UHPC

Ultra High Performance Concrete

Specification & Details

Prepared By: Petra Design Inc.

PETRA™

ARCHITECTURAL MOLDED COMPOSITES

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1.0 About Us

Petra Design, where architectural excellence meets a legacy of over **25 years** in delivering premium GFRC, FRP and Precast architectural products. We take pride in supplying a diverse range of solutions to both commercial and residential projects across North America.

At Petra Design, our extensive product line includes but is not limited to exterior cladding solutions, columns, cornices, door surrounds, sills, porticos, domes, balustrades, and more. Whether you're an architect, interior designer, contractor, builder, or homeowner, we collaborate with you on new

constructions and renovations, ensuring your project receives the highest quality and aesthetic appeal.

1.1 Engineering Excellence

Following an extensive and thorough research effort spanning the past few years, Petra Designs has successfully developed highly refined **Ultra-High-Performance Concrete** (UHPC) and **Glass Fiber Reinforced Concrete** (GFRC) mix designs, each branded differently. These formulations are crafted to be easily customizable, catering to the specific requirements outlined by architects and engineers.

1.2 Quality Assurance

Petra Design engineers benefit from a substantial database of material properties and comprehensive full-scale tests, offering a robust reference point for the creation of new systems. Our Petra team maintains ongoing communication with leading universities and researchers globally, integrating cutting-edge design knowledge into our projects. Many of our engineers have firsthand experience as shop or site engineers, ensuring that the designs not only showcase innovation but are also practical for efficient manufacturing and installation. This collaborative approach, with knowledge shared across the five main domains in which Petra operates, translates into a significant productivity advantage, enhancing the overall effectiveness of design and implementation processes at Petra Design.

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1.0 Scope

A. This section applies to UHPC intended for use in precast components. The work performed under this section includes all labor, material, equipment, related services, and supervision required for the manufacture of the precast UHPC work shown on the contract drawings.

B. UHPC Manufacturer: Petra Design Inc.

C. Location: 47 St. Regis Crescent, Toronto, ON, M3J 1Y6

1.1 Service expectations

A. Manufacturer will be solely responsible for design, mold fabrication, manufacturing and logistics of delivery of UHPC panels.

B. Panels will be cast to custom sizes to reduce waste, based on detailed drawing & site measurements determined by coordination of the Manufacturer and the Installer.

C. Manufacturers must be able to provide smooth and sand blasted finishes of a variety of degrees.

Note: Sand blasted finish can expose the fiber and the client should be notifying before the sample approval.

D. Manufacturers must be able to provide a variety of colors to meet design requirements.

E. Manufacturer will coordinate shipping of panels to site with Installer, upon receiving material should be verified by the site supervisor.

F. Manufacturer's plant must be within 500km of the construction site (Delivery charges should be included with the quotation).

Note: Manufacture can accommodate the delivery in US or Canada (more than 500 km) with a third party logistics if needed.

2.0 Terms and Definitions

The below definitions apply to terms in this section.

1. **Acceptance Testing:** Verifies UHPC compliance with project specifications during production, considering materials, batch proportions, procedures, and methods used.
2. **Batch:** Volume of materials mixed and discharged uniformly.
3. **Binder:** Combination of hydraulic cement, supplementary cementitious materials, and mineral fillers in a UHPC mixture.
4. **Flexural Strength:** Maximum tensile stress during bending per ASTM C1856.
5. **Flow Spread:** Lateral flow distance of UHPC in a flow test per ASTM C1437, modified by ASTM C1856.
6. **Informational Testing:** Non-required testing for additional UHPC material properties or durability info.
7. **Material Identity Card:** Document detailing constituent materials, proportions, mixing, curing methods, and hardened properties of a UHPC mixture.
8. **Mineral Filler:** Finely divided inorganic material from quarried stone, used to improve UHPC properties.
9. **Preblend:** Uniform mixture of powder constituents to which water and admixtures are added; may include fibers.
10. **Qualification Testing:** Pre-production testing to demonstrate UHPC mixture performance and compliance with project requirements.
11. **Thermal Treatment:** Heating UHPC above normal hydration temperature in high humidity, holding it, and cooling slowly to promote hydration, post-initial curing.
12. **Total Water:** Combined batched water, ice, aggregate moisture, and liquid from admixtures and silica fume slurry.
13. **Ultra-High-Performance Concrete (UHPC):** Fiber-reinforced cementitious material with a refined microstructure, high tensile/compressive strength, and excellent durability.
14. **Water-Binder Ratio (w/b):** Weight of total water divided by weight of total binder in UHPC.
15. **Working Time:** Time after adding water during which UHPC maintains at least an 8 in. (200 mm) flow spread, varying with conditions and procedures.

3.0 General

3.1 Reference Standards

ASTM International

ASTM C31/C31M-21a—Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C33/C33M-18—Standard Specification for Concrete Aggregates

ASTM C39/C39M-21—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C138/C138M-17a—Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

ASTM C192/C192M-19—Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM C494/C494M-19—Standard Specification for Chemical Admixtures for Concrete

ASTM C642-13—Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

ASTM C666/C666M-15—Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C1202-19—Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

ASTM C1218/C1218M-20—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1240-20—Standard Specification for Silica Fume Used in Cementitious Mixtures

ASTM C1437-20—Standard Test Method for Flow of Hydraulic Cement Mortar

ASTM C1602/C1602M-10—Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

ASTM C1778-20—Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete

ASTM C1856/C1856M-17—Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete

CSA (Canadian Standards Association)

CSA A23.1- Annex U Materials and Methods of construction for the use of ultra-high performance of the concrete(UHPC)

Precast/Prestressed Concrete Institute (PCI)

PCI MNL-116—Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products

3.2 Submittals

3.2.1 Material Identity Card

A. Must Submit a Material Identity Card for each mixture to be used in the Project. The properties listed in the material identity card shall demonstrate, at a minimum, compliance with all project material property requirements.

B. The material identity card shall include the following:

1. The type and source of each constituent material.

2. Mixing procedures.

3. Curing procedures, including thermal treatment procedures. (According to the project requirements)

3.2.2 Strength Test Records

Submit documentation indicating that the proposed mixture proportions will produce a minimum compression test of 120 Mpa.

3.2.3 Material Test Report

A. Mill or suppliers' test certificates or compliance test reports shall be submitted for the following materials:

1. Cementitious materials.
2. Mineral fillers.
3. Aggregates.
4. Chemical admixtures.
5. Fibers.
6. Other components specified in Contract Documents with applicable standards

4.0 Materials

4.1 UHPC Materials

A. For a specific project: use the same type, brand, and mill source for all materials throughout the UHPC production. Changes in the type or source of cementitious materials, mineral fillers, aggregates, admixtures, or fibers require the submittal and approval of an updated Material Identity Card (Section 3.2.1) for the modified UHPC mixture produced with the alternative material type(s) or source(s).

B. Hydraulic cement: CSA A3001, ASTM C150 or ASTM C595

C. Supplementary cementitious materials and mineral fillers:

1. Raw or calcined natural pozzolan: CSA A3000 or ASTM C618, Class N
2. Silica fume: ASTM C1240.
3. Slag cement: ASTM C989.
4. Ground calcium carbonate and aggregate mineral fillers: ASTM C1797.

Note:

Other supplementary cementitious materials or mineral fillers: Demonstrate suitable mechanical and durability performance when used in UHPC.

D. Fine aggregates: ASTM C33 or ASTM C144.

Note:

Fine aggregates do not need to comply with the grading requirements in ASTM C33 or ASTM C144.

E. Water and ice: Potable municipal water

F. Chemical admixtures:

1. Water-reducing admixture : ASTM C494/C494M, Type A and F, MTO and MTQ approved
2. Water-reducing and retarding admixture: ASTM C494/C494M, Type B & D.
3. Shrinkage-reducing admixture: ASTM C494/C494M, Type S.

G. Steel fibers:

A. ASTM A820/A820M, with a minimum tensile strength of 290 ksi (2000 MPa) and a minimum nominal aspect ratio of 60, unless otherwise approved by the Engineer of Record based on demonstrated adequate performance of the fibers when used in UHPC.

B. Pre Blended UHPC materials for which a Material Identity Card has been approved by the Engineer of Record.

1. Follow all Manufacturer's recommendations for handling, mixing, and placing.
2. Retain a sample of the pre blended material from each lot received, in sufficient quantity that the quality control testing of the fresh and hardened properties of the material may be evaluated for compliance.

4.2 UHPC Mixtures

4.2.1 Mixture Proportions

Proportion mixtures with materials to be used on Project to provide UHPC with the following characteristics:

1. Maximum water-binder ratio w/b: 0.2
2. Minimum steel fiber content: 2% steel fibers, by volume of concrete (263 lb/yd3 [156 kg/m3]).
3. Maximum water-soluble chloride ions: ASTM C1218/C1218M, 0.06% by weight of cement.
4. Minimum fresh properties: As defined in Section 4.2.2.
5. Working time: As needed for element fabrication.
6. Minimum hardened properties: As defined in Section 4.2.3.
7. Minimum durability properties: As defined in Subsection 4.2.3.A.

4.2.2 Requirements for Fresh UHPC

The fresh UHPC shall have the following properties:

1. Temperature: between 10°Cand 27°C at the time of placement, unless otherwise approved by the Engineer of Record.
2. Flow spread: ASTM C1437 as modified by ASTM C1856; 200 to 250 mm, measured not earlier than 15 minutes before anticipated placement time.

4.2.3 Requirements for Hardened UHPC

A. The hardened UHPC shall have the following mechanical properties:

1. Compressive strength: ASTM C39 as modified by ASTM C1856, with the exception that either 3- or 4-in. (75- to 100-mm) -diameter specimens may be used.

   At release: 70 MPa minimum.

   28 days: 120.0 MPa minimum.

2. Flexural performance: ASTM C1609 as modified by ASTM C1856, at service (28 days).

   First-peak (first-crack) flexural strength: 10.34 MPa, minimum.

   Peak flexural strength: 13.79 MPa, minimum.

B. The hardened UHPC shall exhibit the following durability characteristics:

1. Indication of resistance to chloride ion penetration: ASTM C1202 as modified by ASTM C1856, at 28 days; 250 coulombs maximum.
2. Resistance to freezing and thawing: ASTM C666 as modified by ASTM C1856; minimum relative dynamic modulus of 95 after 300 cycles.
3. Absorption: ASTM C642, at 28 days; 3.0% maximum.

4.2.4 Mixture Qualification

A. Material testing of each UHPC mixture shall be performed to support preparation of a Material Identity Card and strength test records, as defined in Subsections 3.2.1 and 3.2.2, respectively, for the purpose of mixture qualification.

B. Testing for mixture qualification shall include, at minimum, the properties listed as:

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.
2. Document the temperature, flow spread for a minimum one 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.
3. Measure flow spread according to ASTM C1437 as modified by ASTM C1856 at 15-minute intervals.
4. Cure test specimens to match the required curing process for the structural product. Project should specify if heat curing is required.

C. Modifications to standard methods for UHPC:

1. Fabricate and cure test specimens for qualification and laboratory trial mixtures in accordance with ASTM C192 as modified by ASTM C1856 and this specification.
2. Unit weight: ASTM C138, except the measure shall be filled in a single, continuous pour, and consolidated by tapping 30 times with a rubber mallet.

5.0 Production

5.1 Forms

Form: Accurately construct forms, mortar tight, of sufficient strength to withstand pressures due to concrete placement and vibration operations and temperature changes.

1. Design formwork to withstand the full hydrostatic pressure of fresh UHPC.
2. The minimum clear spacing between the formwork surface and any internal reinforcing or adjacent formwork shall be greater than both 1.5 times the fiber length and 1.5 times the maximum aggregate size.

5.2 Concrete

A. Do not produce UHPC for construction production until the Material Identity Card has been reviewed and approved by the Engineer of Record.

5.2.1 Storage and Handling of Concrete Materials

Comply with PCI MNL-116 requirements, with the following modifications:

1. Store and handle all supplementary cementitious materials and mineral fillers in a similar manner to cement.
2. Store and handle aggregates in a wet or dry manner that limits segregation.
3. Store fibers in a dry, covered location to prevent oxidation (steel fibers) or ultraviolet (UV) degradation (nonmetallic fibers).
4. Store pre blended materials in a similar manner to cement. If pre-blending materials on site, oven-dry aggregates before blending to limit pre-hydration of the cementitious materials.

5.2.2 Mixing

A. Equipment: Comply with PCI MNL-116 requirements and tolerances for all batching equipment, including scales, water meters, dispensing equipment, and concrete mixers.
B. Mixing: Comply with PCI MNL-116 requirements for batching and mixing, with the following modifications:

1. Mixing time requirements specified in PCI MNL-116 do not apply to UHPC. The time from the start of UHPC mixing to placement may exceed 1 hour, as long as the flow requirements are met, and the water-binder ratio of the approved mixture proportions is not exceeded.
2. Clean the mixer between consecutive batches of UHPC if the mixer is not loaded within the working time of the previous batch.
3. If aggregates are used in a moist (that is, not oven-dry) condition, measure the aggregate moisture content for each batch. Determine moisture content by calibrated moisture probe, rapid measurement technique (ASTM D4944), oven-drying.

   (ASTM C566), or other approved method. Calibrate moisture probes and rapid measurement techniques for each aggregate source.

4. Total water content shall include all sources of water in UHPC, including batch water, ice, moisture content in aggregates, and water fraction of admixtures.
5. Total binder shall include the combined weight of hydraulic cement, supplementary cementitious materials, and mineral fillers.
6. 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 do not need to comply with the requirements of PCI MNL-116.

A. Uniformity of dispersion shall be evaluated, at a minimum, by visual inspection of the fresh UHPC at the time of discharge from the mixer.

7. Batch materials within tolerances.

   Material maximum batching error with plant-batched dry materials with maximum batching error with pre blended dry materials

   Water: ±1%

   Cement: ±1%*

   Silica fume: ±1%*

   Cementitious materials or mineral fillers: ±1%* or ±5 lb, whichever is greater

   Aggregates: ±2%*

   Chemical admixtures: 2%

   Fiber: –2%, +4%

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

A. Mixture adjustments:

1. Adjustments to water or admixture dosages may be performed to achieve target flow properties. The maximum water-binder ratio in the submitted and approved mixture design shall not be exceeded.
2. No adjustments to the mixture shall be made after the concrete is discharged from the mixer.
3. Changes to the constituent materials, mixture proportions, batching equipment, or curing methods will require resubmittal of the Material Identity Card to verify compliance with Project requirements. To limit production delays, provisional approval may be granted at the discretion of the Engineer of Record before strength results at service have been obtained.

5.2.3 Transporting, Placing, and Consolidating Concrete

A. Comply with PCI MNL-116 requirements for transporting and placing concrete, with the following modifications:

1) The temperature of the UHPC at the time of placement shall be between 10°C and 27°C, unless otherwise approved by the Engineer of Record based on local experience.
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) Use placement methods that limit unfavorable alignment of fibers where possible. Because fibers tend to align in the direction of the UHPC flow, avoid placement methods that cause the UHPC to flow in a direction that is perpendicular to the direction of tensile stress if so, directed by the Engineer of Record.
4) Place the UHPC in a manner that integrates the new material into the previously placed UHPC.
5) Limit free-fall placement to a maximum of 3 ft (1 m) above the top of the form.

B. Comply with all PCI MNL-116 requirements for hot- and cold-weather concrete placements.

C. Thoroughly consolidate the UHPC without dislocating or damaging the reinforcement (including fibers) and built-in items. Minimize pour lines, honeycombing, and entrapped air voids on the surface. Use consolidation equipment and procedures complying with PCI MNL-116 requirements, with the following modifications:

1) Do not use internal vibration.
2) Use external vibration when concrete workability is not sufficient to complete placement or if complex forming may inhibit flow. If external vibration is used, evaluate whether a detrimental effect on fiber distribution is expected.

5.2.4 Finishing

A. Strike off or screed the surfaces of the UHPC product to the required level immediately after placement.

Finish as required by the project contract documents. The finish can be smooth or sandblasted according to project requirements.

5.2.5 Curing

A. After finishing, immediately cover all surfaces with plastic, wet burlap, or curing compound to prevent dehydration. Cure the concrete according to PCI MNL-116 requirements, 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.

1. Accelerated heat curing, if used, shall be started after the concrete has attained initial set, determined in accordance with CSA A23.1 - Annex U
2. Cure members until compressive strength is high enough to ensure that stripping does not influence the performance or appearance of the final product.

B. The compressive strength at stripping shall be determined according to Section 4.2.3.

5.2.6 Thermal Treatment (Only for specified project)

A. Apply thermal treatment to members after curing, if used.
B. Do not apply thermal treatment until strands have been de-tensioned and the UHPC member has been stripped from the forms.
C. Apply thermal treatment according to the method employed during qualification testing during preparation of the Material Identity Card:

Note:

Reduce temperature and increase treatment duration in the following paragraph to 40°C and 72 hours if polymer fibers are used.

1. Heat member at 60°C and at least 95% relative humidity for 72 hours.
2. The rate of heating shall not exceed 20°F (10°C) per hour.
3. The rate of cooling after sustained heating shall not exceed 20°F (10°C) per hour.

5.3 Tests and Inspection

5.3.1 Quality Control Testing

A. Modifications to standard methods for UHPC:

1. Fabricate and cure test specimens in accordance with ASTM C31 or ASTM C192, as modified by ASTM C1856 and this specification. Curing shall match the specified curing for the structural product.
2. Unit weight: ASTM A138, except the measure shall be filled in a single, continuous pour, and consolidated by tapping 30 times with a rubber mallet.

B. Test and inspect UHPC according to PCI MNL-116 requirements when used to fabricate precast elements, with the following modifications:

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 5.3.1-1. Measurement of air content is not required.
3. Acceptance of concrete testing shall be as per PCI MNL-116 except the strength of the concrete shall be considered satisfactory if both of the following requirements are met:

C. Concrete records: Maintain records of concrete operations consistent with PCI MNL-116 requirements, with the following additions:

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.
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.

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

1. Fabricate a specimen mold with a height greater than or equal to the height of the element to be produced, a width equal to that to be used for element, and a length of 1 ft (0.305 m).
2. Place concrete into the specimen mold and consolidate using the same transport, placement, and consolidation methods used for production.
3. After the specimen has hardened, cut the specimen by saw along the centerline over the full height of the specimen. Inspect the cut surface for nonuniform dispersion, including fiber settlement.

4. If non uniform settlement is identified, establish a lower allowable limit on flow spread for production of elements of the test height or greater.

Note:

A suggested method for fiber segregation evaluation is provided below. Alternative methods may be specified.

5.3.2 Production Mock-Up

A. To verify that placement and consolidation methods do not adversely affect UHPC uniformity, including fiber distribution and alignment, produce a mock-up element using the placement and consolidation methods intended for the Project.

B. Evaluate uniformity of UHPC fiber at locations specified by the Engineer of Record using one of the following methods.

1. Cut a minimum of three beams at locations specified by the Engineer of Record, with dimensions as required by ASTM C1856, Table 3. Perform flexural strength testing at the designated age in accordance with ASTM C1856.

Note:

Retain the section below if a production mock-up is required for the Project. Revise or add details as needed.