Particular Specification for Structural Use of Ultra-High Performance Concrete

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FOREWORD

The Civil Engineering and Development Department (CEDD) is committed to embracing innovation and technology to build a smart and liveable city. In recent years, Ultra-High-Performance Concrete (UHPC) has emerged globally as a revolutionary cementitious composite known for its exceptional compressive and tensile strengths, unparalleled toughness, enhanced ductility, and extraordinary durability. Ranging from major infrastructure in Chinese Mainland, Europe, and North America to iconic landmarks in Japan and Malaysia, UHPC has proven its transformative value through diverse field applications and advancements in material science.

In a steadfast commitment to expedite the use of UHPC for Hong Kong's infrastructure development, CEDD set up a Joint Task Force with the Highways Department (HyD) in January 2025 with an aim of propelling UHPC adoption by implementing pilot projects in the Northern Metropolis. Complementing this initiative, CEDD collaborated with the Building Technology Research Institute (BTRi) to author the Technical Guidelines and Particular Specifications for Structural Use of UHPC. These documents present the necessary design principles, construction methodologies, material specifications, and quality assurance protocols required for the application of UHPC in civil engineering work.

Capitalizing on Hong Kong's strategic role as an international hub for infrastructure development, CEDD fosters a collaborative platform for experts across Chinese Mainland, Hong Kong, and the international engineering community to contribute in the alignment of China national standards with local requirements and prevailing global practice. I earnestly invite practitioners and stakeholders to share valuable insights and refinements by leveraging valuable experience gained and technological advancements adopted in your projects for establishment and continuous refinement of the design standard for broader application of UHPC in Hong Kong, the Greater Bay Area and beyond.

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SECTION 27[1]

ULTRA-HIGH PERFORMANCE CONCRETE (UHPC)

GENERAL

Preamble The provisions in this Particular Specification are for structural use of UHPC and shall be followed as far as practicable. If deemed necessary, the Project Office may revise relevant provisions to meet project specific requirements.

Designation of UHPC mixes 27.01 Designed mix UHPC shall be designated by the grade strength in compression with the prefix C.

GLOSSARY OF TERMS

UHPC 27.02

(1) UHPC is a type of concrete that exhibits ultra-high mechanical properties and outstanding durability. It is produced using cement and mineral admixtures as binders, combined with aggregates, chemical admixtures, high-strength micro steel fibres and water as raw materials.

(2) The mechanical properties of UHPC include compressive cube strength not less than 120 MPa and direct tensile strength not less than 5 MPa.

Mix constituent 27.03

(1) Cementitious content is the combined mass of cement, Pulverised Fly Ash (PFA) or Ground Granulated Blast-furnace Slag (GGBS), and the dry mass of Silica Fume (SF) per cubic metre of compacted UHPC. PFA, GGBS and SF are referred to as supplementary cementitious materials in this Specification.

(2) Water content is the total mass of the free water contained in the aggregates, the added mixing water, and the water contained in any admixtures or additives used.

(3) Water/cementitious content ratio is the ratio of the water content divided by the total cementitious content and shall be less than 0.25.

Grade 27.04 Grade is a term used to identify the different UHPC mixes in terms of grade strength.

Grade strength 27.05 Grade strength is the compressive / direct tensile strength of UHPC stated in the contract. For designed mix UHPC, compliance with the grade strength shall be ascertained in accordance with Clauses 27.66 and 27.70.

[1] The numbering reference adopted in this Particular Specification is not mandatory and may be amended to suit the documents of individual contract.

MATERIALS

Cement 27.06 Cement shall be Portland cement complying with GS Clause 16.06(1).

Pulverized Fly Ash (PFA) 27.07 PFA shall comply with GS Clause 16.07(1).

Ground Granulated Blast-furnace Slag (GGBS) 27.08 GGBS shall comply with BS EN 15167-1 except that the scheme for the evaluation of conformity of GGBS specified in BS EN 15167-2 is not required. The glass content as determined by X-ray diffraction or optical-microscopy method shall be not less than 67 %. The X-ray diffraction method detailed in Appendix D of BS 6699 is acceptable.

Silica Fume (SF) 27.09 SF shall comply with BS EN 13263-1:2009.

Steel Fibre 27.10 Steel fibres shall comply with the specifications for high-strength microfibres with tensile strength exceeding 2500 MPa as per BS EN 14889-1:2006. The equivalent diameter shall be less than 0.3 mm. The fibre length shall be between 6 mm to 25 mm and at least twice the maximum size of aggregates used.

Aggregates 27.11

(1) Aggregates shall be obtained from a source accepted by the *Project Manager*. Aggregates from marine source shall not be used. All-in aggregates shall not be used.

(2) Fine aggregate shall be clean and hard complying with Section 3 of CS3 except for the grading requirements. Grading of fine aggregates shall be proposed by UHPC suppliers and accepted by *Project Manager*. In addition, the following properties shall meet the stated limits:

(a) Crusher dust content as specified in Table 27.01.

(b) Mud content and clay lump content as specified in Table 27.02.

(c) Chloride ion content, total sulphurs content and mica content as specified in Table 27.03.

(3) Natural sand shall not be used unless with the prior acceptance of the *Project Manager*.

(4) For UHPC, the nominal maximum size of coarse aggregate shall be up to 14 mm. The coarse aggregate shall be clean, hard, and comply with the requirements of Section 3 of CS3, except for the grading requirement. Grading of coarse aggregate shall be proposed by UHPC suppliers and approved by *Project Manager*. Coarse recycled aggregates may be used subject to the prior acceptance of the *Project Manager*.

(5) The content of oversized and undersized coarse aggregate and fine aggregate in each size range shall not exceed 5 %.

(6) The potential alkali-reactivity category of coarse aggregate and fine aggregate shall be determined from the results of tests on potential alkali reactivity of aggregates using the test method given in GS Table 16.7.

(7) Aggregates in the alkali "Reactive" category shall not be used unless with the prior acceptance of the *Project Manager*.

Table 27.01: Crusher dust content of fine aggregate

Methylene Blue (MB) Value	Crusher Dust Content (%)
MB < 1.0	≤ 5.0
1.0 ≤ MB ≤ 1.4	≤ 2.0

Table 27.02: Mud content and clay lump content of fine aggregate

Mud Content (%)	Clay Lump Content (%)
≤ 0.5	0

Table 27.03: Chloride ion, total sulphur content and mica content of fine aggregate

Chloride ion content (%)	Total sulphur content(1) (%)	Mica content (%)
≤ 0.02	≤ 0.20	≤ 0.50
(1) Fine aggregate containing particulate sulphate or sulphide impurities shall be approved for use only after verification that the UHPC meets the durability-related requirements as specified in projects (e.g., permeability and abrasion). If fine aggregate contains pyrite, the total sulphur content must not exceed 0.10%.		

Water 27.12 (1) Water shall comply with GS Clauses 16.09(1) & 16.09(2).

(2) Wash water from concrete mixer washout operations (recycled water) shall not be used.

Admixtures 27.13 Admixtures shall comply with GS Clause 16.10.

Curing compound 27.14 Curing compound shall comply with GS Clause 16.11.

UHPC

UHPC mix 27.15 (1) The mix design of UHPC shall consider the characteristics of the structural form, construction process, and environmental factors. The initial mix design shall be calculated based on the workability, strength, durability, and other necessary performance requirements of the UHPC. The mix design shall be trial-mixed and adjusted to obtain a baseline mix that meets workability requirements, and then confirmed through verification of strength and other technical indicators.

(2) Unless otherwise accepted by the *Project Manager*, the minimum designed slump flow for designed mix UHPC for reinforced elements shall be 660 mm. Should the *Contractor*

wish to use designed mix UHPC with a designed slump flow less than 660 mm in reinforced elements, the *Project Manager* may require the *Contractor* to demonstrate that such UHPC is satisfactorily placed and compacted in trial sections simulating the appropriate sections of the *works*.

(3) Cement, PFA, GGBS, SF, steel fibre, aggregates, water, admixtures and curing compound for UHPC shall comply with Clauses 27.06 to 27.14.

(4) The water/cementitious content ratio for UHPC shall be less than 0.25. For the use of steel fibre in UHPC, the minimum volume content of steel fibres shall be greater than 1.0 %, and demonstrate strain hardening behaviour in accordance with the direct tensile test specified in AASHTO T 397.

(5) The volume of aggregate shall be calculated as the total volume of compacted UHPC minus the volumes of water, cementitious materials, steel fibres, and air content. The total amount of aggregate shall be obtained by multiplying the volume of aggregate by the density of the aggregate.

(6) Either PFA or GGBS shall be used in concrete of all pile caps and substructure construction where the concrete member is thicker than 750 mm.

Chloride content of UHPC 27.16 The maximum total chloride content of UHPC, expressed as a percentage relationship between the chloride ion and the cementitious content by mass in the UHPC mix, shall be limited to:

(a) 0.1 % for prestress UHPC, steam-cured structural UHPC, or

(b) 0.35 % for UHPC with reinforcement or other embedded metal.

Cementitious content of designed mix UHPC 27.17 The cementitious content of designed mix UHPC may be varied during routine production at the discretion of the *Contractor* by an amount not exceeding 50 kg/m^3, provided that the total cementitious content is not less than the minimum value and does not exceed the specified maximum value, if any, as stated in the contract.

SUBMISSIONS

Particulars of materials for UHPC 27.18 (1) All certificates and test reports shall be issued within 6 months prior to submission and shall be accepted by the *Project Manager* before the materials are delivered to the Site or used in the *works*.

(2) Particulars of the proposed cement shall comply with GS Clause 16.17(1)(a).

(3) Particulars of the proposed PFA shall comply with GS Clauses 16.17(1)(b) & 16.17(1)(c).

(4) Particulars of the GGBS shall comply with GS Clause 16.17(1)(e) and include the glass content result as determined by X-ray diffraction or optical-microscopy method.

(5) A certificate issued within 6 months for SF showing the manufacturer's name, the date and place of manufacture and showing that the SF complies with the requirements stated in the contract and including results of tests to BS EN 13263-1:2009, CAN/CSA-A23.5-M86 and BS 4550 for:

- Moisture content
- Fineness
- Density
- Accelerated Pozzolanic Activity Index with OPC at 7 days min. % of control
- Soundness
- Sulphur trioxide (SO_3)
- Silicon dioxide (SiO_2)
- Loss on ignition

(6) Particulars of the steel fibres shall comply with Clause 27.10 and BS EN 14889-1:2006. A certificate issued within 6 months for steel fibres showing the manufacturer's name, the date and place of manufacture and showing that the fibres comply with the requirements stated in the contract and including results of tests for:

- Shape
- Size
- Tensile strength
- Surface quality
- Machining debris
- Length deviation

(7) Particulars of the aggregates shall comply with GS Clause 16.17(1)(d) and shall meet the following specific requirement:

(a) Chloride ion content, total sulphurs content, mica content, mud content and clay lump content, crusher dust content shall be shown in the certificates/documents in accordance with Clause 27.11.

(8) Particulars of the admixture shall comply with GS Clause 16.17(2).

(9) Particulars of the curing compound shall comply with GS Clause 16.17(3).

(10) The particulars, including certificates, shall be submitted to the *Project Manager* for acceptance at least 14 days before the first delivery of the material to the Site, and thereafter each time the source is changed.

Particulars of UHPC mix

27.19 (1) The following particulars of each proposed designed mix UHPC shall be submitted to the *Project Manager* for acceptance:

(a) Quantity of each constituent per batch and per cubic metre of compacted UHPC, with required tolerances on quantities of aggregates to allow for minor variations in grading, silt content etc. The maximum permitted variations in the quantity of fine and coarse aggregates shall be ± 10 kg per 100 kg of cementitious content.

(b) Grading of aggregates.

(c) Workability after the addition of superplasticisers, in terms of designed slump flow.

(d) Method of placing UHPC.

(e) Method of controlling the temperature of the UHPC, if required.

(f) Test or trial mix data including compressive strength, direct tensile strength, static modulus of elasticity, permeability and abrasion resistance for designed mix UHPC of the same grade and with similar constituents and properties, if available.

(g) Test data including compressive strength, direct tensile strength, static modulus of elasticity, permeability and abrasion resistance for designed mix UHPC of the same or other grade produced in the plant or plants proposed to be used, if available.

(2) The particulars shall be submitted to the *Project Manager* for acceptance at least 7 days before trial mixes are made.

(3) Test certificates giving the results of tests required in GS Table 16.7 shall be submitted at quarterly intervals unless accepted otherwise by the *Project Manager*. If the aggregates in the alkali "Reactive" category was found, the *Contractor* shall submit the relevant test certificates and calculations to the *Project Manager* together with his remedial proposals for acceptance.

Particulars of ready-mixed UHPC supplier

27.20 The name of the suppliers and the location of each plant, including a back-up plant, from which the *Contractor* proposes to obtain ready-mixed UHPC shall be submitted to the *Project Manager* for acceptance at least 14 days before trial mixes are made.

Particulars of batching and mixing plant

27.21 Particulars of the proposed batching and mixing plant to be used on the Site, including a layout plan and the output of the plant, shall be submitted to the *Project Manager* for acceptance at least 7 days before the plant is delivered to the Site.

Particulars of precast UHPC units

27.22 (1) The following particulars of the proposed precast UHPC units shall be submitted to the *Project Manager* for acceptance:

(a) Details of precasting yards,

(b) Certificate showing the manufacturer's name, the date and place of manufacture, the identification numbers of the precast UHPC units and including results of tests for:

- Compressive strength of 100 mm UHPC cubes at 28 days in accordance with CS1
- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with Annex D of NF P18-470
- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with AASHTO T 397
- Static modulus of elasticity of UHPC at 28 days in accordance with CS1
- Rapid chloride migration coefficient (D_{RCM}) at 28 days in accordance with XP P18-462:2022 and water absorption coefficient (R_a) of UHPC at 28 days in accordance with ASTM C1585-13
- Abrasion index (I) of UHPC specimens at 28 days in accordance with Annex I of NF P18-470 (optional, may be required by *Project Manager* if specified for the project)
- Routine tests, including loading tests, carried out at the precasting yards

(c) Details of lifting points and methods of handling, and

(d) Procedure for testing precast UHPC units.

(2) The particulars, other than certificates, shall be submitted to the *Project Manager* for acceptance at least 14 days before the first delivery of the precast UHPC units to the Site. The certificates shall be submitted for each batch of precast UHPC units delivered to the Site.

Particulars of construction joints

27.23 Particulars of the proposed positions and details of construction joints in UHPC which are not stated in the contract shall be submitted to the *Project Manager* for acceptance at least 14 days before the relevant elements are concreted.

TRIALS

Trial mix UHPC 27.24

(1) For designed mix UHPC, Plant Trials and Laboratory Mix Trials shall be carried out.

(2) Plant Trials and Laboratory Mix Trials shall be completed at least 35 days before the UHPC mix is placed in the permanent work.

(3) The *Contractor* shall inform the *Project Manager* at least 24 hours before conducting Plant Trials and Laboratory Mix Trials.

(4) For designed mix UHPC, the *Contractor* shall propose the required testing according to the design intent and grade strength requirements stated in the contract and the proposal shall be submitted to the *Project Manager* for acceptance before conducting Plant Trials and Laboratory Mix Trials.

Plant Trials 27.25

(1) Plant Trials shall be made using the plant or plants proposed and the mix designs and constituents submitted to the *Project Manager* for acceptance.

(2) One batch of UHPC of a proposed designed mix shall be made on each of three days in each plant proposed to be used. The batch shall be at least 60 % of the mixer's nominal capacity. If the UHPC is batched in a central plant and mixed in a truck mixer, three different truck mixers shall be used.

(3) Three samples of UHPC shall be provided from each batch at approximately 1/6, 1/2 and 5/6 of the discharge from the mixer. Each sample shall be of sufficient size to perform one slump flow test, and make three compression test cubes, three bending test specimens according to Annex D of NF P18-470, three direct tensile test specimens according to AASHTO T 397, six elastic modulus test specimens, three rapid chloride migration test specimens, three water absorption test specimens and if required by *Project Manager*, three abrasion test specimens. The size of each sample and the method of sampling shall be in accordance with Section 1 of CS1.

(4) Each sample taken in accordance with Clause 27.25(3) shall be tested to determine its slump flow in accordance with Clauses 27.60 to 27.63.

(5) All test cubes and test specimens shall be made from each sample taken in accordance with Clause 27.25(3) and stored, cured and tested to determine

- Compressive strength of 100 mm UHPC cubes at 28 days in accordance with CS1

- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with Annex D of NF P18-470

- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with AASHTO T 397

- Static modulus of elasticity of UHPC at 28 days in accordance with CS1

- Rapid chloride migration coefficient (D_{RCM}) at 28 days in accordance with XP P18-462:2022 and water absorption coefficient (R_a) of UHPC at 28 days in accordance with ASTM C1585-13

- Abrasion index (I) of UHPC at 28 days in accordance with Annex I of NF P18-470 (optional, may be required by *Project Manager* if specified for the project)

Laboratory Mix Trials 27.26 (1) Laboratory Mix Trials shall be made in the *Contractor*'s laboratory using the mix designs and constituents submitted to the *Project Manager* for acceptance.

(2) When trial mixing UHPC, the actual raw materials in the contract shall be used, and the minimum mixing volume for each batch of UHPC shall be of sufficient size to perform all the strength and performance tests.

(3) Laboratory Mix Trials shall be carried out in accordance with Section 11 of CS1. Three separate batches shall be made, each of sufficient size to provide samples for two slump flow tests, and to make six compression test cubes, six bending test specimens according to Annex D of NF P18-470, six direct tensile test specimens according to AASHTO T 397, six elastic modulus test specimens, three rapid chloride migration test specimens, three water absorption test specimens, and if required by the *Project Manager*, three abrasion test specimens.

(4) For steam-cured UHPC, an additional three compression test cubes shall be prepared for standard curing and tested for compressive strength. If there are other performance requirements, corresponding specimens shall be prepared and tested for the relevant indicators.

(5) Two slump flow tests in accordance with Clauses 27.60 to 27.63 shall be performed on separate specimens from each batch of Laboratory Trial Mix UHPC.

(6) All test specimens shall be made from each batch of Laboratory Trial Mix UHPC, stored, cured and tested to determine

- Compressive strength of 100 mm UHPC cubes at 28 days in accordance with CS1

- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with Annex D of NF P18-470

- Direct tensile strength (including the tensile limit of elasticity and the post-cracking tensile strength) of UHPC at 28 days in accordance with AASHTO T 397

- Static modulus of elasticity of UHPC at 28 days in accordance with CS1

- Rapid chloride migration coefficient (D_{RCM}) at 28 days in accordance with XP P18-462:2022 and water absorption coefficient (R_a) of UHPC at 28 days in accordance with ASTM C1585-13

- Abrasion index (I) of UHPC at 28 days in accordance with Annex I of NF P18-470 (optional, may be required by *Project Manager* if specified for the project)

Compliance criteria: Plant Trials

27.27 (1) The slump flow of UHPC should be controlled within the design requirements. The average deviation of the nine measured slump flows from the design slump flow should be within ± 50 mm. All nine measured slump flows shall exceed 660 mm.

(2) The average compressive strength at 28 days of the 27 test cubes shall exceed the grade strength by at least 15 MPa. The compressive strength of each individual test cube shall exceed the grade strength by at least 5 MPa.

(3) The range of the compressive strength of the nine test cubes from each batch of UHPC shall not exceed 10 % of the average compressive strength of the nine test cubes from that batch.

(4) The average tensile limit of elasticity at 28 days of the 27 bending test specimens (Annex D of NF P18-470) shall exceed the grade strength by at least 1 MPa. The tensile limit of elasticity of each individual test specimen shall exceed the grade strength by at least 0.5 MPa.

(5) The range of the tensile limit of elasticity of the nine bending test specimens (Annex D of NF P18-470) from each batch of UHPC shall not exceed 20 % of the average tensile limit of elasticity of the nine specimens from that batch.

(6) The average tensile limit of elasticity at 28 days of the 27 direct tensile test specimens (AASHTO T 397) shall exceed the grade strength by at least 1 MPa. The tensile limit of elasticity of each individual direct tensile test specimen shall exceed the grade strength by at least 0.5 MPa.

(7) The range of the tensile limit of elasticity of the nine direct tensile test specimens (AASHTO T 397) from each batch of

UHPC shall not exceed 20 % of the average tensile limit of elasticity of the nine specimens from that batch.

(8) The average post-cracking tensile strength shall exceed 25% of the average tensile limit of elasticity.

(9) The static modulus of elasticity in compression of each individual elastic modulus test specimen shall exceed 45 GPa.

(10) The average rapid chloride migration coefficient (D_{RCM}) at 28 days of the twenty-seven rapid chloride migration test specimens shall not exceed the requirements specified in Table 27.09.

(11) The average water absorption coefficient (R_a) at 28 days of the twenty-seven water absorption test specimens shall not exceed the requirements specified in Table 27.09.

(12) The average abrasion index (I) at 28 days of the twenty-seven abrasion specimens shall not exceed 0.7.

Compliance criteria: Laboratory Mix Trials

27.28 When test data relating to the proposed plant or plants submitted in accordance with Clause 27.19 show that the plant standard deviation exceeds 12 MPa for 100 mm test cubes, or in the absence of acceptable data, the results of tests on Laboratory Mix Trial UHPC shall comply with the following requirements:

(1) The average of the six measured slump flows shall be within ± 50 mm of the designed slump flow, and each of the six values shall exceed 660 mm.

(2) The average compressive strength at 28 days of the 18 test cubes (i.e. 27 test cubes for steam-cured UHPC) shall exceed the grade strength by at least 18 MPa, and the compressive strength of each individual test cube shall exceed the grade strength by at least 7 MPa.

(3) The average tensile limit of elasticity at 28 days of the 18 bending test specimens (Annex D of NF P18-470) shall exceed the grade strength by at least 1.2 MPa. The tensile limit of elasticity of each individual bending test specimen shall exceed the grade strength by at least 0.6 MPa.

(4) The average tensile limit of elasticity at 28 days of the 18 direct tensile test specimens (AASHTO T 397) shall exceed the grade strength by at least 1.2 MPa. The tensile limit of elasticity of each individual bending test specimen shall exceed the grade strength by at least 0.6 MPa.

(5) The average post-cracking tensile strength shall exceed 25% of the average tensile limit of elasticity.

(6) The static modulus of elasticity in compression of each individual elastic modulus specimen shall exceed 45 GPa.

(7) The average rapid chloride migration coefficient (D_{RCM}) at 28 days of the nine rapid chloride migration test specimens shall not exceed the requirements specified in Table 27.09.

(8) The average water absorption coefficient (R_a) at 28 days of the nine specimens shall not exceed the requirements specified in Table 27.09.

(9) The average abrasion index (I) at 28 days of the nine abrasion specimens shall not exceed 0.7.

Trial panels 27.29 Trial panels required in accordance with GS Clauses 14.22 and 14.23 shall be constructed for each UHPC mix as appropriate.

Non-compliance: trial mix UHPC 27.30

(1) If the result of any strength and performance tests of plant trials and laboratory mix trials does not comply with the specified requirements for the property, particulars of proposed changes to the materials, mix design or methods of production shall be submitted to the *Project Manager*.

(2) UHPC that is assessed as non-compliant with the requirements of strength and performance shall be reworked, strengthened, or adjusted the mix proportion subject to the acceptance of the *Project Manager*.

Further plant trials and laboratory mix trials shall be made until the result of every test complies with the specified strength and performance requirements of trial mix UHPC.

(3) If trial panels are constructed using the non-complying trial mix UHPC, further trial panels shall be constructed unless in the opinion of the *Project Manager* the changes to the materials, mix design or methods of production will not affect the results of the previous trial panels.

Accepted UHPC mix 27.31 An UHPC mix that complies with the specified requirements for laboratory mix trials and plant trials shall become an accepted UHPC mix. The designed slump flow used to produce an accepted UHPC mix shall become the accepted slump flow.

Commencement of concreting 27.32 UHPC shall not be placed in the permanent work until the UHPC mix has been accepted by the *Project Manager*.

Changes in materials and methods of construction 27.33 Unless accepted by the *Project Manager*, the materials, mix design, methods of production or methods of construction used to produce an accepted UHPC mix shall not be changed except that the variations of cementitious content as stated in Clause 27.17 and variations in aggregate quantities within the required tolerances in Clause 27.19(1)(a), will be allowed.

HANDLING AND STORAGE OF MATERIALS

Storage of cement 27.34 Cement in bags shall be stored in a dry, weatherproof store sheltered on the top and 3 sides with a raised floor. Each delivery shall be identified

and kept separate and shall be used in the order of delivery. Bulk cement shall be kept dry. Cement of different types and from different sources shall be stored in separate silos clearly marked to identify the different contents of each.

Storage of PFA, GGBS, SF and admixtures 27.35 Bulk PFA, GGBS, SF and admixtures shall be kept dry. PFA, GGBS, SF and admixtures of different types and from different sources shall be stored in separate silos clearly marked to identify the different contents of each.

Storage of steel fibres 27.36 Steel fibres shall be labelled and stored separately according to type, specification and manufacturer. Also, steel fibres shall be protected from moisture and rust.

Handling and storage of aggregates 27.37 Handling and storage of aggregates shall comply with GS Clause 16.34.

Storage of admixtures and curing compounds 27.38 Admixtures and curing compounds shall be stored in sealed containers marked to identify the contents and protected from exposure to conditions that may affect the material. The materials shall be stored in accordance with the manufacturer's recommendations and shall not be used after the recommended shelf life has been exceeded.

Handling and storage of precast UHPC units 27.39 Handling and storage of precast UHPC units shall comply with GS Clause 16.36.

Storage of Pre-mixed UHPC 27.40 Pre-mixed UHPC raw constituent materials in moisture-proof bags shall be stored in a dry, weatherproof store sheltered on the top and 3 sides with a raised floor or as advised by the supplier. Each delivery shall be clearly identified, stored separately by batch, and used in the order of delivery.

BATCHING AND MIXING UHPC

Batching UHPC 27.41 Batching UHPC shall comply with GS Clause 16.37 and shall meet the following specific requirements:

(1) The accuracy of the measuring equipment shall be within 1 % of the quantity of steel fibre being measured.

(2) Solid raw materials shall be measured by mass, while water and liquid additives shall be measured by volume.

(3) The measurement of raw materials shall use electronic measuring devices. These devices must have a valid calibration certificate issued by a legal metrology department and shall be regularly calibrated. UHPC production units shall self-check at least once a month.

Mixing UHPC 27.42 Batching UHPC shall comply with GS Clause 16.38 and shall meet the following specific requirements:

(1) UHPC shall be produced using either centralized mixing or on-site mixing methods.

(2) Various dry solid materials are pre-mixed into a solid mixture and transported to the construction site. Water and liquid components are then added to create the UHPC mix. The solid mixture shall not segregate during pre-mixing and transportation.

(3) The mixing, transportation, placing, and curing of UHPC shall be performed in an environment with a temperature above 5 °C. Also, the mixing temperature of UHPC shall not exceed 30 °C unless otherwise specified by special studies or by data provided in the product specification of the UHPC and shall be accepted by the *Project Manager*.

(4) The mixing process and mixing time for UHPC shall be determined through testing and shall be in accordance with the UHPC manufacturer's standard mixing procedures and recommendations. Measures shall be taken during mixing to prevent steel fibre clumping.

(5) The mixed UHPC shall be uniform and free of steel fibre clumping.

TRANSPORTATION OF UHPC

Transport of UHPC 27.43

(1) UHPC shall not be transported in a manner that will result in contamination, segregation, loss of constituents or excessive evaporation.

(2) UHPC batched off the Site shall be transported to the Site in purpose made agitators operating continuously or in truck mixers.

(3) The time from when the UHPC mixture is discharged from the mixer into the transport truck to when it is unloaded shall not exceed 90 minutes. If transportation time needs to be extended, effective technical measures shall be taken, and tests shall be conducted to ensure the workability of the mixture meets placing requirements at the time of unloading.

RECORDS OF UHPC

Records of UHPC 27.44 Records of UHPC shall comply with GS Clause 16.40.

PLACING AND COMPACTING UHPC

Placing UHPC 27.45

(1) The permission of the *Project Manager* shall be obtained before UHPC is placed in any part of the permanent work. If placing

of UHPC is not started within 24 hours of permission having been given, permission shall again be obtained from the *Project Manager*. The *Contractor* shall inform the *Project Manager* before concreting starts and shall allow the *Project Manager* sufficient time to inspect the work that is to be concreted.

(2) Unless otherwise accepted by the *Project Manager*, the temperature of fresh UHPC shall not exceed 30 °C when placed in position. The *Contractor* shall submit for details of the proposal for the acceptance of the *Project Manager* to ensure that these temperatures will not be exceeded.

(3) UHPC shall be placed and compacted in its final position within 2.5 hours of the introduction of cement to the UHPC mix. If the time needs to be extended, effective technical measures shall be taken, and tests shall be conducted to ensure the workability of the mixture meets placing requirements.

(4) UHPC that in the opinion of the *Project Manager* is no longer sufficiently workable shall not be placed in the permanent work.

(5) UHPC shall not be placed in water.

(6) UHPC shall be placed as close as practicable to its final position. Trunking or chutes shall be used to place UHPC which will fall more than 2.7 m unless otherwise accepted by the *Project Manager*. Trunking or chutes, where being used, shall be clean and used in such a way to avoid segregation and loss of constituents of the UHPC mix.

(7) UHPC shall be placed in such a manner that the formwork, reinforcement or built-in components are not displaced.

(8) Unless otherwise accepted by the *Project Manager*, UHPC shall be placed in horizontal layers to a compacted depth of not more than 450 mm if internal vibrators are used and to a compacted depth of not more than 150 mm in other cases.

(9) UHPC shall be placed continuously within the element to be concreted to avoid cold joints. Fresh UHPC shall not be placed against UHPC that has been in position for more than 30 minutes unless in the opinion of the *Project Manager* the UHPC already placed is sufficiently workable and the acceptance of the *Project Manager* has been obtained. If acceptance is not obtained, a construction joint shall be formed as stated in Clause 27.48. UHPC shall not be placed against the UHPC already placed for at least 24 hours unless acceptance has been obtained from by the *Project Manager*.

(10) UHPC shall be compacted and shaped using a plate vibrator, an external mould vibrator or the methods and equipment recommended by the UHPC supplier. During placing and shaping, avoid layering and segregation of the mixture, as well as steel fibre exposure on the surface of the component. Ensure that the placed UHPC is dense, with uniformly distributed steel fibres and overall integrity of the component.

Placing UHPC by pumping 27.46

(1) Concrete pumps shall be operated and maintained in accordance with the manufacturer's recommendations. The pumps and pipelines shall be maintained in a clean condition. Internal surfaces of pipelines shall not be aluminium. Joints in pipelines shall be tightly fixed and shall not permit grout loss.

(2) Concrete pumps shall be positioned such that pipelines are as short and straight as practicable and require as little repositioning as practicable. Bends in pipelines shall be arranged in such a manner that the UHPC, formwork, reinforcement or built-in components are not disturbed.

(3) Pipelines shall be lubricated by passing UHPC mix without steel fibres through the pipeline before the UHPC is pumped. The initial discharge of pumped UHPC shall not be placed in the permanent work.

Compacting UHPC 27.47 UHPC shall be compacted to form a dense homogeneous mass by the methods and equipment recommended by the UHPC supplier.

CONSTRUCTION JOINTS

Construction joints 27.48 Construction joints shall comply with GS Clause 16.45.

CURING UHPC

Curing UHPC 27.49

(1) Curing UHPC shall reference GS Clause 16.46 as appropriate to provide the temperature and moisture conditions for the period of time necessary for UHPC to develop its strength, durability, and other properties.

(2) Subject to the acceptance of the *Project Manager*, natural curing method shall be used in accordance with the following requirements:

After concrete placing is completed, it shall be covered and kept moist for more than 7 days. The formwork shall be removed when the compressive strength of the test cubes under the same conditions reaches 30 MPa. The average ambient temperature during curing shall be above 10 °C. If the average ambient temperature is below 10 °C or the minimum temperature is below 5 °C, it shall be treated as winter construction procedures, and insulation measures shall be taken such as covering with insulation layers, heating the surrounding environment, using insulation shelters and steam curing.

(3) Subject to the acceptance of the *Project Manager*, steam curing method shall be used in accordance with the following requirements:

The steam curing generally applies for achieving high early strength requirement, construction in winter and precast UHPC. It is recommended to use an automatic control system to control the steam curing temperature. The curing process includes resting, steam curing, and natural curing.

(a) Resting:
After forming UHPC, static curing should be carried out. The ambient temperature during resting should be above 10 °C, and the relative humidity should be above 60 %. The static rest time should be determined according to the requirements of the curing environment in Clause 27.49(2) and should not be less than 6 hours. During resting, the exposed surface of UHPC components should be kept moist.

(b) Steam curing:
After resting, UHPC components should undergo steam curing. The heating rate should not exceed 12 °C per hour. After reaching the curing temperature, maintain a constant temperature for 24 hours or until the compressive strength of the test cubes under the same conditions reaches the predetermined value. The relative humidity of the environment during steam curing should be maintained above 95 %. After steam curing, the cooling rate should not exceed 15 °C per hour until the surface temperature of the components is no more than 20 °C different from the ambient temperature. The mould should be removed after steam curing.

(c) Natural curing:
After demoulding, UHPC components should undergo natural curing. The average ambient temperature during natural curing should be above 10 °C, and the surface of the components should be kept moist for no less than 7 days. When the average ambient temperature is below 10 °C or the minimum temperature is below 5 °C, winter construction procedures should be followed, and insulation measures should be taken.

INSTALLATION OF PRECAST UHPC UNITS

Installation of precast UHPC units	27.50	Installation of precast UHPC units shall comply with GS Clause 16.47.

LOADING OF UHPC

Loading of UHPC	27.51	Loading on UHPC shall comply with GS Clause 16.48.

TESTING: CEMENT, PFA, GGBS, SF, STEEL FIBRE, AGGREGATE, ADMIXTURE, CURING COMPOUND

Batch: cement, PFA, GGBS, SF, steel fibre, aggregate, admixture, curing compound

27.52 A batch of cement, PFA, GGBS, SF, steel fibre, aggregate, admixture or curing compound is any quantity of cement, PFA, GGBS, SF, steel fibre, aggregate, admixture or curing compound of the same type, manufactured or produced at the same time in the same place, covered by the same certificates and delivered to the Site, or stored at the ready-mixed concrete plant, at any one time.

Sample: cement, PFA, GGBS, SF, steel fibre, aggregate, admixture, curing compound

27.53 (1) Samples of cement, PFA, GGBS, aggregate, admixture and curing compound shall comply with GS Clause 16.50.

(2) The size of each sample and the method of sampling for SF and steel fibre shall be as stated in Table 27.04.

Table 27.04: Size of samples and method of sampling SF and steel fibre

Material	Size of Sample	Method of Sample
SF	20 kg	BS EN 196-7[1]
Steel Fibre	30 fibres per test	BS EN 14889-1:2006[2]

[1] BS EN 196-7 refers to Methods of Testing Cement - Part 7: Methods of Taking and Preparing Samples of Cement.
[2] BS EN 14889-1:2006 refers to Fibres for Concrete - Part 1: Steel Fibres - Definitions, Specifications and Conformity.

Testing: cement, PFA, GGBS, SF, steel fibre, aggregate, admixture, curing compound

27.54 (1) Each sample of cement, PFA, GGBS, aggregate, admixture and curing compound shall be tested to determine the properties stated in GS Table 16.7 and Table 27.05.

(2) The method of testing and acceptance criteria shall be as stated in GS Table 16.7 and Table 27.05.

(3) The method of testing and acceptance criteria for SF shall comply with BS EN 13263-1:2009.

(4) The method of testing and acceptance criteria for of steel fibres shall comply with BS EN 14889-1:2006.

(5) The maximum total chloride content of UHPC shall be determined on the basis of the results of tests for chloride content of each constituent.

(6) The sampling and testing for acceptance inspection at delivery shall be as stated in National Annex NB of BS EN 197-1. The

methods of taking and preparing samples of cement shall be as stated in BS EN 196-7.

Table 27.05: Testing of fine aggregate

Material	Property	Testing Method and Acceptance Criteria
Fine Aggregate	Chloride ion content	CS3
	Total sulphurs content	
	Mica content	JGJ 52-2006*
	Clay lump content	BS EN 12620:2013
	Crusher dust content	

* JGJ 52-2006 refers to the industry standard of China "Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete".

TESTING: UHPC – GENERAL REQUIREMENTS

Batch: UHPC 27.55 (1) A batch of UHPC is any quantity of UHPC produced in one cycle of operations of a batch mixer, or conveyed ready-mixed in a delivery truck, or discharged during one minute from a continuous mixer.

(2) The sampling of UHPC mixtures at the construction Site, after casting and forming, shall be taken from the same batch or the same truck delivery of UHPC. The sample quantity shall be no less than 1.5 times the required amount for testing and shall not be less than 20 Liters.

Reduction of testing frequency 27.56 The number of tests for permeability and abrasion resistance of designed mix UHPC may be reduced if in the opinion of the *Project Manager* the standard of quality control is satisfactory.

Preparation of UHPC cubes / specimens 27.57 When preparing UHPC specimens, it is advisable to start placing from one side of the mould, filling the mould with the mixture in one go, slightly above the top of the mould. For mixtures with a slump flow value greater than 660 mm, gently tap the sides of the mould with a rubber mallet to remove air bubbles after placing. Do not tamp during the moulding process. After the mixture is compacted, scrape off the excess mixture from the surface of the mould and smooth it with a trowel. Prismatic and small beam specimens shall be moulded horizontally. The moulding method for specimens used to inspect or control engineering quality shall be the same as the method used in actual construction.

Testing: UHPC cubes / specimens 27.58 (1) UHPC components cured at room temperature shall use standard conditions (ambient temperature 27 °C ± 3 °C & relative humidity greater than 95 %) for curing UHPC cubes / specimens, and be tested at 28 days after moulding. The UHPC cubes / specimens can also be cured in curing tank at ambient temperature of 27 °C ± 3 °C according to Section 10 of CS1.

(2) For UHPC components with steam curing, the curing UHPC cubes / specimens shall first be cured under the same conditions as the components, then continue curing under standard conditions until 28 days for testing.

Testing Location: UHPC 27.59 Laboratories accredited by HOKLAS for the relevant tests shall be used, if available, in which case results shall be issued on HOKLAS endorsed test reports. Otherwise, independent laboratories accepted by the *Project Manager* shall be used.

TESTING: UHPC – WORKABILITY

Samples: workability of UHPC 27.60 Samples for workability of UHPC shall comply with GS Clause 16.54.

Testing: workability of UHPC 27.61 (1) Each sample of UHPC taken as stated in Clause 27.60 shall be divided into two specimens. Each specimen shall be tested to determine the workability of the UHPC in accordance with sub-clause (2).

(2) The slump flow test shall comply with the requirements as stated in Section 2 of CS1.

(3) The average of the two workability values shall be calculated and referred to as the average measured slump flow.

Compliance criteria: workability of UHPC 27.62 The measured slump flow of the two specimens taken from one sample of designed mix UHPC shall be greater than 660 mm, and the average slump flow shall be within ±50 mm of the designed slump flow value.

Non-compliance: workability of UHPC 27.63 A batch of UHPC shall be considered as not complying with the specified requirements for workability if the result of any test for workability, carried out on a sample taken from the batch, does not comply with the specified requirements for workability. UHPC that fails to comply with the specified requirements for workability shall not be placed in the permanent works.

TESTING: UHPC – COMPRESSIVE STRENGTH

Samples: compressive strength of UHPC 27.64 (1) For each UHPC mix, one sample of UHPC shall be provided from each amount of UHPC as stated in Table 27.06 or from the amount of UHPC produced each day, whichever is less.

(2) If the *Contractor* requests, or if the *Project Manager* instructs, that the UHPC be tested for compressive strength at ages other than 28 days, additional samples shall be provided. The number of additional samples shall be as stated in Clause 27.64(1).

(3) The size of each sample and the method of sampling shall be in accordance with Section 1 of CS1. If a superplasticising admixture is included in the UHPC mix, the samples shall be taken after the superplasticiser is added and after the UHPC is remixed.

Table 27.06: Rate of sampling of UHPC

Type of Structure	Amount of UHPC
Masts Cantilevers 3 m or more in length Columns Shear walls Prestressed elements Other critical elements	10 m^3 or 10 batches, whichever is less
Solid rafts Pile caps Mass concrete	100 m^3 or 100 batches, whichever is less
Other types	25 m^3 or 25 batches, whichever is less

Testing: compressive strength of UHPC

27.65 (1) Two test cubes shall be made from each sample of UHPC taken as stated in Clause 27.64. Each pair of test cubes shall be tested to determine the compressive strength at 28 days.

(2) The method of making test cubes shall be in accordance with CS1.

(3) The method of storing test cubes shall be in accordance with Section 10 of CS1. Test cubes which are cured on the Site shall be delivered to the testing laboratory at least 48 hours before the tests are due to be carried out.

(4) The method of testing shall be in accordance with Section 12 of CS1.

(5) For the purpose of assessing compliance of designed mix UHPC as stated in Clauses 27.66 and 27.67, the average of the two compressive strengths of the pair of test cubes shall be calculated and referred to as the test result.

(6) The size of the test cube shall be 100 mm for UHPC.

Compliance criteria: compressive strength of designed mix UHPC

27.66 (1) The results of tests for compressive strength at 28 days of designed mix UHPC shall comply with the following requirements:

(a) Each test result shall not be less than the grade strength by more than the appropriate amount stated in Column A of Table 27.07, and,

(b) The average of any four consecutive test results, or the average of the first two or first three test results if less than four test results are available, shall exceed the

grade strength by at least the appropriate amount stated in Column B of Table 27.07.

(2) If there is a period exceeding 14 days between any two consecutive test results in any group of four consecutive test results and if accepted by the *Project Manager*, the test results immediately before and immediately after the period may be treated separately for the purpose of Clause 27.66(1)(b).

(3) If the difference between the compressive strengths of two test cubes made from one sample of designed mix UHPC exceeds 15 % of the test result:

(a) The higher of the compressive strengths of the two test cubes shall be used to assess compliance as stated in Clause 27.66(1)(a), and

(b) The test result for that sample shall not be used to assess compliance as stated in Clause 27.66(1)(b) and shall not be used to calculate the standard deviation.

(4) For designed mix UHPC until 40 test results are available either:

(a) Compliance criteria C1 shall apply, or

(b) If in the opinion of the *Project Manager* there is sufficient evidence that the standard of quality control using similar materials and plant is such that the standard deviation for at least 40 test results will not exceed 12 MPa for 100 mm test cubes, compliance criteria C2 shall apply.

(5) For designed mix UHPC, the standard deviation or the coefficient of variation of test results shall be calculated after every test result for each designed mix using the last 40 test results judged by the same compliance criteria. The acceptance criteria shall depend on the calculated standard deviation as follows:

(a) For 100 mm test cubes, if the standard deviation does not exceed 12 MPa, compliance criteria C2 shall apply to subsequent test results. If the standard deviation exceeds 12 MPa, compliance criteria C1 shall apply to subsequent test results.

(b) For the coefficient of variation exceeds 14 %, no further concreting of permanent works should be allowed until an investigation of the materials, mix design, methods of production, sampling and testing has been carried out and measures, which in the opinion of the *Project Manager* will result in restoring a steady and satisfactory production of the UHPC mix, have been taken:

(6) If the compliance criteria are changed from C1 to C2 or from C2 to C1, the new compliance criteria shall apply from the 35th day after making the last pair of test cubes in the set of 40 on which the decision to change was based. For the purpose of Clause 27.66(1)(b), test results immediately before and immediately after the change shall be treated separately.

Table 27.07: Compliance criteria for compressive strength of designed mix UHPC

Compliance Criteria	Column A	Column B
	Maximum amount by which each test result may be below the grade strength (MPa)	Minimum amount by which the average of any four consecutive test results shall be above the grade strength (MPa)
C1	5	12
C2	5	10

Non-compliance criteria: compressive strength of designed mix UHPC

27.67 (1) A batch of designed mix UHPC shall be considered as not complying with the specified requirements for compressive strength if the test result for the pair of test cubes made from a sample taken from the batch does not comply with the requirements stated in Clause 27.66(1)(a).

(2) The batches of designed mix UHPC from which the first and last samples in any group of four consecutive test results were taken and all intervening batches shall be considered as not complying with the specified requirements for compressive strength if the group of four consecutive test results does not comply with the requirements stated in Clause 27.66(1)(b).

(3) If designed mix UHPC is considered as not complying with the specified requirements for compressive strength, the *Project Manager* may instruct that tests as stated in Clauses 27.84 to 27.87 are carried out on UHPC cores or on samples taken from the hardened UHPC.

(4) For non-compliance in compressive strength, where such properties are deemed critical to the design assumption or structural performance of the UHPC unit, destructive testing methods, such as taking UHPC cores, may be considered only if they do not impair the structural integrity or serviceability of the unit. Where reliable verification of compliance is not feasible, the unit shall be rejected unless otherwise accepted by the *Project Manager*.

(5) As the UHPC cores are cylinder in shape, these cores shall be further prepared to meet the specimen dimension and tolerance requirements according to the provisions of Section 12 of CS1.

TESTING: UHPC – DIRECT TENSILE STRENGTH

Samples: direct tensile strength of UHPC

27.68 (1) For each UHPC mix, one sample of UHPC shall be provided from each amount of UHPC as stated in Table 27.08 or from the amount of UHPC produced each day, whichever is less.

(2) The size of each sample and the method of sampling shall be in accordance with Section 1 of CS1.

Table 27.08: Rate of sampling of UHPC

Type of Structure	Amount of UHPC
Masts Cantilevers 3 m or more in length Columns Shear walls Prestressed elements Other critical elements	20 m^3 or 20 batches, whichever is less
Solid rafts Pile caps Mass concrete	200 m^3 or 200 batches, whichever is less
Other types	50 m^3 or 50 batches, whichever is less

Testing: direct tensile strength of UHPC

27.69 (1) Two test specimens shall be made from each sample of UHPC taken as stated in Clause 27.68. Each pair of test specimens shall be tested to determine the direct tensile strength at 28 days.

(2) The direct tensile strength of UHPC shall be determined in accordance with the Annex D of NF P18-470 or AASHTO T 397.

(3) For the purpose of assessing compliance of designed mix UHPC as stated in Clauses 27.70 and 27.71, the average of the two tensile strengths of the pair of test specimens shall be calculated and referred to as the test result.

Compliance criteria: direct tensile strength of designed mix UHPC

27.70 (1) The results of tests for direct tensile strength at 28 days of designed mix UHPC shall comply with the following requirements:

(a) The tensile limit of elasticity of each test shall not be less than the grade strength by 0.5 MPa,

(b) The average tensile limit of elasticity from any four consecutive test results, or the average of the first two or first three test results if less than four test results are available, shall exceed the grade strength by at least 1 MPa,

(2) If the difference between the tensile strengths of two test specimens made from one sample of designed mix UHPC exceeds 15 % of the test result:

(a) The higher of the tensile strengths of the two test specimens shall be used to assess compliance as stated in Clause 27.70(1)(a), and

(b) The test result for that sample shall not be used to assess compliance as stated in Clause 27.70(1)(b).

Non-compliance criteria: direct tensile strength of designed mix UHPC

27.71 (1) A batch of designed mix UHPC shall be considered as not complying with the specified requirements for tensile strength if the test result for the pair of test specimens made from a sample taken from the batch does not comply with the requirements stated in Clause 27.70.

(2) If designed mix UHPC is considered as not complying with the specified requirements for tensile strength, the *Project Manager* may instruct that tests as stated in Clauses 27.84 to 27.87 are carried out on UHPC cores or on samples taken from the hardened UHPC.

(3) For non-compliance in tensile strength, where such properties are deemed critical to the design assumption or structural performance of the UHPC unit, destructive testing methods, such as taking UHPC cores, may be considered only if they do not impair the structural integrity or serviceability of the unit. Where reliable verification of compliance is not feasible, the unit shall be rejected unless otherwise accepted by the *Project Manager*.

(4) As the UHPC cores are cylinder in shape, these cores shall be further prepared to meet the specimen dimension and tolerance requirement according to the provisions of the Annex D of NF P18-470. Depending on the geometry of structural elements, the tensile strength determined in accordance with the provision of the Annex E of NF P18-470 is also acceptable.

TESTING: UHPC – STATIC MODULUS OF ELASTICITY IN COMPRESSION

Samples: static modulus of elasticity in compression

27.72 (1) For each UHPC mix, samples shall be taken at a frequency agreed between *Project Manager* and UHPC suppliers.

(2) The size of each sample and the method of sampling shall be in accordance with Section 1 of CS1.

Testing: static modulus of elasticity in compression

27.73 (1) Two test specimens shall be made from each sample of UHPC taken as stated in Clause 27.72. Each pair of test specimens shall be tested to determine the static modulus of elasticity at 28 days.

(2) The static modulus of elasticity test of UHPC shall comply with the provisions of Section 17 of CS1.

(3) For the purpose of assessing compliance of designed mix UHPC as stated in Clauses 27.74 and 27.75, the average of the two static moduli of elasticity in compression of the pair of test specimens shall be calculated and referred to as the test result.

Compliance criteria: static modulus of elasticity in compression

27.74 Each static modulus of elasticity in compression test result at 28 days of designed mix UHPC shall not be less than the 45 GPa.

Non-compliance criteria: static modulus of elasticity in compression

27.75 (1) A batch of designed mix UHPC shall be considered as not complying with the specified requirements for static modulus of elasticity in compression if the test result for the pair of test specimens made from a sample taken from the batch does not comply with the requirements stated in Clause 27.74.

(2) If designed mix UHPC is considered as not complying with the specified requirements for static modulus of elasticity, the *Project Manager* may instruct that tests as stated in Clauses 27.84 to 27.87 are carried out on UHPC cores or on samples taken from the hardened UHPC.

(3) For non-compliance in static modulus of elasticity, where such properties are deemed critical to the design assumption or structural performance of the UHPC unit, destructive testing methods, such as taking UHPC cores, may be considered only if they do not impair the structural integrity or serviceability of the unit. Where reliable verification of compliance is not feasible, the unit shall be rejected unless otherwise accepted by the *Project Manager*.

(4) As the UHPC cores are cylinder in shape, these cores shall be further prepared to meet the specimen dimension and tolerance requirements according to the provisions of Section 17 of CS1.

TESTING: UHPC – PERMEABILITY

Samples: permeability of UHPC

27.76 (1) For each UHPC mix, samples shall be taken at a frequency agreed between *Project Manager* and UHPC suppliers.

(2) The size of each sample shall be in accordance with the relevant standards, and the method of sampling shall be in accordance with Section 1 of CS1.

Testing: permeability of UHPC

27.77 (1) Two test specimens shall be made from each sample of UHPC taken as stated in Clause 27.76. Each pair of test specimens

shall be tested to determine the permeability of UHPC at 28 days.

(2) The permeability of UHPC shall be evaluated using 1) rapid chloride migration test and 2) water absorption test.

The chloride ion penetration resistance is not required for UHPC with a steel fibre volume content exceeding 2.0 %.

The testing requirements and compliance criteria shall comply with Table 27.09.

(3) For the purpose of assessing compliance of designed mix UHPC as stated in Clauses 27.78 and 27.79, the average of the two permeability tests of the pair of test specimens shall be calculated and referred to as the test result.

Table 27.09: Permeability testing of UHPC

Test Type	Compliance Criteria	References of Test Method
Rapid Chloride Migration Test (RCM)	$D_{RCM} \leq 2.0 \times 10^{-13}$	XP P18-462:2022
Water Absorption Test	$R_a \leq 1.0 \times 10^{-4}$ mm/s$^{0.5}$	ASTM C1585-13

Compliance criteria: permeability of UHPC

27.78 When UHPC requires permeability resistance, test results conforming to the compliance criteria as specified in Table 27.09 shall be deemed acceptable.

Non-compliance criteria: permeability of UHPC

27.79 (1) A batch of designed mix UHPC shall be considered as not complying with the specified requirements for permeability if the test result for the pair of test specimens made from a sample taken from the batch does not comply with the requirements stated in Clause 27.78.

(2) If designed mix UHPC is considered as not complying with the specified requirements for permeability, the *Project Manager* may instruct that tests as stated in Clauses 27.84 to 27.87 are carried out on UHPC cores or on samples taken from the hardened UHPC.

(3) For non-compliance in permeability, where such properties are deemed critical to the design assumption or structural performance of the UHPC unit, destructive testing methods, such as taking UHPC cores, may be considered only if they do not impair the structural integrity or serviceability of the unit. Where reliable verification of compliance is not feasible, the unit shall be rejected unless otherwise accepted by the *Project Manager*.

(4) As the UHPC cores are cylinder in shape, these cores shall be further prepared to meet the specimen dimension and tolerance requirement according to the relevant standards as stated in Table 27.09.

TESTING: UHPC – ABRASION RESISTANCE

Samples: abrasion resistance of UHPC

27.80 If abrasion resistance of UHPC is specified for the project, the *Project Manager* may require sampling and testing at a frequency agreed with UHPC suppliers.

Testing: abrasion resistance of UHPC

27.81 (1) Two test specimens shall be made from each sample of UHPC taken as stated in Clause 27.80. Each pair of test specimens shall be tested to determine the abrasion resistance of UHPC at 28 days.

(2) The testing requirements and compliance criteria shall comply with Table 27.10.

(3) For the purpose of assessing compliance of designed mix UHPC as stated in Clauses 27.82 and 27.83, the average of the two abrasion resistance tests of the pair of test specimens shall be calculated and referred to as the test result.

Table 27.10: Abrasion resistance testing of UHPC

Test Type	Compliance Criteria	References of Test Method
Abrasion resistance test	$I \leq 0.7$	Annex I of NF P18-470

Compliance criteria: abrasion resistance of UHPC

27.82 When UHPC requires abrasion resistance, test results conforming to the compliance criteria as specified in Table 27.10 shall be deemed acceptable.

Non-compliance criteria: abrasion resistance of UHPC

27.83 (1) A batch of designed mix UHPC shall be considered as not complying with the specified requirements for abrasion resistance if the test result for the pair of test specimens made from a sample taken from the batch does not comply with the requirements stated in Clause 27.82.

(2) If designed mix UHPC is considered as not complying with the specified requirements for abrasion resistance, the *Project Manager* may instruct that tests as stated in Clauses 27.84 to 27.87 are carried out on UHPC cores or on samples taken from the hardened UHPC.

(3) For non-compliance in abrasion resistance, where such properties are deemed critical to the design assumption or structural performance of the UHPC unit, destructive testing methods, such as taking UHPC cores, may be considered only if they do not impair the structural integrity or serviceability of the unit. Where reliable verification of compliance is not feasible, the unit shall be rejected unless otherwise accepted by the *Project Manager*.

(4) As the UHPC cores are cylinder in shape, these cores shall be further prepared to meet the specimen dimension and tolerance requirements according to Table 27.10.

TESTING: HARDENED UHPC

Samples: hardened UHPC and UHPC cores 27.84

(1) The number of samples, including cores, of hardened UHPC to be provided for testing shall be as stated in the contract, if testing is to be carried out as a result of the UHPC not complying with the specified requirements, shall be as instructed by the *Project Manager*. In the latter case, all the UHPC being investigated shall be divided as instructed by the *Project Manager* into separate test locations. The number of samples taken from each location shall be as instructed by the *Project Manager* and the quality of UHPC at each location shall be assessed separately. The positions from which the samples are taken shall be as instructed by the *Project Manager*.

(2) The method of sampling shall be in accordance with Section 15 of CS1.

(3) The specimens required for relevant performance tests shall be obtained by coring or cutting, and the specimen dimensions and tolerance requirements shall comply with the provisions of the relevant standards.

(4) Testing on samples of hardened UHPC, including the cored specimens, are required only for the specific material property that failed to meet compliance criteria.

Testing: UHPC cores 27.85

(1) Each UHPC core shall be inspected for evidence of segregation of the constituents and for the presence of voids. Specimens selected from each core shall be tested to determine the compressive strength, direct tensile strength, static modulus of elasticity in compression, permeability and abrasion resistance as instructed by the *Project Manager.*

(2) The method of preparing and inspecting UHPC cores and of testing the cores to determine the compressive strength and the static modulus of elasticity shall be in accordance with CS1.

(3) The testing method for determining the direct tensile strength shall be in accordance with Annex D of NF P18-470 or AASHTO T 397. All tensile specimens shall not be tested until the UHPC has reached an age of 28 days.

(4) The testing method for determining the rapid chloride migration and the water absorption shall be in accordance with XP P18-462:2022 and ASTM C1585-13, respectively.

(5) The testing method for the abrasion specimens to determine the abrasion resistance shall be in accordance with Annex I of NF P18-470.

		(6)	UHPC cores shall not be tested until the UHPC has reached an age of 28 days.
Compliance criteria: UHPC Cores	27.86	(1)	The UHPC core shall be considered as non-compliant if it exhibits honeycombing which means interconnected voids arising from, for example, inadequate compaction or lack of mortar.
		(2)	The results of tests for compressive strength of UHPC cores shall be interpreted in accordance with BS EN 13791:2019. Adjustments to the measured strength in respect of the age of the core when tested shall not be made unless accepted by the *Project Manager*. The estimated in-situ cube strength of each core specimen shall be calculated in accordance with Section 15 of CS1. For any set of cores representing a test location, the average estimated equivalent cube strength shall be at least 85 % of the specified grade strength, and each individual estimated equivalent cube strength shall be at least 75 % of the specified grade strength.
		(3)	For any set of cores representing a test location, the average tensile strength shall exceed 80% of the specified grade strength.
		(4)	For any set of cores representing a test location, the static modulus of elasticity in compression of each individual elastic modulus specimen shall exceed 45 GPa.
		(5)	For any set of cores representing a test location, the average rapid chloride migration coefficient (D_{RCM}) and water absorption coefficient (R_a) shall not exceed the requirements specified in Table 27.09.
		(6)	For any set of cores representing a test location, the average abrasion index (I) shall not exceed 0.7.
Analysis of hardened UHPC	27.87	(1)	Each sample of hardened UHPC shall be tested to determine the properties or the composition of the UHPC as stated in the contract or, if testing is to be carried out as a result of the UHPC not complying with the specified requirements, shall be tested as instructed by the *Project Manager*.
		(2)	Tests on hardened UHPC shall be carried out within 14 days of the *Project Manager* 's instruction for the test.
		(3)	The method of testing shall be in accordance with the relevant standards.

TESTING: PRECAST UHPC UNITS

Precast UHPC units	27.88	Testing for precast UHPC units shall comply with GS Clauses 16.67 to 16.70.

QUALIFICATION OF UHPC SUPPLIER

UHPC supplier 27.89

(1) The UHPC supplier shall be certified under the Quality Scheme for the Production and Supply of Concrete (QSPSC) and accepted by the *Project Manager*.

(2) The UHPC supplier is required to submit a proposed quality assurance system, relevant job references, production capacity, supply logistics and the like for the acceptance of the *Project Manager* for production and supply of UHPC.

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