SPECIAL SEMINAR
Coordinated Technology Implementation Program
Cold Weather Admixture Systems
Presented by Lynette Barna, Force Projection & Sustainment Branch

April 12
1-2:30 PM
Abele Auditorium

A user-oriented, customer-based seminar on CWAS applications
Extending the Season for Concrete Construction and Repair:
Cold Weather Admixture Systems
Putting It Into Practice!

Lynette A. Barna
Cold Regions Research & Engineering Laboratory (CRREL)
US Army Engineer Research & Development Center
Hanover, NH
Lynette.A.Barna@usace.army.mil
603-646-4503 (voice)

12 April 2016, Hanover, NH
Acknowledgements

Coordinated Technology Implementation Program webinar sponsor

Federal Highway Administration Transportation Pooled Fund Program research funding

U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) Installation Technology Transition Program demonstration funding
Outline

• Background
• Development of Cold Weather Admixture Systems
  Laboratory testing
• Application of Cold Weather Admixture Systems
  Field Testing
• Conclusions
Cold Weather Admixture Systems

Background

• Problem
  - Cold weather
  - Low temperatures slow hydration rate of fresh normal concrete slows
  - Fresh concrete susceptible to freezing – and damage
  - No single commercial admixture protects concrete below freezing

• Solution
  - Chemical admixture suites depress mix water freezing point
  - Protects fresh concrete to an internal concrete temperature of −5°C (23°F)
  - Promotes early strength gain at temperatures below freezing
Cold Weather Admixture Systems

• Benefits
  − Saves time and money and energy
  − No external heat required for water & aggregates, or substrate
  − Uses conventional construction practices and equipment
  − Provides an added capability to winter construction
  − Extends the concrete construction & repair season
  − Commercially available admixtures

$800 M/yr
Cold Weather Admixture Systems

Publications
- CRREL technical reports
- Peer reviewed papers and conference presentations
- ASTM C 1622 Standard Specification
- ACI 306 Guide to Cold Weather Concreting
- Website for links to publications
- Public search on: CRREL antifreeze concrete
Cold Weather Admixture Systems
“Antifreeze Concrete”

- How Antifreeze Concrete works
  - Combinations of chemical admixtures
  - Accelerates the rate of cement hydration
  - Reduces the amount of water to protect
  - Initial freezing point temperature
Cold Weather Admixture Systems

- Effects of water
  - Relationship between admixtures and mix water content
  - Account for water in admixtures
Laboratory Testing
Cold Weather Admixture Systems

• Performance Requirements for Laboratory Study
  - Dose admixtures within manufacturer’s recommended range
  - Ensure workable concrete
  - Protect fresh concrete from freezing down to minimum of –5°C (23°F)
  - Gains compressive strength at –4.5°C (25°F) as good or better than curing at +5°C (40°F)
  - No adverse long-term durability effects
  - Compatible with steel reinforcement
  - Does not promote alkali-silica reaction
  - Accepts air entrainment
  - Does not adversely affect finishability
  - Does not present significant problems with equipment use and cleanup in cold weather
Cold Weather Admixture Systems

• Initial Laboratory Study Objectives
  – Develop antifreeze admixture concrete mixtures using commercially available (off-the-shelf) admixtures
  – To mix, place, finish, and cure concrete at below freezing temperatures

• Scope
  – Type I, Type II, or Type I-II portland cement (ASTM C 150)
  – Cement factor 392 kg/m³ (660 lbs/yd³) and w-c ratio 0.44
  – Air content 6% (±1.5%) (ASTM C 173)
  – Accept air entrainment (ASTM C 666, ACI 306)
  – Slump 100 mm (4 in.) (ASTM C 143)
  – Admixtures (ASTM C 494 or C 260)
  – Initial freezing point measurement (CRREL method)
  – Unconfined compressive strength testing (ASTM C 39)
  – Several formulations tested in laboratory and used in field
  – Blended cements and SCMs not considered (future study)
Cold Weather Admixture Systems

- Laboratory Mixtures
  - Control

<table>
<thead>
<tr>
<th>Mixture Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, kg/m³ (lb/yd³)</td>
<td>392 [660]</td>
</tr>
<tr>
<td>¾ in. aggregate, ssd*, kg/m³ (lb/yd³)</td>
<td>1079 [1819]</td>
</tr>
<tr>
<td>Sand, ssd, kg/m³ (lb/yd³)</td>
<td>801 [1350]</td>
</tr>
<tr>
<td>Batch water, L/m³ (gal./yd³)</td>
<td>171 [34.7]</td>
</tr>
<tr>
<td>Air-entraining admixture, mL/100 kg (fl oz/cwt)</td>
<td>97 [1.49]</td>
</tr>
<tr>
<td>Water-reducer, mL/100 kg (fl oz/cwt)</td>
<td>507 [7.78]</td>
</tr>
<tr>
<td>Final water-cement ratio</td>
<td>0.436</td>
</tr>
<tr>
<td>Target slump mm (in.)</td>
<td>100 ± 25 [4 ± 1]</td>
</tr>
</tbody>
</table>

* saturated, surface dry

- Admixture combinations were added to this base mixture
Cold Weather Admixture Systems

- Laboratory Mixtures
  - Chemical Admixtures

<table>
<thead>
<tr>
<th>Specification Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Water-reducing</td>
</tr>
<tr>
<td>Type B</td>
<td>Retarding</td>
</tr>
<tr>
<td>Type C</td>
<td>Accelerating</td>
</tr>
<tr>
<td>Type D</td>
<td>Water-reducing and retarding</td>
</tr>
<tr>
<td>Type E</td>
<td>Water reducing and accelerating</td>
</tr>
<tr>
<td>Type F</td>
<td>High-range water-reducing</td>
</tr>
<tr>
<td>Type G</td>
<td>High-range water-reducing and retarding</td>
</tr>
<tr>
<td>ASTM C 494</td>
<td></td>
</tr>
<tr>
<td>(None)</td>
<td>Air-entraining</td>
</tr>
<tr>
<td>(None)</td>
<td>Corrosion-inhibiting</td>
</tr>
<tr>
<td>(None)</td>
<td>Shrinkage-reducing</td>
</tr>
</tbody>
</table>
Cold Weather Admixture Systems

- Laboratory Study
  - Compressive strength development
  - Antifreeze concrete cured at 25°F (–4°C)
Cold Weather Admixture Systems

- Laboratory Study
  - Freeze-thaw durability testing
Cold Weather Admixture Systems

• Initial Laboratory Study Outcomes
  - Verified concrete mixture characteristics
  - Eight antifreeze formulations developed
  - Conducted four field trials and one final demonstration project

• Findings
  - Antifreeze mixtures workable, transportable, air entrainable
  - Verified initial freezing point temperature of 23°F
  - Compressive strength exceeded standard guidance
  - Antifreeze mixtures can be durable
  - Field trials showed this a feasible approach
  - Developed tools for field use
  - One size fits all
Cold Weather Admixture Systems

• Follow-on research study
  − Optimize admixture dosage rates
  − Addressed one-size-fits-all dosage rates
  − Specify admixture dosage rates based on forecasted weather

• Findings
  − Tailor the admixture dosage rates
  − Added economy for the mixtures
Field Testing
# Field Testing

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>17–18 February 1994</td>
<td>Hanover, NH</td>
<td>Slab and Wall</td>
</tr>
<tr>
<td>10 December 2001</td>
<td>Littleton, NH</td>
<td>Bridge curbing</td>
</tr>
<tr>
<td>27 February 2002</td>
<td>Rhinelander, WI</td>
<td>Pavement</td>
</tr>
<tr>
<td>12 December 2002</td>
<td>North Woodstock, NH</td>
<td>Bridge footing</td>
</tr>
<tr>
<td>18 December 2002</td>
<td>West Lebanon, NH</td>
<td>Bridge curbing</td>
</tr>
<tr>
<td>14 February 2003</td>
<td>Concord, NH</td>
<td>Sidewalk</td>
</tr>
<tr>
<td>18 February 2004</td>
<td>New York, NY</td>
<td>Streets and sidewalks</td>
</tr>
<tr>
<td>23 February 2004</td>
<td>Grand Forks AFB, ND</td>
<td>Airfield pavement</td>
</tr>
<tr>
<td>7 February 2007</td>
<td>Juneau, AK</td>
<td>Pre-cast work</td>
</tr>
<tr>
<td>27 March 2007</td>
<td>Fairbanks, AK</td>
<td>Slabs on grade</td>
</tr>
<tr>
<td>25–27 March 2008</td>
<td>Ft. Wainwright, AK</td>
<td>Communications hardstand</td>
</tr>
</tbody>
</table>
Field Testing

<table>
<thead>
<tr>
<th>Date</th>
<th>Placement Air Temperature °C (°F)</th>
<th>Overnight Air Temperature °C (°F)</th>
<th>Location</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 December 2001</td>
<td>0 °C (32 °F)</td>
<td>-7 °C (20 °F)</td>
<td>Littleton, NH*</td>
<td>Bridge curbing</td>
</tr>
<tr>
<td>27 February 2002</td>
<td>-4 °C (23 °F)</td>
<td>-10 °C (14 °F)</td>
<td>Rhinelander, WI*</td>
<td>Pavement</td>
</tr>
<tr>
<td>12 December 2002</td>
<td>3 °C (37 °F)</td>
<td>-3 °C (27 °F)</td>
<td>North Woodstock, NH*</td>
<td>Bridge footing</td>
</tr>
<tr>
<td>18 December 2002</td>
<td>-9 °C (16 °F)</td>
<td>-17 °C (1 °F)</td>
<td>West Lebanon, NH*</td>
<td>Bridge curbing</td>
</tr>
<tr>
<td>14 February 2003</td>
<td>-15 °C (5 °F)</td>
<td>-25 °C (-13 °F)</td>
<td>Concord, NH*</td>
<td>Sidewalk</td>
</tr>
<tr>
<td>25–27 March 2008</td>
<td>-10 °C (14 °F)</td>
<td>-15 °C (5 °F)</td>
<td>Fort Wainwright, AK†</td>
<td>Communications hardstand</td>
</tr>
</tbody>
</table>

* Korhonen et al. (2004)
† Barna et al. (2010)
Field Placement

Prior to job

<table>
<thead>
<tr>
<th>Trial batch(es)</th>
</tr>
</thead>
<tbody>
<tr>
<td>slump</td>
</tr>
<tr>
<td>air content</td>
</tr>
<tr>
<td>concrete temperature</td>
</tr>
</tbody>
</table>

Day of job

Job Supervisor:
- be aware of weather forecast
- consider pre-construction meeting
- close coordination (in the beginning)

Truck Driver:
- avoid excess water
- slow agitation in transit
- use cold water for antifreeze concrete

Crew:
- substrate free of ice and snow
- substrate CAN BE frozen
- place / finish as normal
- cover with vapor barrier to retain moisture
Field Testing the Technology

West Lebanon, NH (December 2002)

Air temp. = 14°F (Hi 28°F/Lo 0°F)
Concrete temp. = 50°F

Concord, NH (February 2003)

Air temp. = -4°F (at 1030hrs)
Air temp = +14°F (at 1300 hrs)
West Lebanon, NH

Both bridge curb sections placed during Winter 2002

Control concrete (October 2011)

Antifreeze concrete (October 2011)
Field Placement

- Ft. Wainwright, Alaska
  - March timeframe
  - Test site layout
Field Placement

- Ft. Wainwright, Alaska
  - Site preparation 1 week before concrete placement
Field Placement

- Ft. Wainwright, Alaska
  - Five instrumented test sections
  - Varying admixture dosages
  - Frozen substrate

Air Temp = 14°F
Ground Temp = 21°F

Sections with temperatures:
- Section 1: 25.4°F (-3.7°C)
- Section 2: 29.2°F (-1.6°C)
- Section 3: 29.8°F (-1.2°C)
- Section 4: 30.2°F (-0.8°C)
- Section 5: 30.5°F (-0.8°C)
## Field Placement

### Base Concrete Mix

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg/m³)</td>
<td>390</td>
</tr>
<tr>
<td>Coarse Aggregate (kg/m³)</td>
<td>1,044</td>
</tr>
<tr>
<td>Fine Aggregate (kg/m³)</td>
<td>800</td>
</tr>
</tbody>
</table>
# Field Placement

## Admixtures

<table>
<thead>
<tr>
<th>Test Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (L/m³)</td>
<td>94</td>
<td>99.5</td>
<td>119</td>
<td>101</td>
<td>121</td>
</tr>
<tr>
<td>HRWR (mL/100kg)</td>
<td>521</td>
<td>456</td>
<td>319</td>
<td>391</td>
<td>261</td>
</tr>
<tr>
<td>Water Reducer &amp; Accel (mL/100kg)</td>
<td>4,433</td>
<td>2,934</td>
<td>1,434</td>
<td>2,217</td>
<td>2,223</td>
</tr>
<tr>
<td>Corrosion Inhib (L/m³)</td>
<td>19.8</td>
<td>14.9</td>
<td>7.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Extra Water (L/m³)</td>
<td>7.9</td>
<td>5.9</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/c</td>
<td>0.39</td>
<td>0.39</td>
<td>0.38</td>
<td>0.38</td>
<td>0.47</td>
</tr>
<tr>
<td>Total Solids (%)</td>
<td>11.8</td>
<td>8.3</td>
<td>4.4</td>
<td>6.6</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Field Placement

• Ft. Wainwright, Alaska
  - Day Before – trial batch at ready-mix plant
Field Placement

Ft. Wainwright, Alaska – Day 1 of 2

Air Temp = 14°F
Ground Temp = 21°F
Field Placement

Ft. Wainwright, Alaska – Day 1 of 2

10:30hrs
Field Placement

Ft. Wainwright, Alaska – Day 1 of 2

Air Temp = 19°F
Ground Temp = 23°F

11:00hrs
Field Placement

Ft. Wainwright, Alaska – Day 1 of 2

Section 3
Start time = 12n
Completed before 13:30hrs
Air Temp = 22°F

Section 5
Start time = 13:34hrs
Completed by 14:30hrs
Air Temp = 24°F

Overnight:
Minimum air temp = 5°F
Day 2 Max/Min = 32°F / 3°F
Day 3 Max/Min = 31°F / 0°F
Day 4 Max/Min = 45°F / 20°F
140hrs temps stayed above freezing
Field Placement

Ft. Wainwright, Alaska – Day 1 of 2

Concrete mix
28 day compressive strength = 4,000psi
w-c ratio range = 0.34 to 0.47
Cement = 658 lb/yd³ Type I-II
Air content = 5 – 7%
Field Placement
Field Testing

• Measuring initial freezing point temperature
  - Tool to verify water-cement ratio
Field Testing

- Compressive strength
Estimating Strength

• Test Section 1

<table>
<thead>
<tr>
<th>Time of pour</th>
<th>Center Location, Upper Surface</th>
<th>Edge Location, Lower Surface</th>
<th>Corner Location, Lower Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>26-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31-Mar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Apr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Apr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Apr</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Room temp cylinder breaks start 1 day
Field cured cylinders breaks start 2 days

Strength (MPa)
Field Placement
Conclusions

• Provided a general overview of Cold Weather Admixture Systems
• Provided the background of CWAS development
• Applied the approach in demonstration projects
• Developed tools and guidance to mix, place, and cure concrete at sub-freezing conditions
• Tailor admixture dosage on forecasted weather conditions
• Additional information is available on our website
• Shown the feasibility of using this approach to extend the concrete season
• *Putting It Into Practice!*
Questions?

Lynette A. Barna
Cold Regions Research & Engineering Laboratory
US Army Engineer Research & Development Center
72 Lyme Road, Hanover, NH
Lynette.A.Barna@usace.army.mil
603-646-4503 (voice)

Ft. Wainwright, AK