Addendum to MNL 116-21 – Structural UHPC Requirements

The following sections of MNL 116-21 are revised to incorporate requirements and the associated commentary for structural Ultra-High-Performance Concrete (UHPC).

The requirements of this section are intended for use with UHPC as defined by PCI and PCI TR-9, *Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete*. This limits applicability to structural precast concrete products and UHPC utilizing steel fibers. Since this is a relatively new class of concrete which is evolving rapidly, alternate requirements may be appropriate for other uses and definitions, such as mixtures defined by other agencies.

MNL 116-21 Addendum

4.1.2 Qualification of Concrete Mixtures

(Add the following as a new second paragraph in this section.)

If a UHPC mixture is being qualified, refer to section 4.1.14.

4.1.14 Ultra-High-Performance Concrete (UHPC)

(Add the following as a new section 4.1.14. Add the new Commentary, where noted)

UHPC mixtures will be qualified by the requirements herein. UHPC mix designs may be developed through any one of three methods: Iterative Laboratory Trial Batching, Experimental Design, or Particle Packing Models, as described in PCI TR-9, *Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete.*

Requirements for Fresh UHPC

The fresh UHPC shall have the following properties:

1. Temperature: ASTM C1064/C1064M - between 50°F (10°C) and 95°F (35°C) at the time of placement, unless otherwise permitted by the project specifications or approved by the Engineer of Record (EOR).

   Commentary - The acceptable temperature upper bound is influenced by many factors. Examples of these factors include mixture design, ambient conditions, and product volume and shape. In some cases, a temperature of 95°F (35°C) will not be appropriate. Flow and working time may be restricted at the anticipated upper temperature limit and may require additional testing to validate upper temperature limits.

2. Flow spread: ASTM C1437 as modified by ASTM C1856/C1856M - 8 to 10 in. (200 to 250 mm), measured not earlier than 15 minutes before anticipated placement time. A flow spread of greater than 10 in. (250 mm) may be permitted by the project specifications or approved by the Engineer of Record if the mixture is qualified at that flow spread and is determined to exhibit no significant segregation or settlement of steel fibers.

   Commentary - A lower flow spread limit of 8 in. (200 mm) is typical in general specifications. The flow spread will need to be evaluated for specific mixture designs, plant conditions, and member type.

Requirements for Hardened UHPC

The hardened UHPC shall have the following mechanical properties:

1. Compressive strength: ASTM C39/C39M as modified by ASTM C1856/C1856M, with the exception that either 3 x 6 in. (75 x 150 mm) or 4 x 8 in. (100 x 200 mm) cylinders may be used.
    a. At prestress transfer or lifting: 10.00 ksi (68.95 MPa), minimum – This limit may be modified as required by the Engineer of Record.
    b. At 28-days or as otherwise defined for service by the EOR: 17.40 ksi (120.0 MPa), minimum.
2. Flexural performance: ASTM C1609/C1609M as modified by ASTM C1856/C1856M, at 28-days or as otherwise defined for service by the EOR.
    a. First-peak (first-crack) flexural strength: 1,500 psi (10.34 MPa), minimum.
    b. Peak flexural strength: 2,000 psi (13.79 MPa), minimum.
    c. Peak flexural strength shall be at least 1.25 times first-peak (first-crack) flexural strength.
    d. Residual flexural strength at midspan deflection of L/150: 75% of first-peak flexural strength, minimum.

The hardened UHPC shall exhibit the following durability characteristics:

1. Indication of resistance to chloride ion penetration: ASTM C1202 as modified by ASTM C1856/C1856M, at 28-days; 250 coulombs maximum.

When the UHPC mixture contains metallic fibers, testing in accordance with ASTM C1202 shall be performed on specimens produced from UHPC having the same relative proportions of the other constituent materials but produced without metallic fibers.

Mixture Qualification

Testing for mixture qualification shall include, at minimum, the properties listed as “Qualification” and “Informational (mandatory)” in Table 4.1.14.1. All test specimens shall be fabricated from UHPC mixtures produced with the same materials, mixture proportions, batching equipment, and mixing sequence intended for the Project.

Document the temperature, flow spread, and density (unit weight) for each batch produced for mixture qualification. The temperature and flow spread of the UHPC shall be within the specified range at the time of specimen fabrication.

Cure test specimens to match the required curing for the structural product. If a thermal treatment will be applied to the product, apply the same thermal treatment to all test specimens, in accordance with ASTM C1856/C1856M, Section 7.4, or as applicable to the thermal treatment being qualified.

Evaluate the potential for fiber segregation and settlement during production or as part of a trial placement as part of the mixture qualification process.

> Commentary - A method to evaluate the potential for fiber segregation can be found in section 5.3.1D of the Guide Specification for PCI-UHPC Materials in Appendix A of *Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete* (TR-9).

Table 4.1.14.1. Qualification and Informational Test Requirements

Property	Test Method	Purpose of Test*
Flow spread	ASTM C1437 as modified by ASTM C1856/C1856M	Qualification
Temperature	ASTM C1064/C1064M	Qualification
Density (Unit weight)	ASTM C138/C138M	Informational (Mandatory)
Working Time	ASTM C1437 as modified by ASTM C1856/C1856M	Informational (optional)
Time of set	ASTM C191 as modified by ASTM C1856/C1856M	Informational (optional)
Compressive strength	ASTM C39/C39M as modified by ASTM C1856/C1856M	Qualification
Flexural strength	ASTM C1609/C1609M as modified by ASTM C1856/C1856M	Qualification
Static modulus of elasticity	ASTM C469/C469M as modified by ASTM C1856/C1856M	Informational (Mandatory)
Creep in compression	ASTM C512/C512M as modified by ASTM C1856/C1856M	Informational (optional)
Length change	ASTM C157/C157M as modified by ASTM C1856/C1856M	Informational (Mandatory)
Resistance to chloride ion penetration	Either ASTM C1202 as modified by ASTM C1856/C1856M, or ASTM C1556, with tests performed on specimens without metallic fibers. ASTM C1202 shall be performed for qualification purposes, unless the project specifications require ASTM C1556 testing and provide an acceptance criteria. If required, then ASTM C1556 testing shall be conducted to qualify the UHPC relative to the project requirements	Qualification
Chloride diffusion coefficient	ASTM C1556, with tests performed on specimens without metallic fibers	Informational (optional)
Sulfate resistance	ASTM C1012/C1012M, with tests performed on specimens without metallic fibers	Informational (optional)
Resistance to freezing and thawing	ASTM C666/C666M as modified by ASTM C1856/C1856M	Informational (optional)
Absorption	ASTM C642	Informational (Optional)

*Qualification tests are required for mixture approval. Informational (mandatory) tests are required for submittal but are not required for mixture approval. Informational (optional) tests may be performed and reported at the discretion of the producer but are not required for submittal or approval.

Number of tests:

Unless otherwise specified, a minimum of nine compressive strength and nine flexural strength tests shall be performed to qualify the mix design. The tests shall represent a minimum of three consecutive batches, with no more than three tests performed for each batch. For hardened properties, a test consists of three specimens.

Unless otherwise specified, a minimum of one test shall be performed for other properties and performance characteristics indicated as informational (mandatory) in Table 4.1.14.

Required average strength:

Determine the required average strength for the following properties, as defined below, based on the specified strengths defined below:

1. Compressive strength: f'_{cr}
2. First-peak (first-crack) flexural strength f'_{1r}
3. Peak flexural strength f'_{pr}

Use the larger of the two values provided below:

$$f'_{Xr} = \max \begin{bmatrix} f'_X + 1.34ks_s \\ 0.9f'_X + 2.33ks_s \end{bmatrix}$$

where

f'_{Xr} = required average strength for the property X

X = c for compressive strength, X = 1 for first-peak flexural strength, and X = p for peak flexural strength

f'_X = specified strength for the property X in accordance with Subsection 4.2.3

k = a modification factor listed in Table 4.1.14.2 to adjust for the number of tests considered in calculating the sample standard deviation

s_s = sample standard deviation

Table 4.1.14.2 k-factor for increasing sample standard deviation based on number of tests

Total number of tests considered	k-factor for increasing sample standard deviation
9	1.25
15	1.16
20	1.08
25	1.03
30 or more	1.00

Note: Linear interpolation for intermediate number of tests is acceptable

Adapted from ACI 301-20 Table 4.2.3.3(a)2. ACI 301 does not include the value for 9 total tests

Commentary: Once a mixture is qualified, additional field data can be used to refine calculations

Modifications to standard methods for UHPC:

Fabricate and cure test specimens for qualification and laboratory trial mixtures in accordance with ASTM C192/C192M as modified by ASTM C1856/C1856M and herein.

Density (Unit weight): ASTM C138/C138M, except the measure shall be filled in a single, continuous pour, and consolidated by tapping 30 times with a rubber mallet.

4.2.5 Storage and Handling of Concrete Materials for UHPC

(Add the following as a new section 4.2.5.)

Materials used to produce UHPC shall comply with the requirements of section 4.2, with the following modifications:

Store fibers in a dry, covered location to prevent oxidation (steel fibers) or ultraviolet (UV) degradation (nonmetallic fibers). Some surface oxidation (rust) of steel fibers is permissible, provided that the fibers remain as individual wires (that is, do not clump) and the severity of the oxidation is documented.

Store preblended materials in a similar manner to cement. If preblending materials, aggregates shall be oven-dried before blending to limit prehydration of the cementitious materials.

4.6.7 Batching and Mixing of UHPC

(Add the following as a new section 4.6.7)

Comply with the requirements of section 4.6 for batching and mixing, with the following modifications:

1. Mixing time requirements specified in section 4.6.6 do not apply to UHPC. The time from the start of UHPC mixing to placement is permitted to exceed 1 hour if the flow requirements are met and the water-binder ratio of the approved mixture proportions is not exceeded.
2. If aggregates are used in a moist (that is, not oven-dry) condition, measure the aggregate moisture content for each batch. Determine the moisture content by calibrated moisture probe, rapid measurement technique (ASTM D4944 or AASHTO T 217), oven-drying (ASTM C566 or AASHTO T 255), or other approved method. Correlate moisture probes and rapid measurement techniques for each aggregate source.
3. Total water content shall include all sources of water in UHPC, including batch water, ice, moisture content in aggregates, and water fraction of admixtures.
4. Total binder shall include the combined weight of hydraulic cement, supplementary cementitious materials, and mineral fillers.
5. The batching sequence and mixing procedures shall produce uniform dispersion of the constituent materials and fibers, and achieve the fresh properties required for transporting and placing the UHPC. The batching sequence and mixing procedures of section 4.6.2 through .6.6 are not applicable to UHPCC.

Uniformity of dispersion shall be evaluated by visual inspection of the fresh UHPC at the time of discharge from the mixer. It is permitted to reject a UHPC mixture if there is a presence of excessive fiber clumps and/or agglomerates of the powder constituents.

Materials shall be batched within the tolerances listed in **Table 4.6.7**.

Table 4.6.7 Batching Tolerances

Material	Maximum batching error with plant-batched dry materials, % by weight	Maximum batching error with preblended dry materials, %
Water	±1%	±1%
Cement	±1%*	±2%
Silica fume	±1%*	
Other supplementary cementitious materials or mineral fillers	±1%*, or ±5 lb, whichever is greater	
Aggregates	±2%*	
Chemical admixtures	±3%	±3%
Fiber	–2%, +4%	–2%, +4%

*Total weight of dry materials shall not exceed ±2% of target.

Mixture adjustments:

It is permitted to perform adjustments to water or admixture dosages to achieve target flow properties. The maximum water-binder ratio in the submitted and approved mixture design shall not be exceeded.

No adjustments to the mixture shall be made after the concrete is discharged from the mixer into the delivery system.

4.7.11 Transporting and Placing UHPC

(Add the following as a new section 4.7.11)

Comply with the requirements of section 4.7 for transporting and placing concrete, with the following modifications:

1. The temperature of the UHPC at the time of placement shall be between 50°F (10°C) and 95°F (35°C), unless otherwise approved by the Engineer of Record based on experience with the mix design.
2. Place the UHPC in a continuous operation that prevents cold joints or planes of weakness from forming, limits fiber segregation, and reduces the entrapment of air.
3. Place the UHPC in a manner that integrates the new material into the previously placed UHPC.
4. Limit free-fall placement to a maximum of 3 ft (1 m) above the top of the form.

4.9.7 Curing and Thermal Treatment for UHPC

(Add the following as a new section 4.9.7. Add the new Commentary, where noted):

Curing

After finishing the UHPC member, immediately cover all surfaces with plastic, wet burlap, curing compound, or a combination of these methods to prevent dehydration. Cure the concrete in accordance with the requirements of section 4.9, either by moisture retention without heat or by accelerated heat curing using live steam or radiant heat and moisture. Maintain a minimum relative humidity of 95 % if curing with live steam or radiant heat and moisture.

Thermal Treatment

If thermal treatment is used for the UHPC member, apply thermal treatment to members after curing.

> Commentary: Thermal treatment is different from conventional or accelerated curing, which typically occurs before detensioning.

Do not apply thermal treatment until strands have been detensioned and the UHPC member has been stripped from the forms.

Apply thermal treatment according to the method employed during qualification testing.

Heat the member at a maximum of 194°F (90°C) and a minimum of 95% relative humidity for 48 hours.

Thermal treatment is permitted to be applied at any time until the member has reached 14 days of age.

The rate of heating shall not exceed 20°F (10°C) per hour.

The rate of cooling after sustained heating shall not exceed 20°F (10°C) per hour.

6.2.3.10 Quality Control Testing for UHPC

(Add the following as a new section 6.2.3.10. Add the new Commentary, where noted)

The standard test methods described in section 6.2.3 shall be used for UHPC, with the following exceptions:

1. Fabricate, cure, and thermally treat, if applicable, test specimens in accordance with ASTM C31/C31M or ASTM C192/C192M, as modified by ASTM C1856/C1856M and herein. Curing and thermal treatment, if applicable, of the test specimens shall match the member.
2. Density (Unit Weight): ASTM C138/C138M, except the measure shall be filled in a single, continuous pour, and consolidated by tapping 30 times with a rubber mallet.

The testing and inspection of UHPC shall be in accordance with sections 6.2.2 and 6.2.3, with the following exceptions:

1. A test for strength and other hardened properties of the UHPC shall be defined as the average results from at least three specimens made from the same concrete sample and tested at the same age.
2. Perform temperature, flow spread, unit weight, compressive strength, and flexural strength testing as defined in Table 6.2.3.10. Measurement of air content is not required.
3. If test specimens are match cured, follow procedures of AASHTO R 72, except that the specimen sizes, specimen molding, and other testing are as defined herein.
4. Minimum testing frequencies are listed in Table 6.2.3.10. Perform additional testing and cast additional samples if a change in quality is suspected.

5. The potential for fiber segregation and settlement shall be evaluated during production or as part of a trial placement as part of the mixture qualification process.

    Commentary - A method to evaluate the potential for fiber segregation can be found in section 5.3.1D of the Guide Specification for PCI-UHPC Materials in Appendix A of Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete (TR-9).

The acceptance of concrete testing shall be as outlined in sections 6.2.2 and 6.2.3 except that the strength of the concrete shall be considered satisfactory if both of the following requirements are met:

1. Every average of three consecutive strength tests equals or exceeds the specified strength f_X' for the property.
2. No single strength test result falls below f_X' by more than $0.10f_X'$.

Table 6.2.3.10 Minimum Testing Frequencies

Property	Test Method	Minimum Frequency
Flow spread	ASTM C1437 as modified by ASTM C1856/C1856M	Each batch.
Temperature	ASTM C1064/C1064M	Each batch.
Density (Unit weight)	ASTM C138/C138M, except the measure shall be filled in a single, continuous pour, and consolidated by tapping 30 times with a rubber mallet	First batch per day, whenever test specimens are cast, and whenever a change in quality is suspected.
Compressive strength	ASTM C39/C39M as modified by ASTM C1856/C1856M	6 test specimens from 1 batch per day per element, or every 50 yd^3 (35 m^3), whichever is more frequent. Test 3 cylinders at release and 3 cylinders at an age defined by the Engineer of Record.
Flexural strength	ASTM C1609/C1609M as modified by ASTM C1856/C1856M	3 beams from 1 batch per day per mix design. If volume exceeds 50 yd^3 (35 m^3), an additional 3 beams are required. Test at an age defined by the Engineer of Record.

6.3.4 Concrete Records

(Add the following to section 6.3.4)

Records of UHPC operations shall also include the following:

1. Maintain reports of each batch of UHPC produced, including quantities of materials weighed, the batching sequence used, the time that concrete was discharged from the mixer, and the time that concrete was placed into the forms.
2. Record all testing performed as specified in Table 6.2.3.10.

3. Maintain records of any additional testing performed, including any strength testing performed at ages other than at release and at an age defined by the Engineer of Record.
4. Records related to the potential for fiber segregation and settlement.

Appendix E, Reference Literature
(Add the following references to Appendix E)

ASTM International

ASTM C512/C512M - Standard Test Method for Creep of Concrete in Compression

ASTM C1012/C1012M - Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

ASTM C1202 - Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

ASTM C1437 - Standard Test Method for Flow of Hydraulic Cement Mortar

ASTM C1556 - Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient

ASTM C1609/C1609M - Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)

ASTM C1856/C1856M - Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete

ASTM D4944 - Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

American Association of State Highway and Transportation Officials (AASHTO)

AASHTO R 72 - Standard Practice for Match Curing of Concrete Test Specimens

AASHTO T 217 - Standard Method of Test for Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester.

AASHTO T 255 - Standard Method of Test for Total Evaporable Moisture Content of Aggregate by Drying

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