Non-Proprietary UHPC Workshop

Mixing, Placement, and Curing

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Outline

- Typical Mixers for UHPC
- Mixing Procedure
- Flow and Workability
- Formwork and Placement
- Curing Options

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Background on Mixing UHPC

- UHPC requires more energy to mix than conventional concrete or grout
  - Low water content
  - Little or no coarse aggregate
- Typically, specialized high-shear mixers are used (both electric and gas options are available)
  - Pan mixers
  - Planetary mixers / Horizontal shaft mixers
- Mixing times (and UHPC properties) can vary depending on the type of mixer

Photo from OU field placement (courtesy of Floyd)

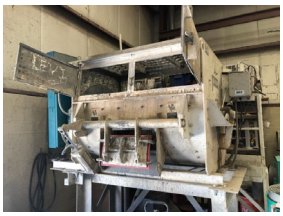

Photo of horizontal shaft mixer at OU (courtesy of Floyd)

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Mixers Previously used for Small Batches

- 20 Qt. Commercial Planetary Floor Baking Mixer (w/ Guard and Timer),
  - (~$1k to $4k)
  - Mixes about 0.15 ft^3
- Similar mixers have been used by other researchers (at OU, UArk, etc.)

(photo from manufacturer)

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Mixers Previously used for Large Batches

- Imer Mortarman 750 Vertical Shaft Mixer (about 4 ft^3 capacity w/5 hp single-phase electric engine)
  - (~$10k)
- Mixer System Horizontal Shaft Mixer (about 16 ft^3 capacity)
  - (~$80-$100k)

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(photos from manufacturers) 5

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Other Options for Large Batches

- Teka Planetary Mixers (9 to 13.5 ft^3 capacity)

- EIRICH (6 to 12 ft^3 capacity for RV and RV12 models)

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(photos from manufacturers) 6

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Precaster Experience with UHPC

- Six (6) precasters participated in PCI study by Tadros et al. (2020)
- Precasters used:
  - Planetary pan mixers
  - Horizontal shaft mixers




Photos from Tadros et al. (2020), Implementation of Ultra-High-Performance Concrete in Long-Span Precast Pretensioned Elements for Concrete Buildings and Bridges

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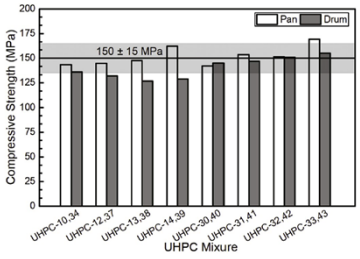
Mixing UHPC in Drum Mixers

- Some have used drum mixers or ready-mix trucks to mix UHPC
- Alsalman et al. (2020) compared results of pan and drum mixers
  - Mixing time for pan mixer (15-20 minutes) less than for drum mixer (45-60 minutes)
  - Pan mixer led to about 8.3% higher compressive strength (on average)
  - Lower strength attributed to more entrapped air caused by drum mixer
- Proprietary Mix (Cor-Tuf) has been mixed in ready-mix trucks



1. Alsalman, A., Dang, C. N., Martí-Vargas, J. R., & Hale, W. M. (2020). Mixture-proportioning of economical UHPC mixtures. Journal of Building Engineering, 27, 100970.
2. https://www.newswire.com/news/concrete-industry-first-uhpc-mixed-in-a-standard-ready-mix-truck-21546439

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Typical UHPC Mixing Procedure

1. Measure and prepare all materials (e.g., oven dry fine aggregate)

Small batch Large batch

2. Mix all dry materials together for about 10 minutes

3. Add water and chemical admixtures slowly (over a few minutes) to dry mix and continue to mix for 10-20 minutes

4. Add steel fibers and continue mixing for around 2 minutes

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General working time is 30 to 60 minutes depending on the temperature (shorter working time in hotter environments)

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Flowability and Placement of UHPC

Left video is a joint between slab beams (FSB) being cast for FDOT research project

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Spread, Workability, and Fiber Segregation

- Workability of UHPC is typically measured using a flow table test
  - **ASTM C1437 – Flow of Hydraulic Cement Mortar** with modifications from **ASTM C1856 – Fabrication and Testing Specimens of UHPC** (using mold and flow table from **ASTM C230 – Flow Table for Use in Tests of Hydraulic Cement**)



Good Flowability in UHPC

- Typical desirable flowability → 8 to 10 inches (static flow table)


Possible Issue: Low Flowability

- Low flow mixtures can be harder to work with (e.g., placement, shorter working time)

C9	
Component	**Amount**
Cement	1175 lb/cy
Slag	588 lb/cy
Silica Fume	196 lb/cy
Fine aggregate	1960 lb/cy
Fiber content	2% (OL)
HRWR	352 oz/cy
w/cm	0.20
f'_c	14.0 ksi

with OU cement and FIU fine aggregate; found we needed more HRWR

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Possible Issue: Low Flowability

- Possible Solution → Add more HRWR

C7	
Component	**Amount**
Cement	1188 lb/cy
Slag	594 lb/cy
Silica Fume	198 lb/cy
Fine aggregate	1981 lb/cy
Fiber content	2% (OL)
HRWR	490 oz/cy
w/cm	0.20
f'_c	14.6 ksi
Static flow	10 in.

(HRWR from C9 was 352 oz/cy)

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Possible Issue: Fiber Segregation

- Fiber segregation can occur in mixtures with too high flow, heavy fibers, excessive vibrations during placement, or combination of these

B25	
Component	**Amount**
Cement	1188 lb/cy
Slag	594 lb/cy
Silica Fume	198 lb/cy
Fine aggregate	1981 lb/cy
Fiber content	2% (OL)
HRWR	435 oz/cy
w/cm	0.20
f'_c	16.7 ksi
Static flow	> 10 in.

(high moisture sand)

C6	
Component	**Amount**
Cement	1161 lb/cy
Slag	581 lb/cy
Silica Fume	194 lb/cy
Fine aggregate	1936 lb/cy
Fiber content	2% (4D)
HRWR	479 oz/cy
w/cm	0.20
f'_c	13.0 ksi
Static flow	9.5 in.

(larger fibers)

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Possible Issue: Fiber Segregation

- Possible solutions → decrease HRWR/water content; add VMA; decrease vibration during placement

Photos from split cylinder and compression test of L6

L6 (Large Batch)	
Component	**Amount**
Cement	1199 lb/cy
Slag	600 lb/cy
Silica Fume	200 lb/cy
Fine aggregate	2000 lb/cy
Fiber content	2% (4D)
HRWR	550 oz/cy
VMA	90 oz/cy
w/cm	0.20
f'_c	17.3 ksi
Static flow	9.5 in.

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Temperature and Flowability

- Increasing temperature leads to reduced flow and shorter working time
- Standard practice to replace some of mix water with ice if temperature is over about 75°F

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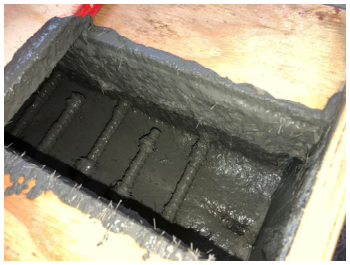
Formwork and Placement

- Use material with impermeable layer for forms (e.g., metal, plastic, plastic-coated or sealed wood)
- Forms need to be watertight and able to resist near hydrostatic pressure
- Consider fiber alignment and distribution during placement:
  - Continuous placement is required for proper fiber distribution
  - Fibers will align with the flow of UHPC
  - Over-vibration or overdosing with high-range water-reducing admixtures can lead to fiber settlement
- Typically, UHPC is transported from mixer using wheelbarrows, buggies, and concrete buckets



Photos from casting of joint for FDOT project on UHPC joints between slab beams (FSBs)

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Preparing Joint Surface for Casting

- A saturated surface dry (SSD) surface condition is desired prior to casting of the joint. There are two primary ways to achieve a satisfactory pre-wetted condition before casting of the joint:
  1. Keeping the substrate surface saturated by placing wet burlap on the surface for several hours before casting,
  2. Achieving an SSD condition by ponding water for a 24-hour period and drying the surface with a paper towel right before casting.
- Both methods showed similar results in Graybeal. (2017). Bond of Field-Cast Grouts to Precast Concrete Elements. FHWA-HRT-16-081

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Preparing Joint Surface for Casting

- Water ponding is often also useful as it will help to evaluate water-tightness of the joint before casting of the joint material. Joint materials (e.g., grout, UHPC) are often very fluid and require watertight formwork to prevent leaks of the joint material.
- Note that simply spraying the joint with water immediately before casting will not sufficiently pre-wet the interface. Spraying water does not give the water a chance to soak into the interface concrete.

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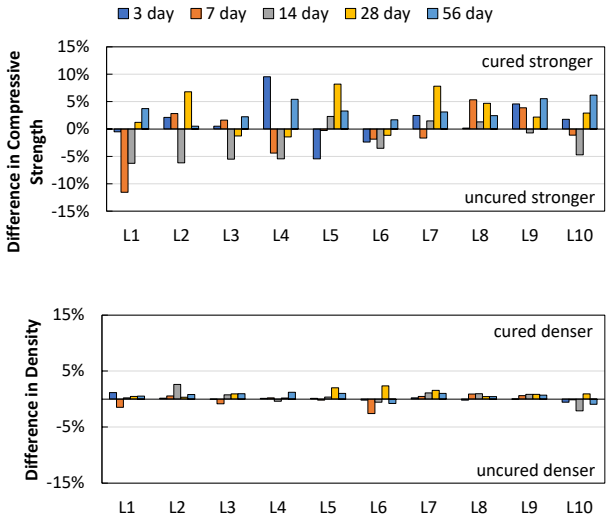
Curing Options

- UHPC should be sealed with an impermeable layer (e.g., metal, plastic, plastic-coated wood) immediately after casting
  - UHPC should be kept in forms until no longer self-desiccating (10 to 14 ksi after about 2 to 3 days)
- Heat curing can accelerate setting time and increase early-age strength
- Steam curing can increase durability and general mechanical properties
  - Common = 194°F (90°C), 95% humidity environment, for 2 days after form stripping

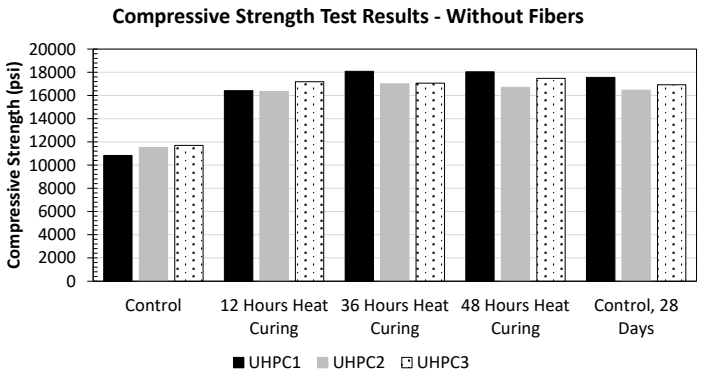
Effect of Curing

- FIU looked at the impact of moist curing on strength
  - Half moist cured
  - Half kept in molds
- No correlation between moist curing and increase in strength or density



Effect of Heat Curing

- Increased early-age strength, but did not have significant effect on 28-day strength



- All specimens were tested at 3 days (other than 28-day control)
- Heat curing was started at 12 hours of age for each curing duration
- Heat cured specimens generally did not show much strength increase after end of heat curing (e.g., 36-hr. heat cured specimens had about same strength at 3 days and 28 days)

Looney, T., McDaniel, A., Volz, J., and Floyd, R. (2019) "Development and Characterization of Ultra-High Performance Concrete with Slag Cement for Use as Bridge Joint Material", *British Journal of Civil and Architecture Engineering*, 1(2): 1-14.

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Thank You

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