Field Implementation of Montana Ultra-High Performance Concrete

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UHPC Background

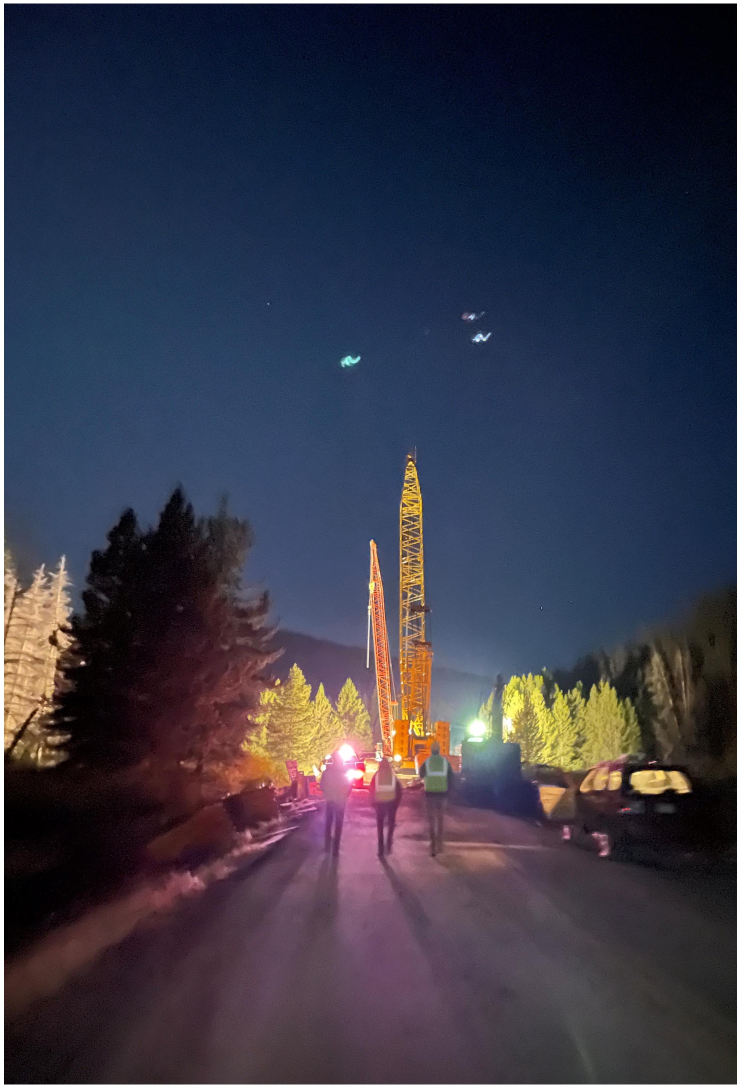
- High compressive strength - 17,000 psi minimum
- High tensile strength – 1,400 psi minimum
- Self-consolidating material
- Impermeable
- Durable
  - Freeze/thaw resistance
  - Chloride resistance
  - Abrasion resistance
- Proprietary
  - Costly ~ 30 times more expensive than conventional concrete

Previous MSU Research

- Phase I
  - Develop and characterize nonproprietary UHPC mix designs
  - Made with materials readily available in Montana
  - Mechanical/durability testing
- Phase II
  - Material sensitivity
  - Rebar pull-out testing

Phase III-Implementation

- Objective
  - The focus of this project was on the field implementation of MT-UHPC. Specifically, MT-UHPC was used in all field cast joints on two ABC bridges in Montana.



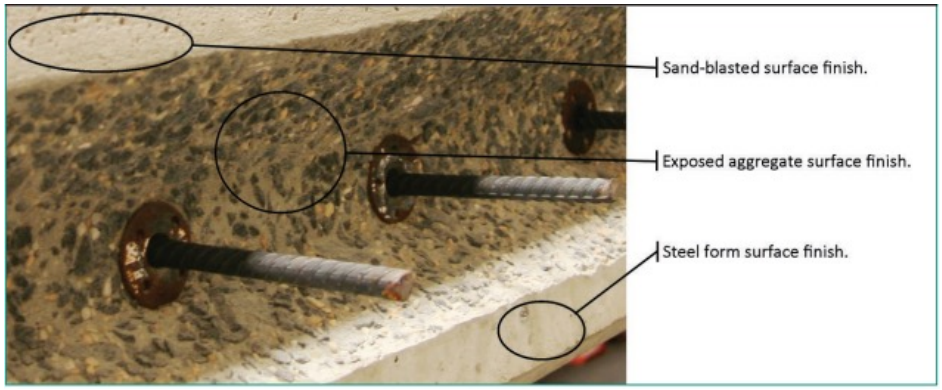
Scope

- Literature Review
  - Field Implementation of UHPC
- Material Selection
- Implementation-Related Research
- Trial Batches on Mockup Bridge Joints
- Bridge Construction

Literature Review

Literature Review – Field Implementation

- Surface Preparation for Bond Between UHPC and Precast Concrete
  - Roughened surface
  - Pre-wetting interface
- Formwork for UHPC Elements/Connections
  - High pressure
  - Water-tight seal
  - Top forming
- UHPC Mixing Considerations
  - Temperature effects
  - Batch sizes
- Placing and Finishing UHPC
  - Prior coordination
  - Non-Traditional finishing



MATERIAL SELECTION

MATERIALS

- Portland cement
  - GCC cement plant Trident, MT
- Fly ash
  - Prairie state
- Silica fume
  - MasterLife SF 100 from BASF
- Fine aggregate
  - Masonry sand from Quikrete Billings, MT
- HRWR
  - CHRYSO Fluid Premia 150
- Steel fibers
  - Hiper Fiber

Item	Weight (lbs)
Water	298.7
Portland Cement	1299.5
Fly Ash	371.3
Silica Fume	278.4
HRWR	64.4
Steel Fibers	262.9
Fine Aggregate	1556.4

IMPLEMENTATION-RELATED RESEARCH

Material Sensitivity

Scope of Implementation Research

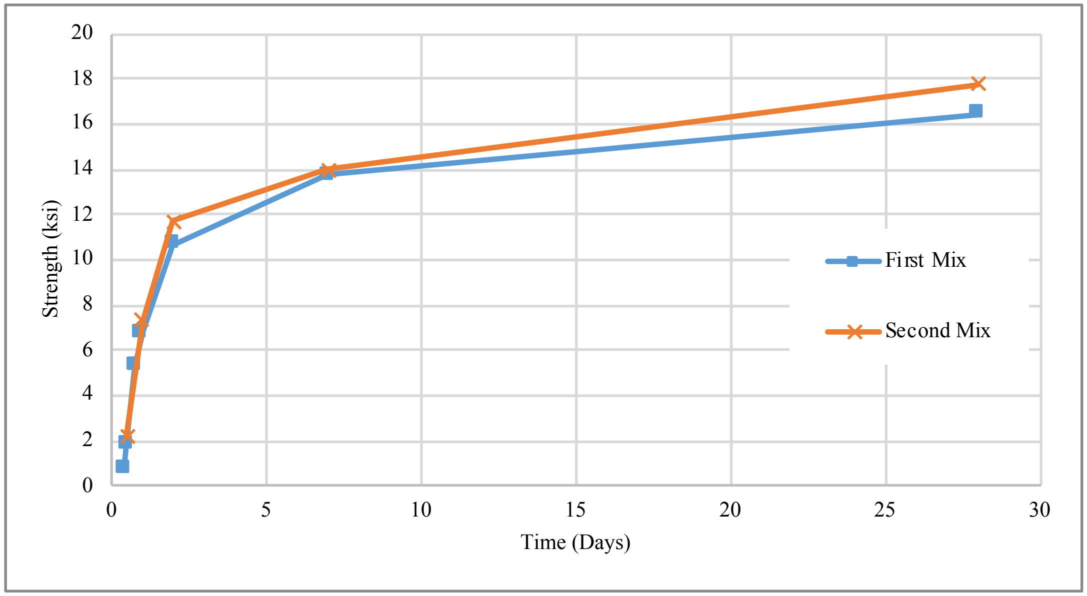
- Ensure successful field implementation of MT-UHPC
  - Mixing process
  - Batch size
  - Mixing and curing temperatures
  - Maturity curve development
- Collaboration with contractor was key

Summary of Mixes

Mix Number	Description	Batch Size (cuft)	Ambient Temp (˚F)	Cure Temp (˚F)	24-hr Strength (ksi)	28-day Strength (ksi)
1	Baseline mix using materials sourced from the contractor	2.5	48	70	6.9	18.4
2	First of two consecutively mixed batches	2.5	67	70	6.8	16.4
3	Second of two consecutively mixed batches	2.5	67	70	7.3	17.8
4	First 4.5-ft^3 batch	4.5	57	70	7.7	17.1
5	Mix that investigated a new mixing method of adding 2/3rd of dry material with water, then adding the remaining dry material after turnover	4.5	61	70	9.53	17.4
6	A failed 4.5-ft^3 mix that stiffened up in the mixer	4.5	63	70	6.5	13.7
7	Mix that investigated the effects of curing cylinders under varying temperatures	3	67	70	7.3	17.2
				Varying (56-93)	8.7	---
8	Mix investigating replacing 40% of the mix water with ice to combat temperature effects	3	86	70	7.9	20.1
9	Mix investigating temperature effects by curing cylinders in hot, cold and room temperature conditions for varying amounts of time.	3	45	34	0.4	12.4
				70	5.9	17.8
				100	11.8	18.6

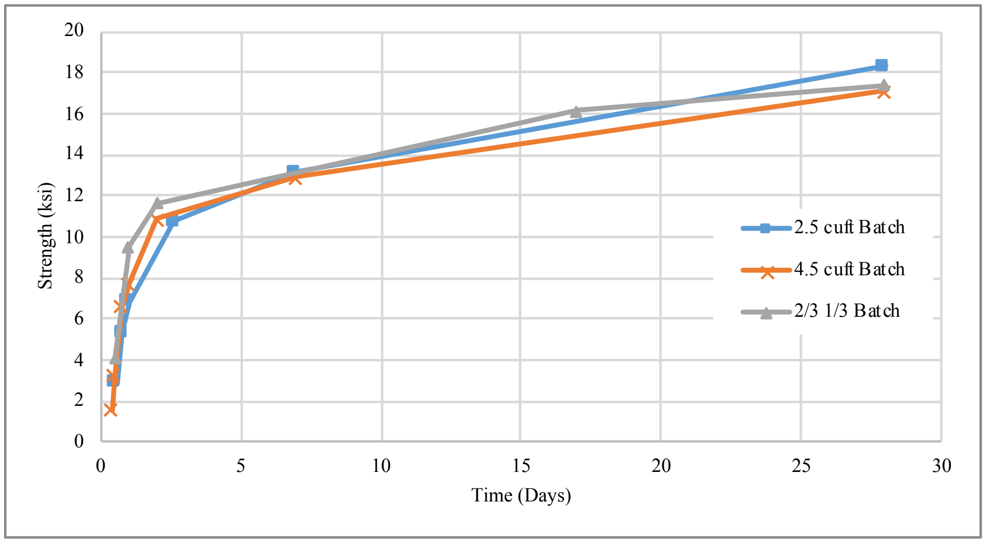
Consecutive Batches

- Construction will require numerous consecutive batches
- Cleaning mixer after every batch would be time consuming



Batch Size

- UHPC requires smaller batch sizes than conventional concrete
- Maximize batch size
- 3 ft^3 batch size selected

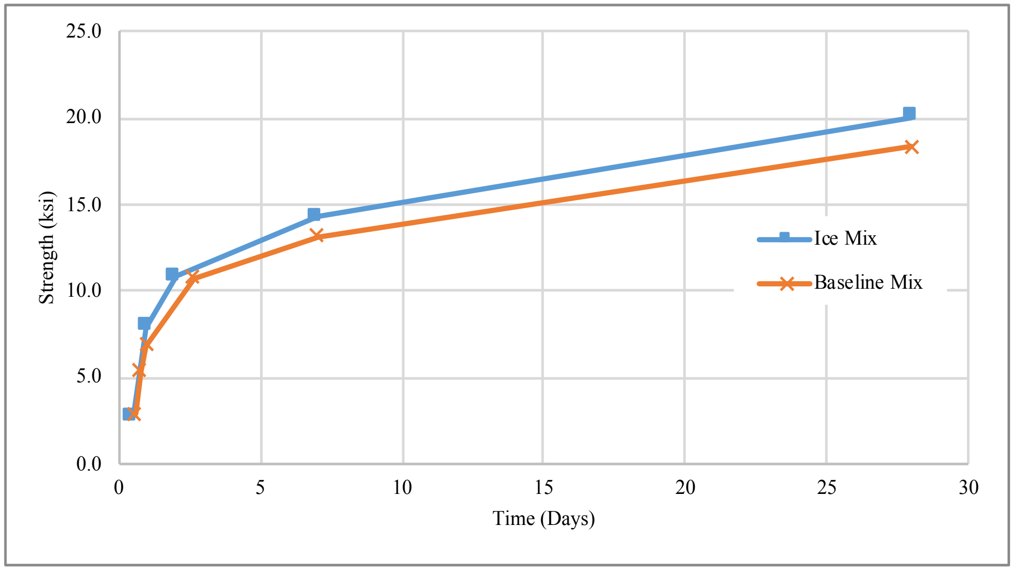


Failed Mixes

- Stiffening
  - Premature exothermic reaction
  - 50/50 on 4.5 cu ft batches
- Oversized
- Temperature

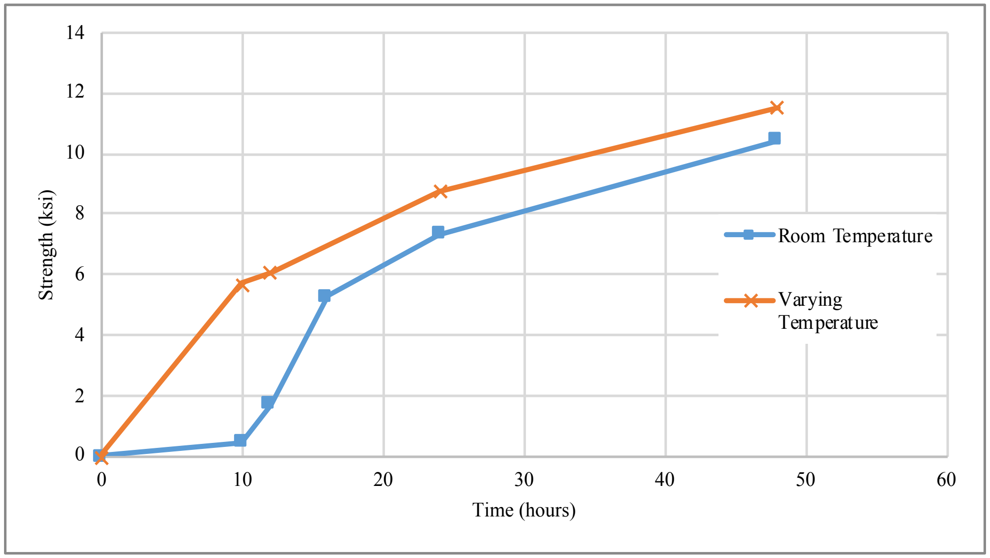
Temperature Range for Batching

- Prescribed Range for Batching
  - 40 ˚F to 80 ˚F
- Elevated Temperature
  - Premature stiffening
- Mitigation strategies



Temperature Effects on Curing - Preliminary

- Elevated temperature curing (93˚F)
- Room temperature curing (70˚F)

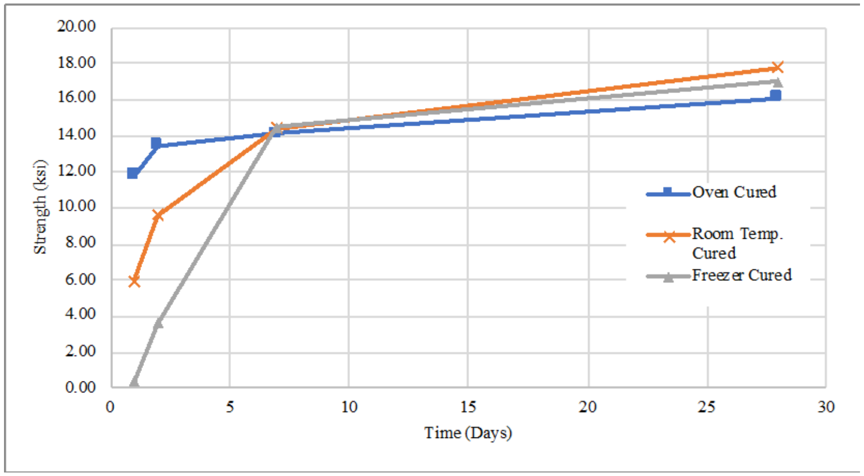


Systematic Temperature Investigation

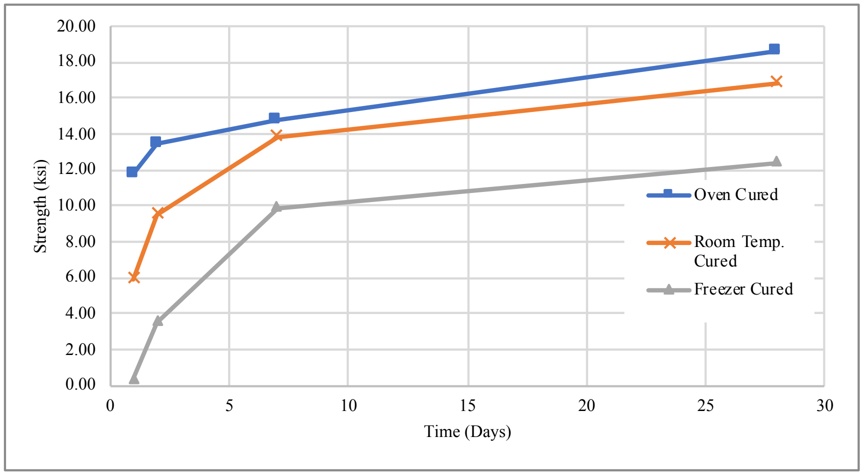
- Curing Conditions
  - 34˚F - Freezer
  - 70˚F - Lab
  - 100˚F - Oven
- Varying curing times

Cure Condition (Initial 48hr)	Cure Condition (After 48hr)	24-hr strength (ksi)	48-hr strength (ksi)	7-day strength (ksi)	28-Day strength (ksi)
Freezer (34˚F)	Cure Room (70˚F)	0.37	3.57	14.43	17.00
Lab (70˚F)	Cure Room (70˚F)	5.93	9.57	14.37	17.77
Oven (100˚F)	Cure Room (70˚F)	11.77	13.43	14.07	16.10
Freezer (34˚F)	Freezer (34˚F)	0.37	3.57	9.90	12.40
Lab (70˚F)	Lab (70˚F)	5.93	9.57	13.87	16.87
Oven (100˚F)	Oven (100˚F)	11.77	13.43	14.73	18.60

Varied Curing Temperatures



48-hour Temperature Curing



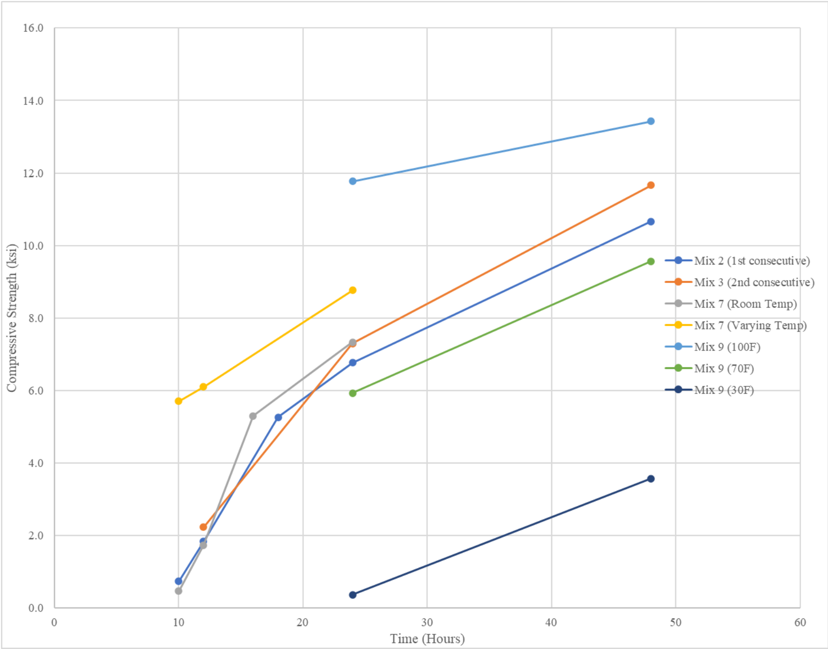
28-day Temperature Curing

Estimating Early Strength Gain with Maturity Method

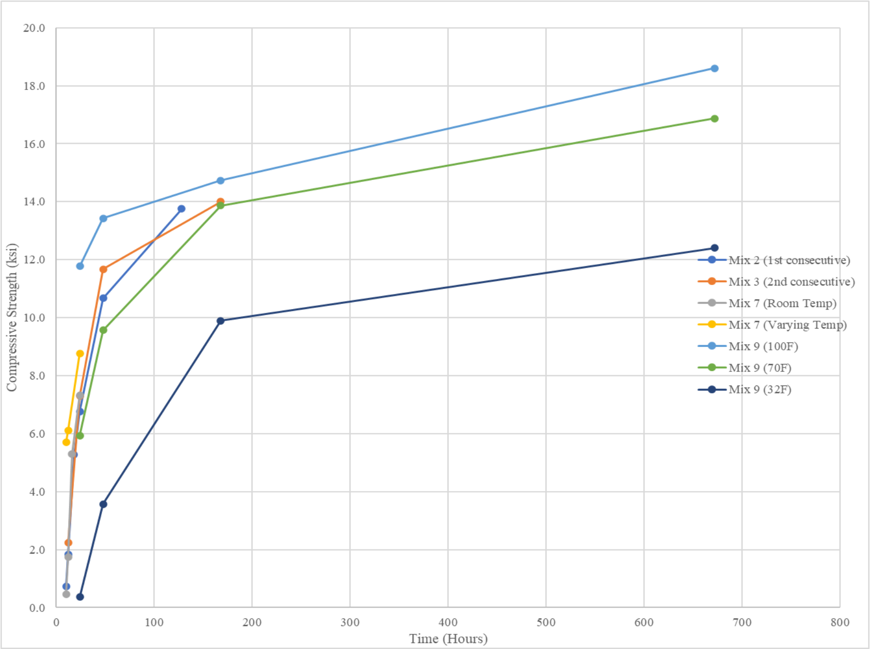
- Non-destructive method of estimating compressive strength of concrete
- Relates temperature and time to strength
- Requires the creation of maturity curves specific to the material
- Typically used to estimate early strength

$$M(t) = \sum (T_a - T_0)\Delta t$$

Strength vs. Time Profile



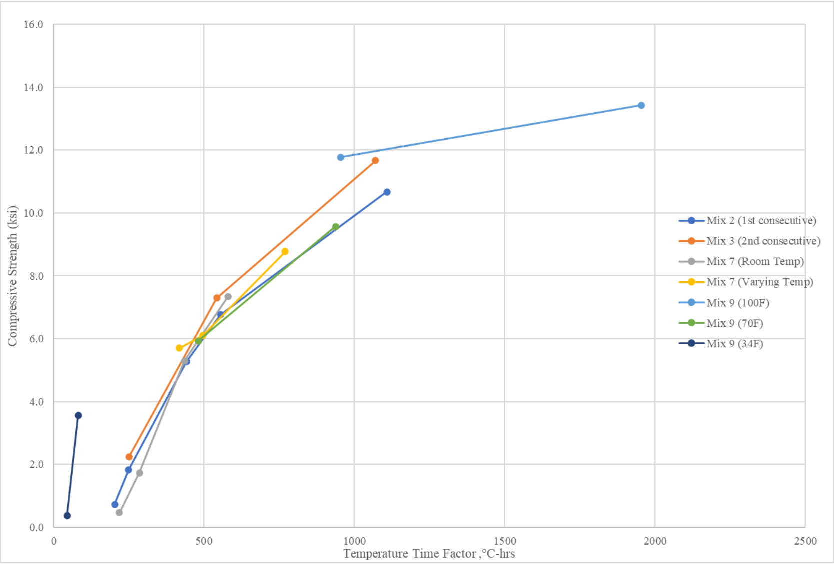
48-hours



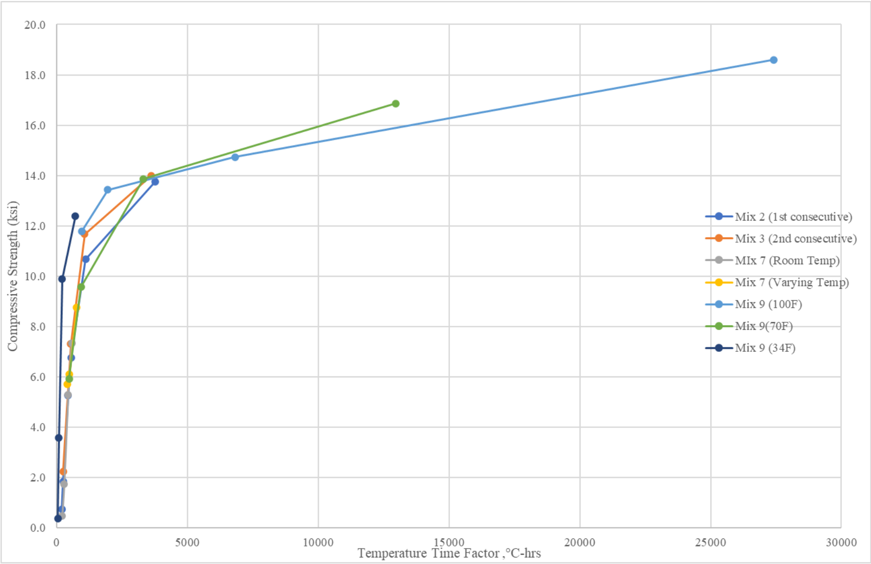
28-days

Maturity Curves (0 °C Datum)

- Strength vs. Temperature-Time Factor aligns the data

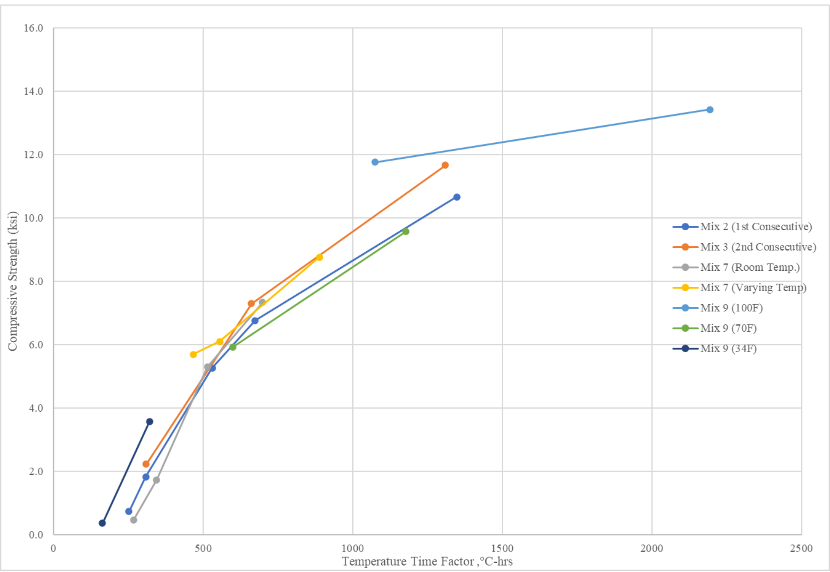


48-hours

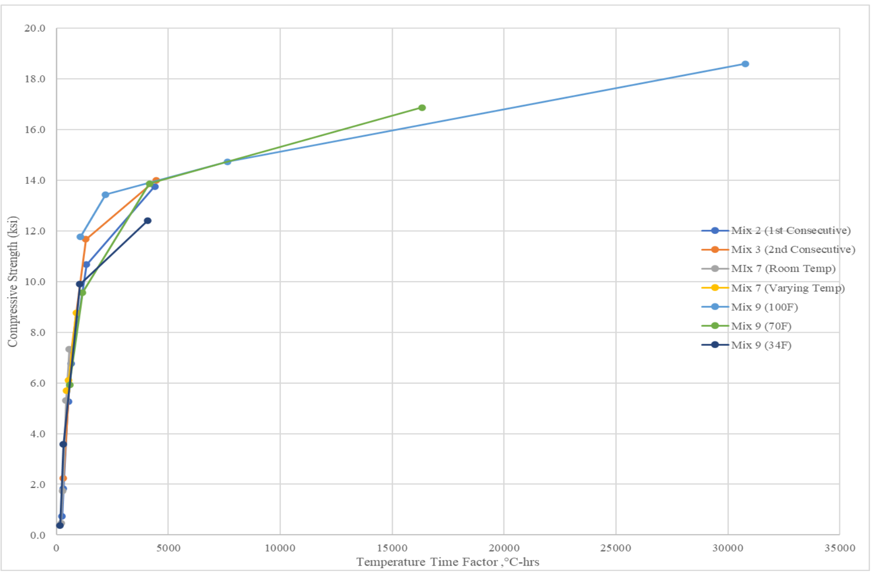


28-days

Maturity Curves (-5 °C Datum)



48-hours



28-days

Summary of Research Findings

- Batches can be mixed consecutively
- Batch sizes should be limited to 3 ft^3 when mixing MT-UHPC with Imer Mortarman 360s
- MT-UHPC should be placed at lower temperatures and when material temperatures are low.
- Cure temperature should be accounted for when estimating the compressive strength of the material in the field
- The maturity curves developed in this research may be used to estimate compressive strength of MT-UHPC in the field.

Trail Creek Structures Overview

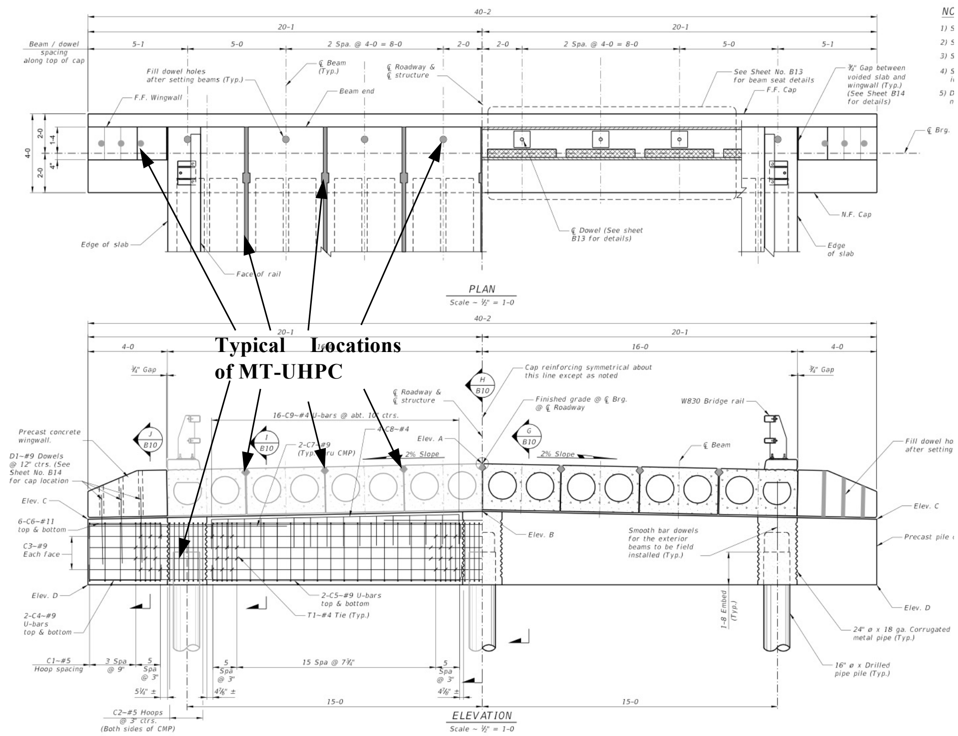
Location and Bridge Closure

- Highway 43, 17 miles west of Wisdom, MT, near Lost Trail Pass
- No convenient detours
- 96-hour construction window
- $2,500 per hour – cost to the traveling public from bridge closure

Bridge Replacement

Replacement Structure

- Two precast pile caps
- Eight precast/prestressed hollow-core beam elements
- 60 ft single span
- MT-UHPC used in all field-cast connections
  - Pile to pile-cap connections
  - Longitudinal shear keys
  - Wing walls
  - Between beams and caps



MT-UHPC Special Provisions

- Materials and mixing methods
- 4,000 psi - Minimum compressive strength prior to backfilling around pile caps, operating compaction equipment, placing beams on caps
- 12,000 psi - Minimum required 28-day compressive strength
- 3,000psi - minimum compressive strength prior to grinding.
- (40°F – 80°F) - Temperature range of placing
- Trial pour and joint mockups must be completed
- Incentive/Disincentive
- Quality control procedures

Mixing and Batching

- Premixed and bagged off site
- Transported on site in sling bags

Mixing and Batching

- UHPC batched on site
- HRWR, water and steel fibers added separately

Trial Batches and Joint Mockups

Trial Batches and Joint Mockups

- Batched near location of bridge replacement (Wisdom, MT)
- Same methods and environmental conditions expected during construction
- Three replica field-cast connections
  - Mockup Pile cap
  - Two mockup keyways

UHPC Batching and Mixing

Keyway Mockups

- Overpour ½ inch
- Placed with buckets

Keyway Mockups

- Sloped and flat applications
- Highlighted need for top forming

Grinding

- Performed at ~1 ksi compressive strength
  - (6-hrs)
- Premature grinding

Pile Cap Mockup

Trial Pour Results

- Successful batching and mixing procedures
- Adequate Strengths and flows
- Sloped keyway requires top forming
- Grinding at 1ksi was too early

Mix	Application	Spread (in)	24-hr strength (ksi)	48-hr strength (ksi)	7-day strength (ksi)	28-day strength (ksi)
1	Keyway	10	9.4	9.2	11.5	15.1
2	Pile Cap	10	10.3	10.7	13.4	17.1

Bridge Construction

Demolition and Site Preparation

Demolition and Site Preparation

Pile Caps

- 6 drilled pipe piles (3 on each side)
- Soil preparation/foam application

UHPC Placement Preparation

MT-UHPC Placement

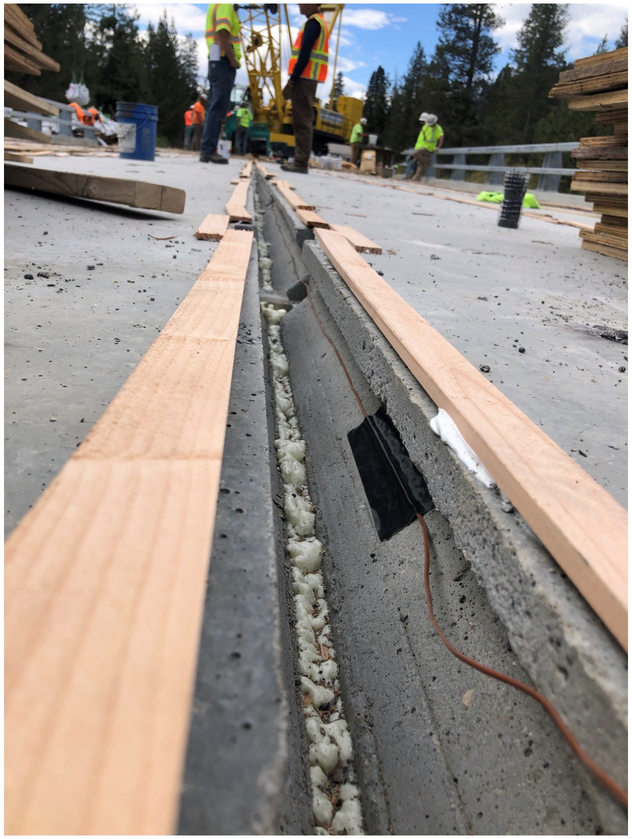
Longitudinal Beam/Deck Elements

- 8 precast/prestressed hollow-core beam elements

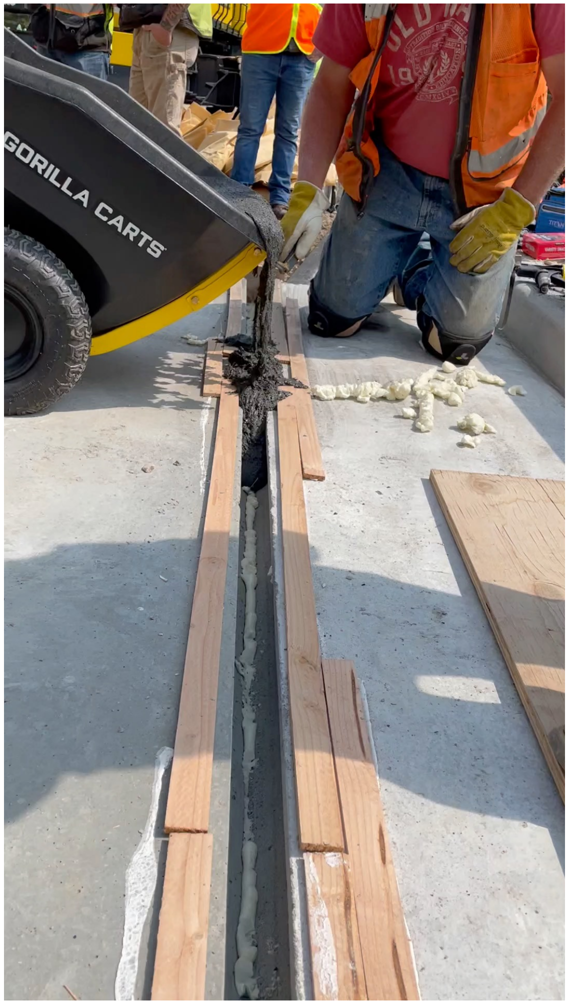
Leveling and Welding

Keyway Preparation

- Forms for overcast
- Thermo-coupling wires



MT-UHPC Placement



Top Forming

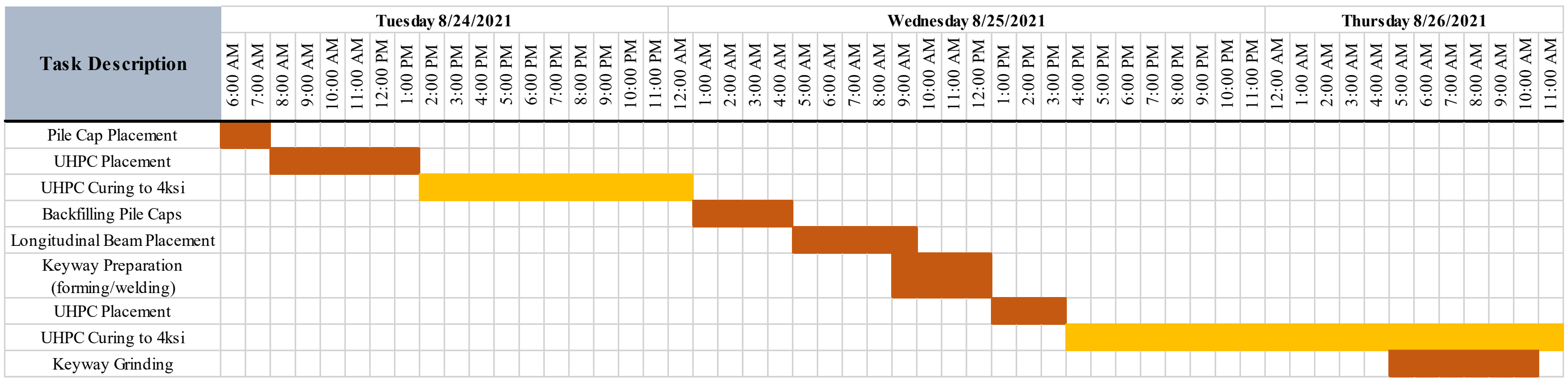
Keyway Grinding

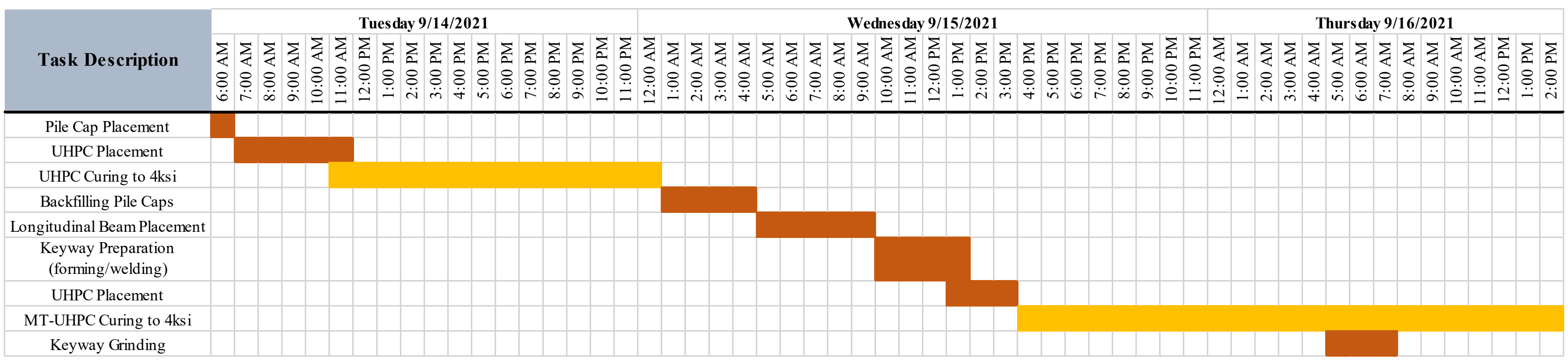
Epoxy Application

- Some air pockets left after grinding



Timeline of UHPC Related Activities





Bridge Completion

Research Team

- Montana State University
- Montana Department of Transportation
- Dick Anderson Construction

Summary of UHPC Strengths

- All MT-UHPC reached minimum specified compressive strength (12 ksi)
- 17.6 ksi – Average compressive strength of MT-UHPC on first bridge
- 17.5 ksi – Average compressive strength of MT-UHPC on second bridge

First Bridge Compressive Strength and Flow Results

Time Sampled	Date	Application	Spread (in)	Ambient Temp. (˚F)	28-day Strength (ksi)
8:45 AM	8/24/21	Pile cap	11	49	18.4
10:50 AM	8/24/21	Pile cap	11	61	18.8
1:05 PM	8/24/21	Pile cap	10.25	72	16.6
1:45 PM	8/25/21	Keyway	10.5	74	18
2:35 PM	8/25/21	Keyway	10	82	18.2
3:20 PM	8/25/21	Keyway	10	88	15.7

Summary of UHPC Strengths

- Temperature and Wind effects on spread

Second Bridge Compressive Strength and Flow Results

Time Sampled	Date	Application	Spread (in)	Ambient Temp. (˚F)	Internal Temp. (˚F)	28-day Strength (ksi)
7:50 AM	9/14/21	Pile cap	11	42	61.6	18.5
10:00 AM	9/14/21	Pile cap	10.5	55	67.9	17.7
11:15 PM	9/14/21	Pile cap	10	62	71.9	16.7
1:45 PM	9/15/21	Keyway	8.7	82	78.4	17.6
3:00 PM	9/15/21	Keyway	9.5	84	75.4	16.5
3:50 PM	9/15/21	Keyway	9.5	84	76	17.8

Monitoring Bridge Performance

- Visited Site approximately 1 year after placement
- Look for general signs of damage
  - Cracking
  - Spalling
  - Debonding

  - No signs of damage


- Some rusting of fibers and around ducts for bridge dowel connection

Conclusions

Preliminary research

- MT-UHPC can be batched consecutively without cleaning the mixer in between batches.
- Batch sizes should be limited to 3 ft^3 when mixing MT-UHPC with IMER Mortarman 360s.
- MT-UHPC should be placed at low temperatures and when material temperatures are low to reduce the risk of the material stiffening and premature setting (which was observed to occur at elevated temperatures).
- Cure temperature should be accounted for when estimating the compressive strength of the material in the field, as temperature was observed to greatly affect the rate of strength gain. Specifically, increased temperatures resulted in a higher rate of strength gain and decreased temperatures delayed strength gain.
- Maturity curves developed in this research may be used to accurately estimate compressive strength of MT-UHPC in the field, regardless of cure temperatures.

Conclusions

Trial batches and joint mockups

- MT-UHPC was successfully batched and mixed in the field using the exact materials, mixers, and methods to be used in the actual bridge project. The flows of the trial mixes were around 10 inches, and the compressive strengths exceeded the minimum specified 28-day strength of 12 ksi, with an average strength of 16.1 ksi.
- The methods used to form and place the UHPC in the connection mockups were primarily successful. However, the UHPC in the sloped-keyway mockup demonstrated the need for top forming the keyways, as the UHPC in these connections overflowed at the low end and fell short on the high end.
- Grinding the UHPC before it reaches a strength of 1 ksi resulted in a rough surface on the UHPC and steel fibers being pulled from the material. It is recommended that the MT-UHPC reach at least 3 ksi prior to grinding, as is specified in the Special Provisions.

Conclusions

Conclusions from bridge construction

- Pre-mixing and bagging the dry constituent materials (i.e., cement, fly ash, silica fume, and sand) was an effective/efficient strategy for the implementation of MT-UHPC in the field.
- The on-site batching and mixing methods worked well. However, the use of larger mixers should be investigated. The 3-ft^3 limit per batch resulted in an excessive number of mixes per application, which slowed progress on the bridge.
- The MT-UHPC was successfully mixed, batched, placed, and cured under varied environmental conditions. Specifically, temperatures ranged from the low 20s to the upper 80s (°F), and moderate winds were present.
- The maturity method provided an efficient and accurate means for estimating the early strength of the MT-UHPC in the field.
- The top-forming method used on this project could be improved.

Conclusions

Conclusions from bridge construction

- The Special Provisions developed for this project were a good starting point for implementing MT-UHPC in a bridge construction project in Montana. However, they should be updated and modified for future projects to incorporate some of the key findings from this inaugural project.
- It was imperative to establish a good working relationship with the contractor and establish good lines of communication. The contractor on this project, Dick Anderson Construction, was a pleasure to work with, making this project possible.

Acknowledgements

- Financial support for this project was provided by the Montana Department of Transportation (MDT)
- Thanks to the MDT Research Section and the technical panel for their participation in this project
- Dick Anderson Construction was a valuable asset to this project. Specifically, Tyler Baumberger was integral to this success.


PRESIDENT'S TRANSPORTATION AWARD
for
RESEARCH
Presented to
Trail Creek Structures Project
Montana Department of Transportation
For performing exemplary service
to the states furthering transportation
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Trail Creek Structures Project Team
Montana Department of Transportation

Thank You