Feasibility of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Use in Highway Bridges in Montana: Phase II Field Application

Authors: Michael Berry
Riley Scherr
Kirsten Matteson

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Background

Advantages of UHPC

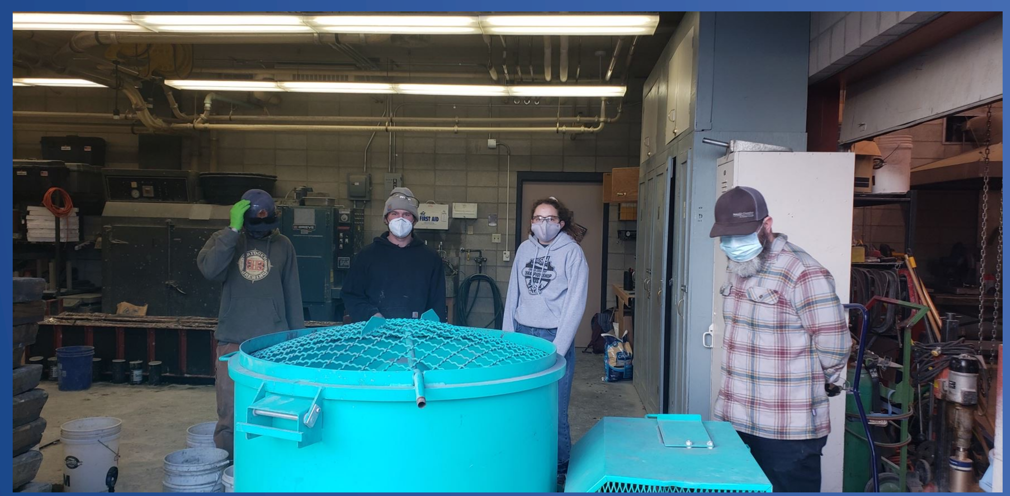
- Exceeds mechanical and durability properties of conventional concrete
- Reaches compressive strength upwards of 20 ksi
- Reduces development lengths and required spacing between precast bridge deck panels

Beech Creek Bridge in Georgia Using UHPC in between Precast Deck Panels

Research Objective and Scope

Focus of Research

- Develop non-proprietary UHPC mix design using materials available in Montana
- Investigate variability in performance related to variation in materials
- Investigate issues related to field batching and mixing in various conditions
- Test rebar bond strength in relation to requisite development lengths



Researches Team Performing a UHPC Mix

Non-Proprietary UHPC

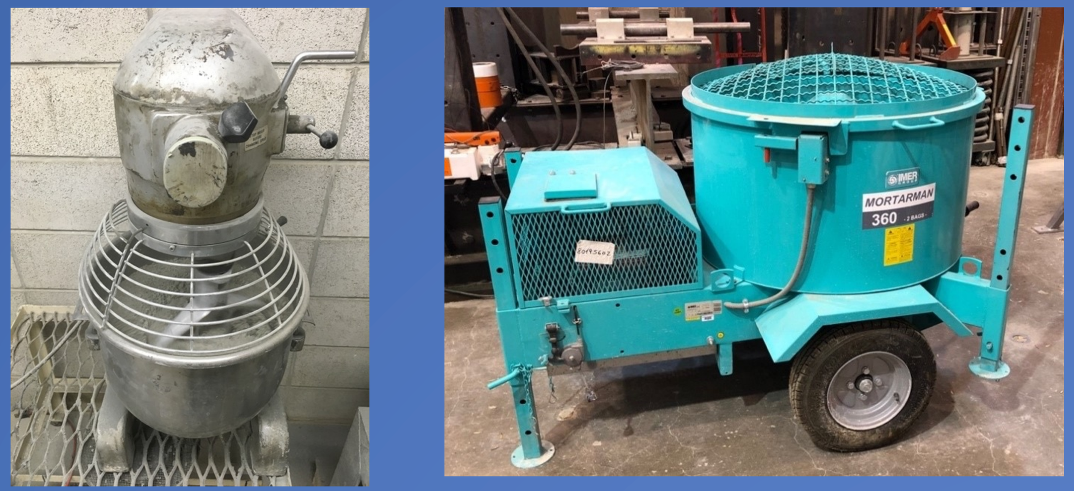
- Significantly less expensive than commercially available UHPC mixes
- Commercial UHPC costs approximately 30 times more than conventional concrete
- Opens the door to MDT for UHPC use in Montana construction projects
- Utilizes material readily available in Montana

Freshly Mixed Non-Proprietary UHPC

Methodology

Mixing Set up

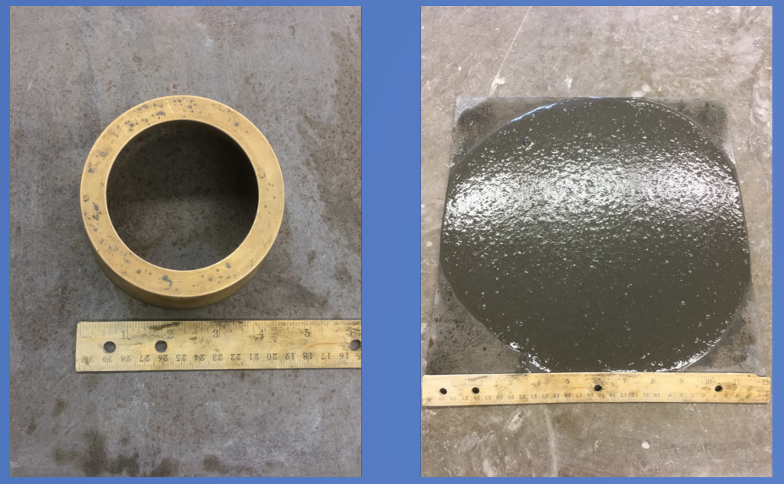
- Mixes performed in MSU structures lab utilizing a small-scale Hobart mixer and a large-scale Mortarman mixer
- The effects of batch size were investigated using this equipment



Small- and Large-Scale Mixers

Flow Testing

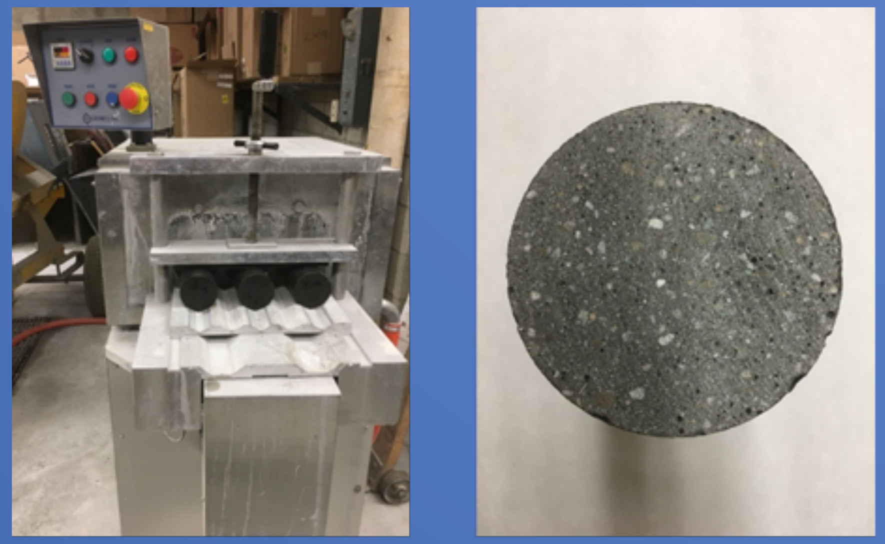
- Flow testing utilized a spread cone mold filled with concrete
- Minimum and maximum diameters of spread are measure to quantify flow



Flow Cone with Resulting Flow Measurement of UHPC

Specimen Casting, Preparation, and Curing

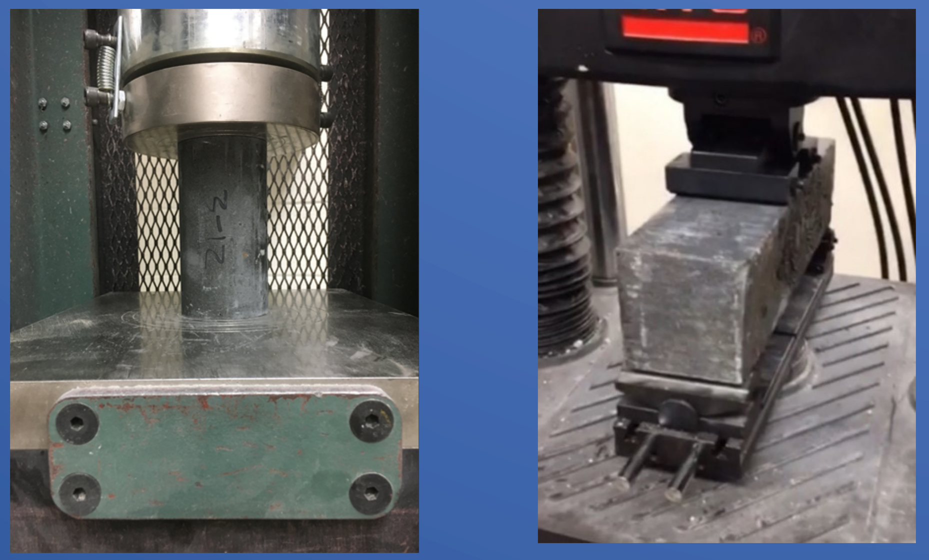
- For each batch, 3-by-6-in cylinders were prepared in reusable plastic molds
- After approximately 48hrs, a diamond-blade saw was used to remove the uneven surface layer
- The cylinders were then ground using a cylinder end grinder



Cylinder End Grinder Used for Leveling Test Surface

Compression/Flexural Testing

- Cylinders were loaded in a hydraulic load compression frame with 400,000 lb capacity
- Flexural testing was performed on beam molded concrete



Compression and Flexural Testing Setups

Sensitivity to Material Variability

Base Mix Design

Item	Item Type	Amount (lbs)
Water	-	27.66
High Range Water Reducer (HRWR)	CHRYSO Fluid Premia 150	5.96
Portland Cement	Type I/II Trident	120.32
Silica Fume	BASF MasterLife SF 100	25.78
Fly Ash	Trident Genesee	34.38
Fine Aggregate	O.D. BBB&T Concrete Sand	144.11
Steel Fibers	Bekaert Dramix OL 13/0.20	24.34

Materials and Experimental Design

- Mixes were performed with various material sources and properties.
- Cement Source: Two cement sources were used to prepare the UHPC (Trident and Ash Grove).
- Fly Ash Source: Three different Class F fly ash sources were tested in this research (Genesee, Coal Creek and Sheerness).
- Fine Aggregate Source and Properties: Six masonry sands and 4 concrete sands were tested and evaluated.
- Moisture Content: Moisture contents were varied between 0% and 300% SSD.
- Steel Fibers: Two different types of steel fibers were investigated in this research (HiPer Fiber and Baekert).

Key Findings

- The flow of the UHPC mixes generally increased with increasing aggregate moisture content, and the 7- and 28-day compressive strengths generally decreased.
- However, adjusting the mix water to account for the variations in aggregate moisture contents did not significantly affect the observed flow of the mixes.
- While variations in the source of the constituent materials (e.g., cement, fly ash, aggregate) had some effects on UHPC performance, the effects were fairly minor.
- Some of the differences in performance could be eliminated if the mix design was adjusted accordingly to account for the variations in the material.

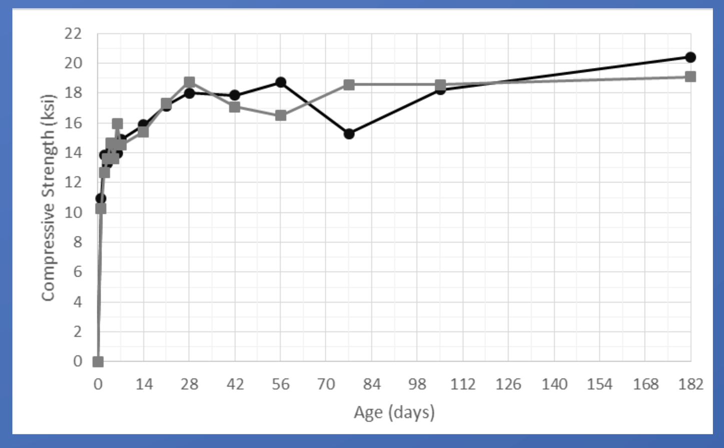
Sensitivity to Mixing Variability and Field Conditions

Experimental Design

- UHPC Mixes were performed with varying mixing and field conditions (e.g., temperature, batch size, etc).

Key Findings

- UHPC continued to gain strength over time, eventually reaching a compressive strength of around 20 ksi at 28 days.
- Temperature was shown to have a noticeable effect on several performance measures. The cold mix was found to have greater flows and earlier strength gain.
- Batch size did not have a significant effect on flow or compressive strength; however, it was observed that the larger scale mixes used in this phase of research required 10% more water and High Range Water Reducer (HRWR) to obtain the same performance observed for the smaller batches.



Strength Profile of Two Identical Mixes

Mix	Outside Temperature (°F)	Dry Material Temperature (°F)	Flow (in.)	Compressive Strength, f'c (ksi) 7-day	28-day	56-day
Cold Mix	45	32	10	16.15	17.89	17.98
Room Temperature	70	60	9	14.9	18.01	18.71
Hot Mix	75	90	6.25	14.78	16.62	17.03
		Average:	8.42	15.27	17.51	17.91
		C.O.V.:	18.8%	4.1%	3.6%	3.8%

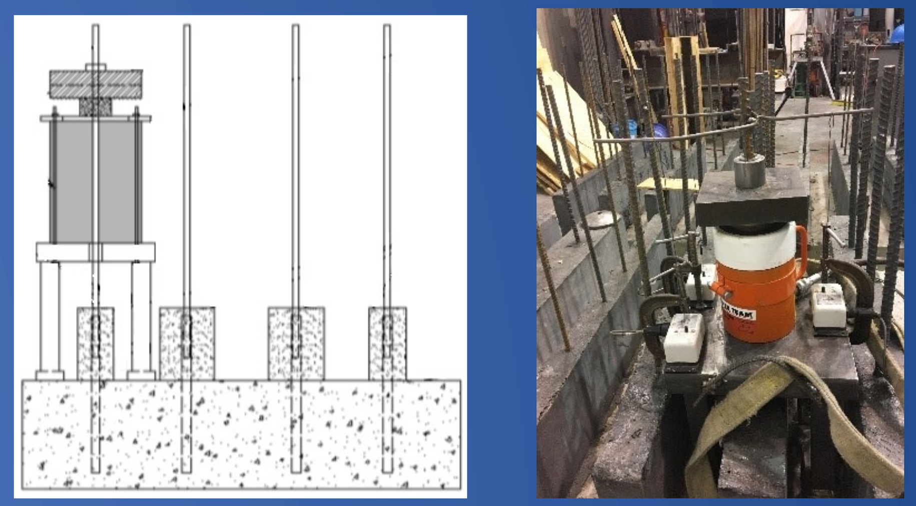
Effect of Mix Temperature on Flow and Compressive Strength

Bar Pullout Tests

Experimental Design

- Rebar of various sizes were embedded into concrete with varying depths and clear covers and loaded until failure while monitoring applied load and deflections.

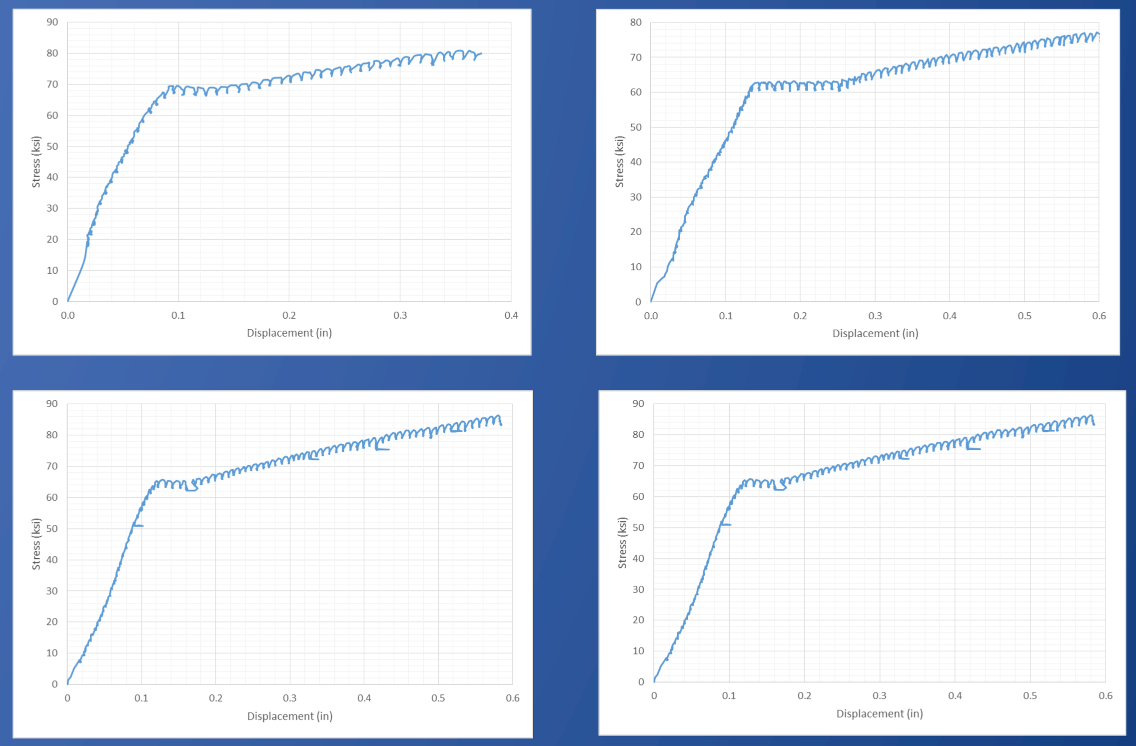
Test Specimens During and After Construction



Idealized and Actual Test Setup

Key Findings

- All of the reinforcing bars that met the minimum FHWA recommendations for embedment depth and clear cover reached at least their yield stress prior to bond failure, indicating that the FHWA recommendations are suitable for use in connections made with the MT UHPC.
- These results are promising and indicate that the FHWA embedment depth recommendations may be suitable for use in bridge closure pours made with the UHPC mix developed in this research.



Typical Stress vs. Displacement Plots for FHWA Pullout Tests of Rebar #4-#7

Overall Conclusions

- All mixes in this study had flows between 6 and 11 inches, and respective 7- and 28- day compressive strengths of at least 13 and 16 ksi.
- Rebar that is embedded to depths specified by FHWA recommendations will yield prior to concrete bond failure.
- This consistent/adequate performance under varying conditions indicates that the MT UHPC mix is suitable for field applications in Montana.

References

- Michael Berry, Riley Scherr, and Kirsten Matteson. Feasibility of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Use in Highway Bridges in Montana: Phase II Field Application. United States. Montana Department of Transportation. Western Transportation Institute – Montana State University