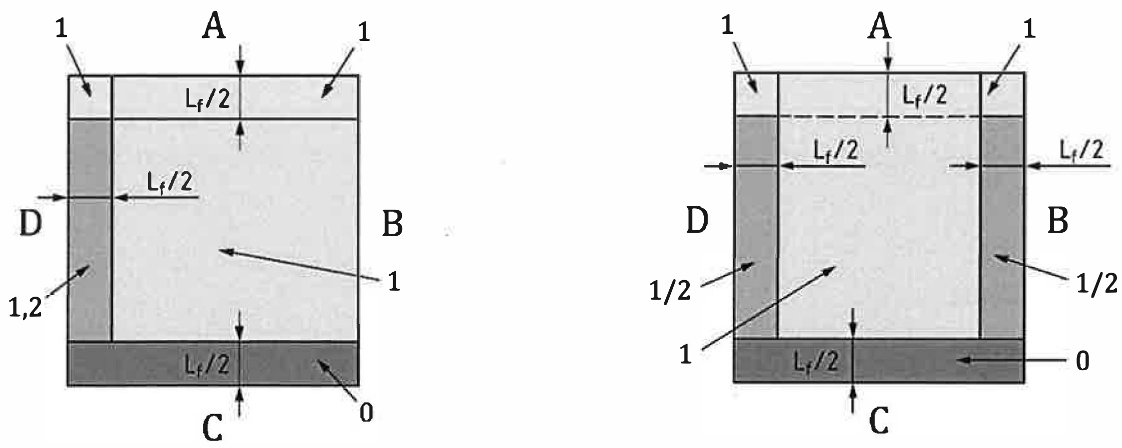
D.6.3 Notch

The surface area of the notch is not taken into account in calculating the effective area submitted to tensile stresses. No reduction coefficient is applied for the surface area at the bottom of the notch, where the anchoring and orientation of the fibres have not be disturbed.

D.6.4 Calculation of the correction

The experimental result obtained is associated with a cross section weighted by the coefficient 1 in the central section, and by the coefficients detailed above along the side edges. The correction consists of dividing the stress values of the stress-strain curve from the above analysis by the coefficient weighted over the whole of the cross-section of the test prism. After making this correction, the assumed intrinsic constitutive curve is obtained.

Figure D.4 gives an example of a moulded prism and that of a sawn prism with the coefficients to be applied.



Key

A Formed surface, edge under compression
B Non-formed surface
C Formed surface cancelled by the notch effect
D Formed surface

a) Moulded prism

Key

A Non-formed surface, free edge under compression
B Sawn surface
C Surface corresponding to the notch
D Sawn surface

b) Sawn prism

Figure D.4 — Examples of accounting for edge effects

D.7 Simplified representation

It is possible to provide a piecewise linear description of the tensile constitutive characteristic curve of the UHPFRC from the data processing method according to D.4 and D.5. This description, which is consistent in particular with the conventional laws described in 3.1.7.3.2 of standard NF P 18-710:2016, is equivalent to giving a set of stress values, taken from the curve, associated with crack openings which are fixed in principle: limit of elasticity (associated with w = 0), stress corresponding to a crack opening of 0,3 mm or maximum stress σ_w if this is obtained for a crack opening of greater than 0,3 mm, stress relating to a crack opening equal to 1% of the height of the test prism, assumed null stress associated with an opening $L_f/4$ (L_f being the length of the longest fibres contributing to non-brittleness).

If the limit of elasticity is greater that the peak stress or the stress corresponding to an opening of 0,3 mm, the curve shall be clipped at the lowest of these values.

It is possible to carry out a similar simplified representation for the average curve.

The stress values associated with these simplified representations shall be determined to the nearest 0,1 MPa.

Annex E
(normative)

Bending tests on thin plates and method of data processing

E.1 Introduction

This annex describes the experimental and results analysis procedures for characterising the tensile performance of UHPFRCs through bending tests, when (unlike for so-called thick members for which Annex D is applied), the orientation of the fibres is influenced by a reduced member thickness relative to the dimension of the fibres. It is accepted that this influence occurs for a thickness less than 3 times the length L_f of the longest fibres contributing to non-brittleness.

The four-point bending test on thin plates described below results in a measurement of the deflection as a function of the force applied. The method of processing the data from these tests described in E.4.enables an equivalent response curve for the material under direct tension to be determined by inverse analysis. Using this analysis, the multi-cracking behaviour expected is described by a stress-strain law which makes it possible to ascertain the limit of the linear behaviour, the contribution of the fibres as reinforcement to a cracked section and to determine the tensile behaviour class (see 4.4.3) by using a conventional transformation of the strain into a crack opening, to satisfy the inequality ensuring a sufficiently strain hardening behaviour. For this transformation, it is conventionally accepted that the crack opening is equal to the strain multiplied by the minimum of 2/3 the thickness e of the member and twice the length L_f of the longest fibres contributing to non-brittleness.

The tests shall be carried out and used by means of a series of at least 6 test specimens of the same type. In particular, the method described below which envisages 6 test specimens per direction results in the determination of two constitutive laws corresponding to the directions X and Y.

The inverse analyses making it possible to determine the post-peak tensile behaviour shall be applied to the average curve and the characteristic curve from the series of test results. The scope of the analysis (simplified or otherwise) and the curves obtained shall however be limited for safety to the smallest value of the deflection associated to the peak bending moment obtained for each curve in the series of test results considered.

E.2 Dimensions and preparation of test specimens

The thickness *e* of the test body shall be equal to that of the structure being characterised, or, if this value is unknown, to 3 times the length L_f of the longest fibres contributing to non-brittleness.

The test body shall consist of prisms sampled by sawing into four square plates of thickness e produced using the same method as that planned for the structure.

For plates poured in UHPFRC of consistence class Ca and Cv, the test sample shall be produced by leaving the UHPFRC to flow from one end of the mould, the flow being encouraged by rodding only for UHPFRCs of consistence class Cv, reloading being carried out systematically behind the flow front. For these consistence classes, vibration is prohibited.

For plates poured in UHPFRC with consistence class Ct, a repeatable installation method derived from that used for the structure shall be defined.

In all cases, filling the mould using heaps placed side-by-side is prohibited.

The length of the prisms is L_p = min [20 e ; 60 cm].

The width of the prisms is $b = 8\ L_f$.

The distance to the edge is d = Max [L_f ; 2 cm].

The side of the plates is equal to Max [L_p + 2d ; 26 L_f + 2d].

The two main directions of the plates (X and Y axes) shall be identified along with their correspondence with the concreting method. Three prisms shall be taken from each plate by sawing according to the dimensions and layout defined in Figure E.1. Two series of 6 prisms are thus obtained, one along the X axis and one along the Y axis.

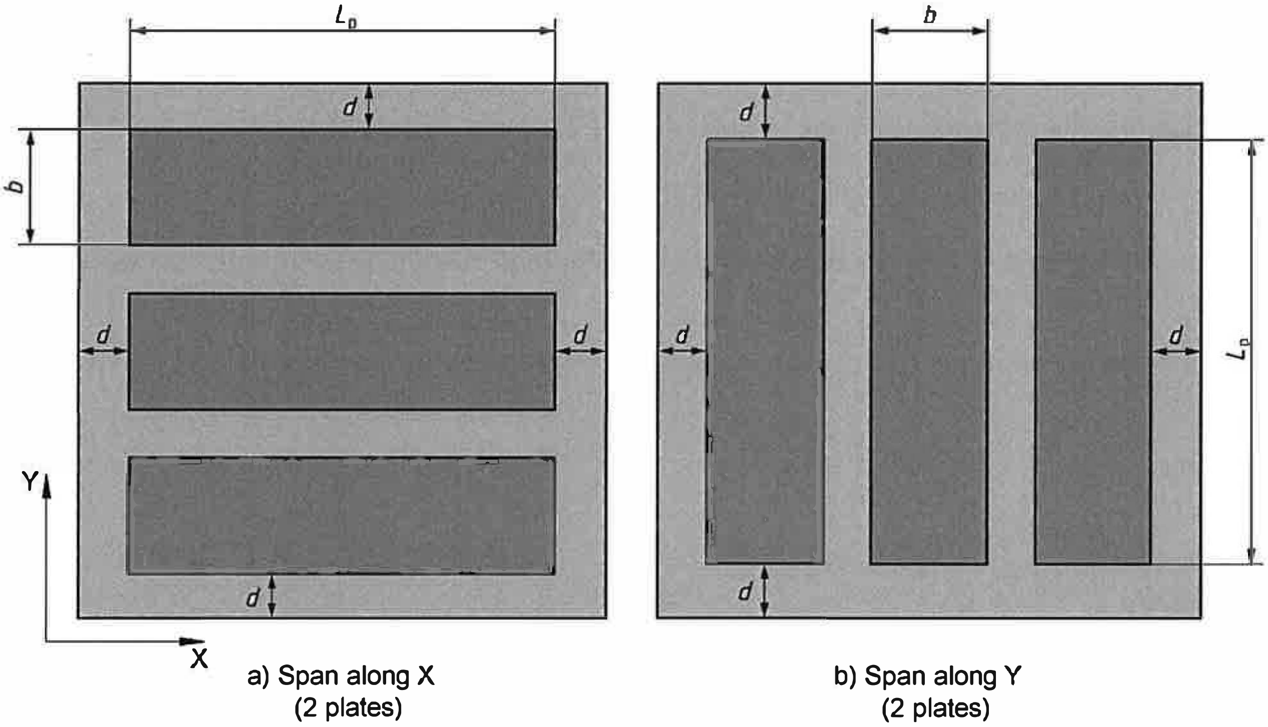
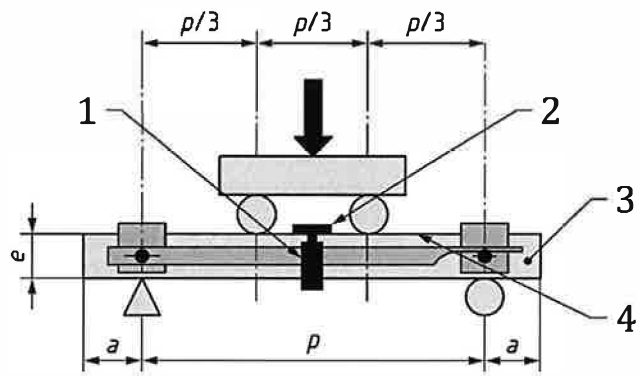


Figure E.1 — Scheme of specimens sampling

E.3 Conducting the tests

The prisms shall be submitted to circular bending tests (4 points) as described in Figure E.2.



Key

1 Displacement sensor

2 Glued idler plate, e.g. made of aluminium

3 Specimen

4 Yoke for measuring the central deflection

Figure E.2 — Scheme of the test and measuring principle of the deflection at mid-span

$$a = \max(e/2\ ;\ 3\ \text{cm})\ ;\ p = Lp - 2\,a$$

The test machine shall be a universal testing machine which can be servo-controlled with respect to the actuator load or displacement, or to an external sensor. The support and load application system shall be made up of a fixed point and moving points (for example supports on rollers), to limit the spurious axial force. The slabs shall be instrumented by means of two displacement sensors at mid-span, located each side of the test body, except when their width is less than 120 mm where it is allowed to use a single sensor at the centre. These sensors shall be installed using a yoke fixed to the test specimen to deduce settlement on the supports, as indicated in Figure E.2.

Depending on the sensor chosen for controlling the test, the loading rate shall be adapted as follows:

— under actuator displacement control, a rate of (0,25 ± 0,1) mm/min will be adopted,

— under control by average deflection, a rate of (0,1 ± 0,05) mm/min will be adopted

The test shall be continued until the average deflection is at least equal to twice the peak average deflection, and not less than $e/2$.

Data shall be recorded during the test at a frequency of at least 5 recordings per second. The signals to be recorded are:

a) the time;

b) the average deflection;

c) the force;

d) if necessary, the displacement of the cylinder.

E.4 Data processing

E.4.1 Determination of elastic behaviour

The determination of the bending elastic modulus E shall be carried out in the central third of the linear part of the rising phase of the average moment-deflection curve obtained from n tests of the series (n ≥ 6). The slope of the curve in this interval shall then be multiplied by a coefficient $(23.p^2)/(216.b.e^3/12)$, to obtain the bending elastic modulus.

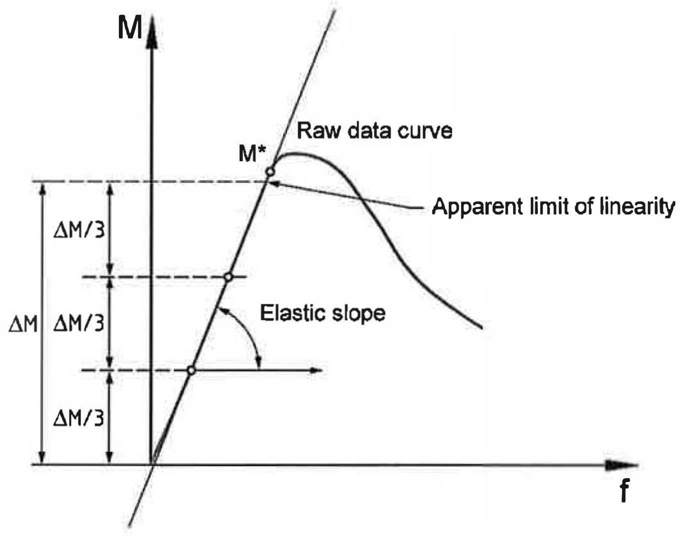


Figure E.3 — Determination of elastic behaviour

The limit of *elasticity* $f_{ct,el}$ shall be determined for each Moment-deflection curve. The amplitude of the linear domain ΔM is determined manually, then a line is drawn through $\Delta M/3$ and $2\Delta M/3$, as shown in Figure E.3. The point M^* where the experimental curve departs from the line is then more visible. The value of the moment corresponding to this point where linearity finishes shall be multiplied by $6/be^2$ to obtain the limit of elasticity $f_{ct,el}$. The average and characteristic values $f_{ctm,el}$ and $f_{ctk,el}$ are derived using the usual statistical treatment (see Annex B). The design curve shall be obtained by concatenating the linear part obtained up to $f_{ct,el}$ and the law obtained by inverse analysis in accordance with E.4.2.

E.4.2 Stepwise inverse method from the Moment-deflection curve

Beyond the limit of elasticity, the constitutive curve is identified by the moment-curvature relationship from the experimental results. Indeed the relationship between the curvature χ and the deflection δ under elastic conditions is no longer valid when the material becomes non-linear as the curvature then increases more than the moment. The variation of the curvature as a function of the x-axis is therefore changed as shown in Figure E.4. Knowing the moment-deflection curve, the moment-curvature curve shall be inferred by carrying out an inverse analysis. An iterative process is then used.

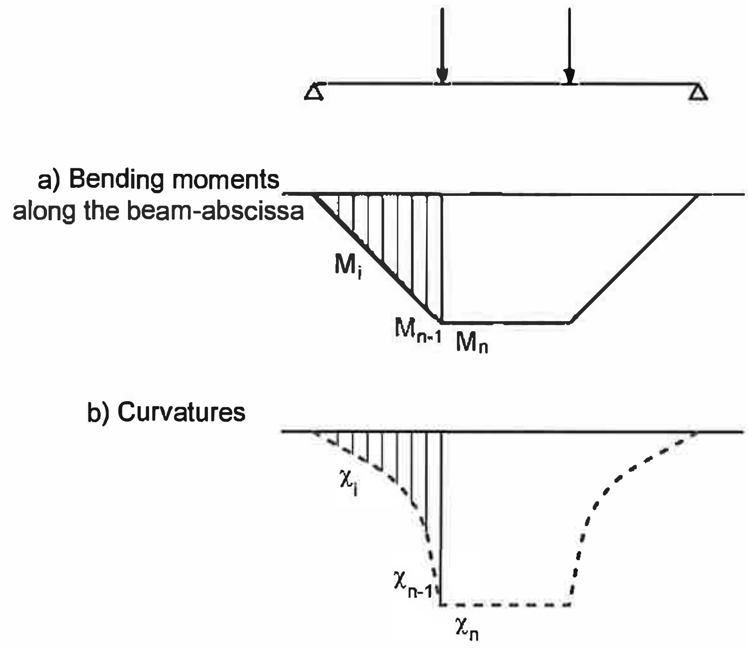


Figure E.4 — Moment and curvature curves after yielding

For a null moment, the deflection and the curvature shall be taken as null. For a given moment M_n - deflection δ_n couple, if we assume the curvatures χ_i associated with moments M_i are known, where i varies from 1 to n-1, then curvature χ_n shall be determined to obtain the deflection δ_n (see Figure E.4). Taking all the curvatures χ_i, with i from 1 to n, we integrate these curvatures twice to obtain the deflection. Once all the M_i, χ_i couples have been obtained, a second inverse analysis is carried out to infer the stress strain law.

At each step i, the input data is a couple of M_i, χ_i values. The objective is to obtain values ε_i of lower fibre strain along with the associated stresses σ_i. Recurrence shall again be used. At step 0, $\varepsilon_0 = 0$ and $\sigma_0 = 0$. At step n, we assume the values ε_i and σ_i are known for i=1 to n-1 along with the moment M_n and the curvature χ_n. Defining β_i as the relative depth of the neutral axis under moment M_i, the equation describing the variation in linear deformation leads to relationship (E.1):

$$\varepsilon_n = -\chi_n \beta_n . e \qquad \text{(E.1)}$$

The null value of the axial force allows equation (E.2) to be written:

$$N = N_c + N_t = \frac{1}{2}(1-\beta_n)^2 e^2.b.\chi_n.E + \frac{1}{\chi_n}\sum_{i=1}^{n}(\varepsilon_{i-1}-\varepsilon_i).\frac{\sigma_i+\sigma_{i-1}}{2}.b = 0 \qquad \text{(E.2)}$$

At step n-1, the term N_c from the compressed area may be written in accordance with equation (E.3):

$$N_c(n-1) = \frac{1}{2}(1-\beta_{n-1})^2 e^2.b.\left(-\frac{\varepsilon_{n-1}}{\beta_{n-1}e}\right).E \qquad \text{(E.3)}$$

Still at step n-1, term N_t from the area under tension satisfies the relationship (E.4):

$$N_t(n-1) = \left(-\frac{\beta_{n-1}.e}{\varepsilon_{n-1}}\right).b.\int_{\varepsilon_{n-1}}^{0}\sigma(\varepsilon)d\varepsilon = -\frac{1}{2}\frac{(1-\beta_{n-1})^2}{\beta_{n-1}}e.b.(-\varepsilon_{n-1}).E \qquad \text{(E.4)}$$

At step n, term $N_t(n)$ may therefore be written using expression (E.5):

$$N_t(n) = \left(-\frac{\beta_n.e}{\varepsilon_n}\right).b.\int_{\varepsilon_n}^{0}\sigma(\varepsilon)d\varepsilon = -\frac{\beta_n.e}{\varepsilon_n}.b.\int_{\varepsilon_{n-1}}^{0}\sigma(\varepsilon).d\varepsilon - \frac{\beta_n.e}{\varepsilon_n}.\int_{\varepsilon_n}^{\varepsilon_{n-1}}\sigma(\varepsilon)d\varepsilon \qquad \text{(E.5)}$$

Which can still be written according to (E.6):

$$-\frac{1}{2}\frac{(1-\beta_n)^2}{\beta_n}e.b.(-\varepsilon_n).E = \frac{1}{2}\frac{\beta_n}{\varepsilon_n}.\frac{(1-\beta_{n-1})^2}{(\beta_{n-1})^2}.(\varepsilon_{n-1})^2.e.b.E - \frac{\beta_n}{\varepsilon_n}.\frac{\sigma_n+\sigma_{n-1}}{2}.(\varepsilon_{n-1}-\varepsilon_n).e.b \qquad \text{(E.6)}$$

From this last equation, we can infer a direct relationship between σ_n and β_n, by using the fact that ε_n is obtained as a function of $\varepsilon_{mes,n}$ or χ_n and β_n.

Whereas, the equation on the moment gives, at step *n*, the relationship (E.7):

$$M = M_c + M_t = \frac{e^3}{3}.(1-\beta_n)^3.b.\chi_n.E + \left(\frac{1}{\chi_n}\right)^2.\sum_{i=1}^{n}(\varepsilon_{i-1}-\varepsilon_i)\frac{(2\varepsilon_i+\varepsilon_{i-1}).\sigma_i+(2\varepsilon_{i-1}+\varepsilon_i).\sigma_{i-1}}{6}.b \qquad \text{(E.7)}$$

M_n is therefore a function of σ_n, β_n and ε_n (or χ_n). Now ε_n is obtained from $\varepsilon_{mes,n}$ or χ_n and β_n. As σ_n is a function of β_n, the equation on the moment can be written directly as the expression M_n as a function of β_n, we have therefore reduced the determination of three unknowns ε_n, σ_n and β_n to a problem with one equation and one unknown.

It is possible to provide a piecewise linear description of the tensile constitutive characteristic curve of the UHPFRC from the above treatments. This description is equivalent to providing a set of stress values, taken from the curve, associated with characteristic values of strains. It is possible to carry out a similar simplified representation for the average curve. The stress values associated with these simplified representations shall be determined to the nearest 0,1 MPa.

In particular, the bilinear description of the characteristic curve determined by the limit of elasticity $f_{ctk,el}$ associated with the strain ε_{el}, and the post-cracking strength $f_{ctf,k}$ associated with the limit strain ε_{lim} is the basis of the standard calculation law known as "law 2" defined in 3.1.7.3.3 of standard NF P 18-710:2016, the post-cracking part then being divided by the orientation factor K by applying Annex F to this standard, and the ULS law being obtained by the affinity of a factor $1/\gamma_{cf}$.

E.4.3 Simplified representation

For parts subject to simple flexure or a flexure-compression combination with no average tensile resultant in the section, it is allowed to simplify the constitutive law which would be obtained by applying E.4.1 and E.4.2, both for the average law and the characteristic law, in accordance with the curve represented in Figure E.5.

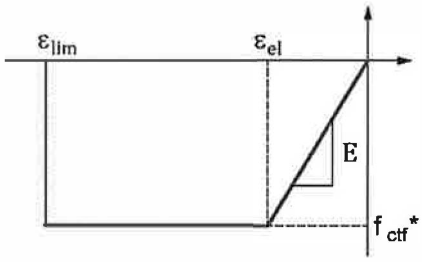


Figure E.5 — Simplified law

The modulus of elasticity E used shall be determined according to E.4.1., the elastic strain limit ε_{el} shall be inferred from the determination of the post-cracking stress limit f_{ctf}* according to the following.

The simplified inverse analysis described below shall be carried out keeping the elastic relationship (E.8) between the curvature χ in m^{-1} in the constant moment area, the deflection δ in m and the span p in m:

$$\delta = \frac{23}{216} \chi \, p^2 \qquad \text{(E.8)}$$

f_{ctf}^* along with ε_{lim} shall be calculated from the strain and stress states obtained under the maximum moment M of the curve considered (Figure E.6):

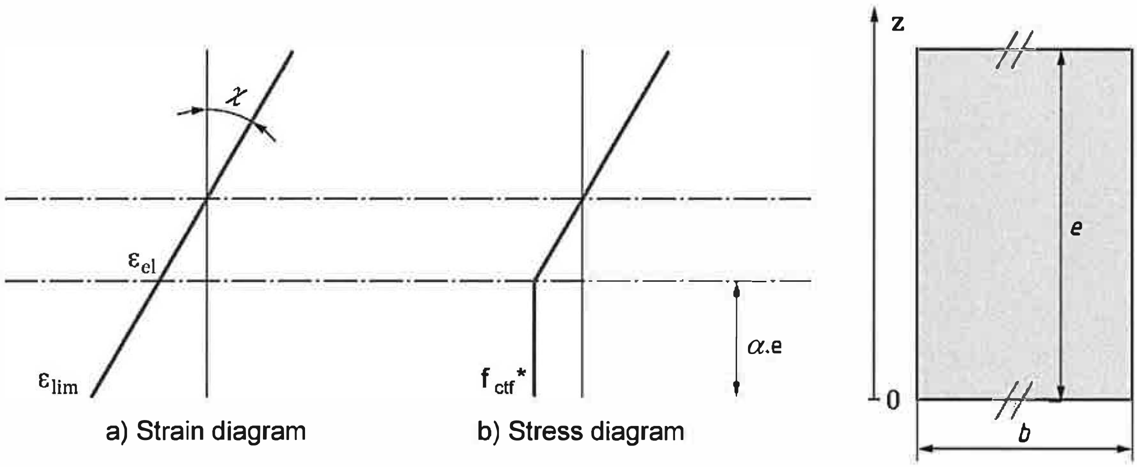


Figure E.6 — Distribution of strains and stresses with the simplified law

The stresses are expressed as a function of the depth z, of the cracked depth $\alpha.e$ and f_{ctf}* according to equations (E.9) and (E.10):

$$\sigma(z) = f_{ctf}^* \text{ if } 0 \le z \le \alpha.e \qquad \text{(E.9)}$$

$$\sigma(z) = f_{ctf}^* + (z - \alpha.e).\chi.E \text{ if } \alpha.e \le z \le e \qquad \text{(E.10)}$$

The axial force N and the bending moment M may be written respectively according to expressions (E.11) and (E.12):

$$N = b.e.f_{ctf}^{*} + \frac{1}{2} b.(1-\alpha)^2 .e^2 \chi.E \qquad \text{(E.11)}$$

and $$M = b.\frac{e^2}{2}.f_{ctf}^{*} + b.\left(\frac{1}{3} - \frac{\alpha}{2} + \frac{\alpha^3}{6}\right).e^3 \chi.E \qquad \text{(E.12)}$$

Given that N = 0, we derive equation (E.13):

$$M = \left(2\alpha^3 - 3\alpha^2 + 1\right).\frac{b.e^3 \chi.E}{12} \qquad \text{(E.13)}$$

Knowing M and χ, we infer α, from which the relationships (E.14) and (E.15) are drawn:

$$f_{ctf}^{*} = -\frac{1}{2}(1-\alpha)^2 .e.\chi.E \qquad \text{(E.14)}$$

and $$\varepsilon_{\lim} = -\chi.\alpha.e + \frac{f_{ctf}^{*}}{E} \qquad \text{(E.15)}$$

The determination of f_{ctf}* shall be given to the nearest 0,1 MPa.

Annex F
(normative)

Determination of orientation factors *K* from bending tensile tests

F.1 Introduction

By comparison with a situation where the fibres would ideally be distributed randomly and in a tri-dimensional isotropic way in the structure so as to provide the same post-cracking tensile force contribution as in the moulded characterisation test specimens, the orientation factors K, determined in the suitability test, make it possible to take into account the distribution and effective orientation of the fibres in the actual structure.

The non-linear part of the experimental response curve obtained on the moulded test specimens (determined by application of Annex D or Annex E according to the geometry of the members in the project) shall be multiplied by the ratio $1/K$, a linear connection illustrated in Figure F.1 being produced if necessary between the linear part of the behaviour and the maximum of the non-linear part (post-cracking strength, denoted by f_{ctf}) to eliminate an artefact associated with a local minimum. Failing a local maximum for the non-linear part, the connection shall be carried out by capping the stress to the value f_{ctf} normally used as it applies to a crack opening of 0,3 millimetres.

This curve shall be used as a reference for the design curve at the serviceability limit states and, divided by the partial factor for the tensioned UHPFRC γ_{cf}, for the design curve at the ultimate limit states.

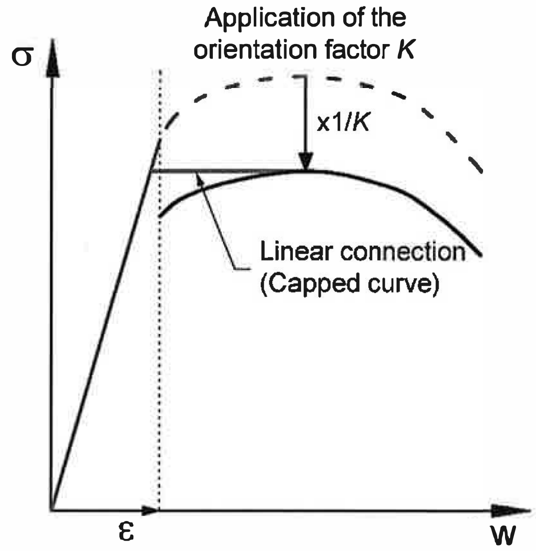


Figure F.1 — Application of the orientation factor *K*

The orientation factors K shall be obtained by comparison between the resistant moment of the plates or prisms sampled from the structure relative to the plates or prisms moulded to the same dimensions from the same manufacture in the suitability test; they are determined by reference to a main tensile direction in the structure and are associated with a part of the structure which is uniform in terms of placement and orientation of the fibres (core, slab, bottom flange, anchoring area, etc.).

F.2 Methods of determination

The suitability test shall include the determination of orientation factors K from the representative mock-up mentioned in 7.3 of this standard, according to a sampling plan developed and approved jointly by the specifier, UHPFRC user, prime contractor and person responsible for the execution studies. This sampling plan shall take into account the directions of internal tensile forces to which the structure may be subject. The mock-up shall allow minimum of 6 plates or prisms to be sampled per part of the structure and per relevant tensile force direction, of the same geometry as the moulded members (equal in number) associated with the characterisation of the tensile behaviour according to Annex D or in Annex E depending on the geometry of the project members. These test specimens (generally taken by sawing) shall be tested in accordance with Annex D or Annex E of this standard according to their thickness relative to the size of the longest fibres contributing to non-brittleness. Both sides of the members tested shall in all cases be either the sawn faces or moulded faces. The corrections described in D.6 shall be applied to all results.

By direction and by part of the structure considered, the ratio between the average of the peaks of the moment-deflection curves obtained on moulded test samples and the average of the peaks of the moment-deflection curves obtained on sawn plates or prisms is denoted by K_{global}.

By direction and by part of the structure considered, the ratio between the average of the peaks of the moment-deflection curves obtained on moulded test samples and the lowest value of the peaks of the moment-deflection curves obtained on sawn plates or prisms is denoted by K_{local}.

Minimum and maximum values are imposed to be 1,0 and 2,0 for K_{global}, and 1,0 and 2,5 for K_{local}, respectively.

When a check involving tensile behaviour does not just relate to one direction, a single value for the orientation factor K may be adopted independently of the direction of tension considered, the maximum of the K values obtained in the various relevant directions for a given part of the structure shall then be taken.

At a preliminary study design, when relevant data in the identity card for the UHPFRC being considered are missing, the following data may be adopted:

$$K_{global} = 1,25 \qquad K_{local} = 1,75$$

Annex G
(normative)

Control of the production of premixes of constituents

A premix of constituents intended for the production of UHPFRC shall be produced under quality assurance provisions and subject to an internal control by the premix supplier. The procedure shall include:

a) controls on the constituents forming part of the composition of the premix based on the regularly-updated product technical data sheets, periodically supplemented by reception control tests;

b) controls on the compliance of the regularity of composition of the premix according to the objectives described in 5.1.10;

c) controls on samples of the premix produced, described below;

d) the definition of corrective actions in the event of a deviation.

A production campaign is a production period of a type of premix during which no other type of premix may be produced. This may be made up of a succession of premix production operations (whose volume depends on the mixer used). Each premix batch shall be identified by a code for traceability purposes. Traceability shall attach the batch to the production campaign during which it was produced, and to the production operations within this campaign.

The number of control samples to be taken on the premix shall be determined according to the number of production operations during a production campaign, whatever the volume. The first operation of a production campaign shall be systematically sampled for control purposes. Under normal control conditions, the samples shall be distributed regularly throughout the campaign as shown in Table G.1. The level of control may be reduced or strengthened relative to the normal level under Annex D of NF EN 13369:2013.

Table G.1 — Samples for production control

Number of operations in the production campaign	1	2 - 9	10 - 19	20 - 29	30 - 39	40 – 79	≥ 80
Number of samples to be checked	1	2	3	4	5	8	1 every 10 mixes

The checks shall be carried out on a control material which shall derive from one of the UHPFRCs obtained from the premix and which has an identity card (see 5.1.10). The composition, manufacturing protocol and test procedure for the control material shall be defined in the premix producer's quality manual. The composition of the control material shall include the premix subject to sampling, along with the constituents needed to carry out tests on the fresh or hardened material under the conditions described in the quality manual.

Each premix sample shall be tightly packaged, given a reference number and be used for the manufacture of control material in a single mixing operation. This mix shall be used to carry out the following measurements according to the methods described in the quality manual:

— consistence check;

— compressive strength check in accordance with Annex C of this standard.

The target values and tolerances on the results of these checks shall make it possible to assume that the performance figures described in the identity card of the UHPFRC from which the control material derives by reference to the tests mentioned in 5.4.1 and 5.4.2 are regularly achieved.

Checks on colour, temperature rise during mixing, density of the control material when fresh or the setting time may be carried out in addition to the tests performed on some of the samples. The time limits for obtaining the results of these checks shall be compatible with the discarding before delivery of batches which would not comply with the target values.

From each sample taken for checking, a sample shall be also taken to be kept by the premix supplier for a minimum of 6 months under the usual storage conditions.

The quality system of the premix supplier shall enable a batch which does not comply with the target values of this system to be isolated, either at the weighing stage or the checking phase of UHPFRC samples. If additional investigations do not resolve the problem, the non-compliant batch shall be excluded from future reuse in the premix production line.

The internal control associated with the production of premixes of components intended for the production of UHPFRCs shall be supplemented by a check performed by a third party.

Annex H
(informative)

Behaviour at high loading rates

The impact strength of the UHPFRC associated with the instantaneous increase in the strength of the cement matrix with the loading rate, and with the energy dissipation by the fibres in the micro-cracking phase (which also increases with the loading rate) may constitute a useful or indeed critical property depending on the project. When the method used to calculate the impact (equivalent static calculation, explicit dynamic calculation, etc.) refers to an instantaneous "dynamic" strength (at high stress rates), it may be necessary to characterise this property by high-rate tensile, compressive or flexural tests in the design phase if not provided in the identity card of the material.

The results of these tests will enable the increase in strength with loading rate (for example a strength ratio equal to a power of the loading rate ratio, or the assumed linear increase of the strength or of the post-peak tensile stress with the loading rate in a semi-logarithmic scale) or the UHPFRC failure criterion (in the case of a plasticity model with viscous strain hardening for example) to be calibrated. Standard NF P 18-710:2016 provides information on the impact design methods and the design values describing the change in mechanical characteristics with the stress rate which can be used for the project.

Annex I
(informative)

Hydraulic abrasion test

I.1 Principle and expression of the results

The test representing the effect of abrasion by alluvia-charged waters consists of submitting three test specimens of the UHPFRC to be tested in-between two glass plates of thickness (24,5 ± 0,5) mm to a jet of water charged with sand at an angle of 45°.

NOTE These plates act as a reference to take account of changes made by the wear of the sand and of the injection nozzle.

Practically speaking, the UHPFRC test specimens subjected to this test have a minimum thickness of 30 mm and are made up of plates of at least 100 mm along each side or cylinders of minimum diameter 100 mm. The surface exposed is the plane moulded surface at the bottom of the mould. The tests are carried out at 28 days except for UHPFRCs of type TT2 or TT1+2 where they are conducted after heat treatment.

The duration of the test is (75 ± 1) min. The imprints created by the jet in 3 test bodies in the UHPFRC to be tested are compared with imprints obtained in glass companion specimens used as a reference which allows the abrasion index to be determined:

$I = V / V0$

$V0$ = average volume of the imprints on the glass

V = average volume of the imprint on the UHPFRC

The water in the reservoir A is sucked by pump B and sent to nozzle C (3,0 bars).

The sand stored at D is sucked up by the passage of water at E, mixes with it and the water + sand mix passes into the nozzle C and hits the specimen F at an angle of 45°.

The specimen F is supported and positioned with a guiding rail.

The sand falls back to D through a grid and the water is decanted in the reservoir H located along the reservoir A into which it flows.

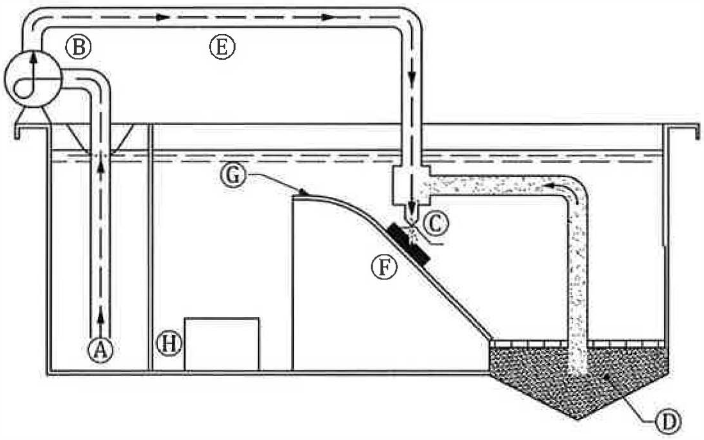


Figure I.1 — Operating principle of the abrasion test bench

I.2 Operation of the test bench

The abrasion test bench, the diagram of which is represented in Figure I.1, operates as follows:

a) the test specimen is immersed in a pool. Its surface is attacked at about 45° by a jet of water charged with sand;

b) the injector producing the jet is itself immersed, it comprises:

   1) a central nozzle of diameter (20 ± 2) mm located at a distance of (62 ± 2) mm from the test specimen and supplied with water from a pump at a pressure of 3,0 bars,

   2) a lateral sand inlet. the sand in suspension in the water being sucked up by the jet from the central nozzle by the vortex effect,

   3) the sand used for wearing the specimen is a very pure siliceous sand ($SiO_2 \geq 97$ %), 95 % of whose grains are between 1,0 mm and 4,0 mm in diameter. The sand should be renewed when the volume of the imprint on the glass is reduced to (60 ± 5)% of the initial volume obtained using new sand,

c) the sand falls back to the bottom of the pool where it is taken up again by suction and returns to the injector;

d) the volume of each imprint is measured by photogrammetry; two successive measurements shall be made on each sample which do not differ by more than 5%. Otherwise, the test is disregarded, the causes of the deviation are sought, identified and treated and the test is repeated.

   The reference glass should have a thickness of (24,5 ± 0,5) mm, a density between 2400 kg/m^3 and 2600 kg/m^3, and a Knoop hardness of about 500.

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- *"Guide for selecting exposure classes of maritime and fluvial structures"*
- *"Guide for selecting exposure classes of road equipment structures"*
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