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Installation Technology Transition Program

Cold Weather Admixture Systems Demonstration at Fort Wainwright, Alaska

Lynette A. Barna, Peter M. Seman, and Charles J. Korhonen

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Abstract: Cold Weather Admixture Systems (CWAS) is a new approach to cold weather concreting that incorporates suites of commercially available chemical admixtures in concrete mixes. When used in combination, these admixtures depress the freezing point of the concrete mix water, protect the fresh concrete down to an internal temperature of 23°F, and promote early strength gain. In stark contrast to conventional winter concreting operations, no external heat is required in the CWAS approach. As a result, the construction and heating of temporary shelters is not required, as dictated by current practice. Given the significant cost of energy associated with external heating, a real advantage of the CWAS approach is the cost saving potential for cold weather concreting as compared to current practice. In March 2008, a full-scale field test was conducted at Fort Wainwright, Alaska. This field test provided an opportunity to apply the CWAS approach to an infrastructure project on an Army installation. This report describes the placement of a concrete hardstand using the CWAS approach and the monitoring of the structure after construction to estimate the strength gain.

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Preface

This work was funded through the Installation Technology Transition Program (ITTP), and this report is a deliverable product in support of this program. ITTP is administered by the Office of the Assistant Chief of Staff for Installation Management, Washington, DC. Mr. Martin Savoie, U.S. Army Engineer Research and Development Center - Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL, is the ERDC Program Manager.

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The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
gallons (U.S. liquid) of admixture per cubic yard of concrete	4.95113	liters of admixture per cubic meter of concrete
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
ounces (mass)	0.02834952	kilograms
ounces (U.S. fluid)	2.957353 E-05	cubic meters
ounces (U.S. fluid) of admixture per 100 pounds (mass) of cement	65.1984	milliliters of admixture per 100 kilograms of cement
ounces (U.S. fluid) of admixture per cubic yard of concrete	38.6807	milliliters of admixture per cubic meter of concrete
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic yard	0.593278	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

Acronyms

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BASF	Badische Anilin und Soda Fabrik (chemical company)
COTS	Commercial off-the-shelf
CRREL	Cold Regions Research and Engineering Laboratory
CWAS	Cold-Weather Admixture Systems
DOT	Department of Transportation
ERDC	Engineer Research and Development Center
FHWA	Federal Highway Administration
ITTP	Installation Technology Transition Program

1 Introduction

Background

In cold climates, the use of conventional methods to place normal concrete is hindered because of the detrimental effects of low temperatures. Standard practice dictates that the lowest allowable internal temperature for early-age concrete is 40°F (ACI 1988). Should the cross-sectional thickness be 6 in. or less, this low-temperature threshold is set even warmer. The permanent damage that occurs should early-age concrete freeze is due to the 9% volume increase when water changes phase into ice. Current methods for winter concreting are limited and revolve largely around avoidance.

The first concreting option is all out evasion, where all attempts are made to either complete the construction prior to the arrival of colder temperatures or delay the project until warmer temperatures return. The traditional summer construction season is already overcrowded, especially in northern latitudes such as Alaska that experience a short summer season. A second, customary option is to construct and heat a temporary envelope around the project to maintain a favorable curing environment for the concrete. While this has typically been the option implemented, the cost of energy for heating has long been a limitation, keeping this method at a competitive disadvantage compared to warmer times of the year. As energy prices continue to rise, cost continues to be a shortcoming of this method. The last option is to add chemical admixtures into the concrete mix that protects the concrete from freezing.

Cold-Weather Admixture Systems technology

A new approach to cold weather concreting, Cold-Weather Admixture System (CWAS), uses new construction techniques to mix and place concrete at below freezing temperatures. The CWAS approach uses chemical admixtures to depress the freezing point of the water in the mixture, allowing cement hydration down to an internal concrete temperature of 23°F, without the need for external heat, saving both time and money. The concrete also gains appreciable strength at this temperature, even when the ambient air temperature is well below zero. To pave the way for acceptance of CWAS, American Society for Testing and Materials (ASTM) C1622, *Stan-*

dard Specification for Cold-Weather Admixture Systems, was initially approved for use in 2006. This technology has been successfully demonstrated at numerous field sites in northern tier states and is ready for adoption into widespread standard practice.

CWAS was developed during a 3-year study sponsored by the Federal Highway Administration (FHWA) in conjunction with ten State Departments of Transportation (DOTs). Combinations of commercial-off-the-shelf (COTS) admixtures were tested to identify successful formulations that protected concrete against freezing and allowed appreciable strength gain. This approach was tested during four field trials and a final demonstration with the DOT project partners. The study showed that CWAS is a practical and viable approach to winter concreting. The results of this study were published in ERDC/CRREL Technical Report 04-2, *Extending the Season for Concrete Construction and Repair, Phase I – Establishing the Technology* (Korhonen et al. 2004). Standards for using CWAS technology have been adopted by ASTM (C1622) and are under consideration by the American Concrete Institute (ACI).

CWAS has a complete set of tools to design, mix, place, and cure concrete when the weather is below freezing. Rudimentary quality assurance tools have also been developed to verify the thermal safety of the mixes. Chemical admixtures are regularly used to control and enhance concrete mixtures. This approach uses COTS admixtures from major manufacturers within their recommended dosage levels. The admixtures selected for use meet the standard requirements approved for use in concrete mixtures (ASTM C494, *Standard Specifications for Chemical Admixtures for Concrete*). There are no restrictions on the number of admixtures that may be added to a concrete mix, provided the dosages are within the recommended limits. Using commercial products that have successfully met the approval process ensures that the admixtures have been tested at length for use in concrete. Depending on the user’s needs, this approach provides the flexibility to either modify a current concrete mix, or select from one of the eight developed formulations.

Employing the emerging CWAS approach will provide a true all-season capability for military engineers and contractors, reducing the cost penalty associated with cold-weather operation—especially for horizontal construction. This capability extends the construction and maintenance window for mission-essential facilities later into the fall months, resulting in reduced conflicts between work scheduling and high-tempo military operations or essential training activities. If the minimum concrete temperature was lowered to 23°F, instead of the current limit of 40°F, it is estimated that an additional 3 to 4 months could be added to the construction season within the continental United States (Figure 1). The benefits of this work will impact military construction and maintenance at all Department of Defense installations worldwide that experience temperatures below 40°F with particular advantages in the most severe climates that have the shortest construction seasons and highest facility costs.

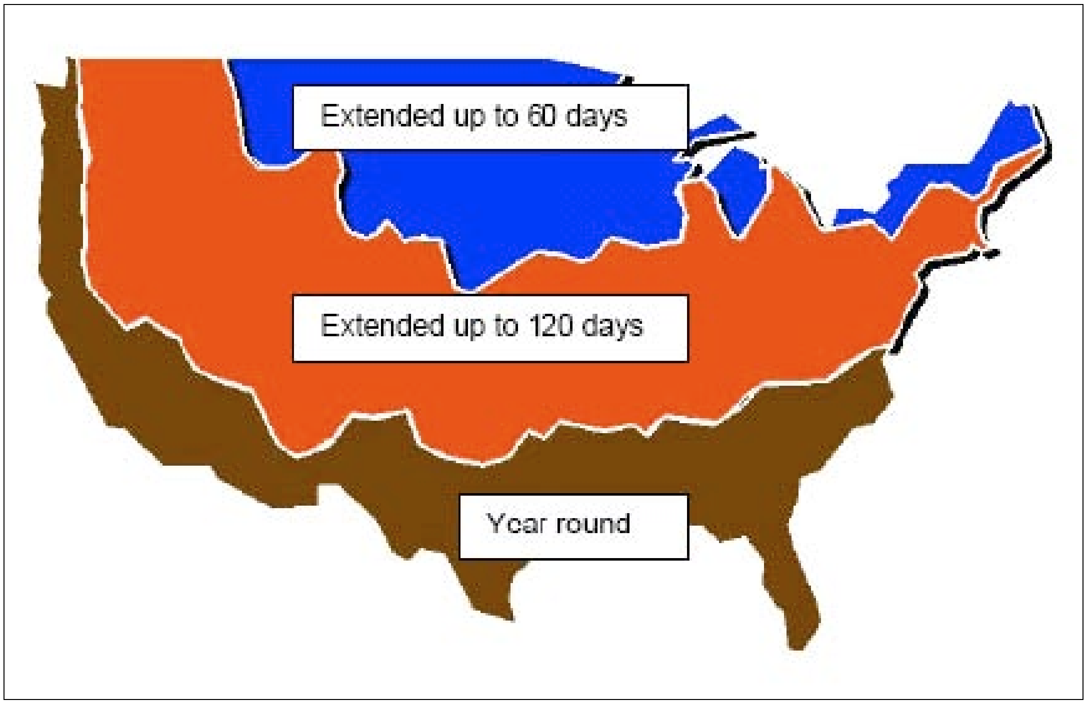

Figure 1. Estimated extension of concrete construction season if temperature limit is lowered to 23°F.

Project objective

This study provided an opportunity to demonstrate the CWAS technology during a full-scale field trial at a time when placing conventional concrete would require protection. As with other CWAS mixes investigated, the mixes used in this field trial had to:

- be capable of meeting performance requirements including acceptable workability and finishability;
- use standard construction equipment and quality control methods;
- provide freeze protection as low as 23°F;

- develop early-age strength at or better than normal concrete; and
- meet acceptable air entrainment requirements.

Project scope

The scope of the project was to construct a concrete communications hardstand to accommodate military vehicles. While the hardstand was designed using standard criteria and called for a 28-day compressive strength of 4,000 psi, the project purposely excluded the use of tenting and heating as a method for protecting the fresh concrete as it cured. The base concrete mixture was considered typical for cold weather application in the local area and used a Type I/II portland cement. Using the CWAS approach, a freeze protection admixture 'suite' was produced by combining the commercially available chemical admixtures which were then added to the base concrete mixture. Multiple mixes were used to complete the hardstand, providing the opportunity to investigate the effects of varying admixture dosage levels in each mix.

2 Field Demonstration

Antifreeze concrete has been successfully used in a minimum of 12 large-scale field trials and is a proven technology for cold weather concreting (Korhonen and Jeknavorian 2005; Korhonen and Seman 2005; USAF 2005). The full-scale field trial at Fort Wainwright, AK was conducted during a 2-day period (26 and 27 March 2008). The purpose of the field trial at Fort Wainwright was to demonstrate to the Fort Wainwright Department of Public Works (DPW) the practicality of using the antifreeze concrete technology for adoption into standard practice This hands-on approach interacts directly with the user community (i.e., local area contractors, concrete suppliers, and testing laboratories). The site was prepared the week before the field demonstration by the contractors. Sensors were installed by ERDC-CRREL in the test sections to record the concrete temperature. A local concrete supply company batched and transported the antifreeze concrete mixtures to the site. During the placement of the concrete, standard quality control and quality assurance (strength) testing was conducted by a local concrete testing laboratory. The 2 days set aside to place concrete proceeded as planned.

In addition to providing an opportunity to demonstrate the antifreeze concrete technology to DPW, the field trial also allowed the chance to vary the chemical admixture dosage rates used in the antifreeze mixtures. Currently, antifreeze concrete mixtures are of a "one-size-fits-all" design providing freeze protection down to an internal concrete temperature of 23°F, which may be more than is needed for a particular job (Korhonen et al. 2004). The ability to tailor the admixture dosage rates specifically to the job site characteristics and forecasted weather conditions would achieve lower levels of freeze protection, reduce the quantity of admixtures needed, and further economize antifreeze concrete mixtures.

Test area layout

The designated test area was selected as the location of a mobile combat tactical operations hardstand for military vehicle use. Construction of the slab was the initial phase. Communications conduits were to be installed at a later time. The overall dimensions of the hardstand were 75 ft x 25 ft, partitioned into five separate sections of 15 ft x 25 ft (Figure 2). The slab thickness was 6 in., and each section required roughly 10 cubic yards (yd^3)

of concrete. The five individual test sections made it possible to field test five antifreeze concrete mixtures dosed at varying levels to further understand the effects of lower admixture dosage while still providing freeze protection.

Site preparation

The site was prepared by the contractors in accordance with construction specifications by the Army Corps of Engineers and ACI guidance. The week prior to concrete placement, the site was prepared by removing accumulated snow and excavating the still frozen upper 18 in. of unsuitable soil. The surface of the in-situ soil was graded and compacted in preparation for the overlying base layer. The base layer consisted of a non-frost susceptible, well-draining fill material. It was placed in 8-in. lifts and compacted to a 95% of maximum dry density of 145 lb/ft^3. A heated tent set up over the test area to heat the base material ensured the specified density was obtained (Figure 3). Nuclear density testing was performed to confirm the specified compaction requirement. While a heated enclosure was used for this project due to the frost-susceptible nature of the in-situ soil, it is conceivable that both the need and cost for the temporary structure is avoidable if the site is prepared prior to the onset of cold temperatures (for example, during autumn).

Once the base layer was installed, the tent structure was dismantled. Antifreeze concrete mixtures may be placed on frozen, ice-free substrates, so the base material was left exposed to the cold temperatures. The formwork for the hardstand was constructed and standard, reinforcing steel installed in the first test sections scheduled for completion on 26 March, Test Sections 1, 3, and 5 (Figure 4). After the concrete was placed and cured sufficiently overnight in Test Sections 1, 3, and 5, the remaining two test sections (Test Sections 2 and 4) were readied for concrete. The interior formwork was removed, and the rebar was installed in Test Sections 2 and 4 on 27 March. During the concrete placement of each test section, standard quality control and quality assurance (strength) procedures (mixture temperature, slump, air content, and casting compressive strength cylinders) were followed. Quality control and assurance testing was conducted by a local concrete testing laboratory.

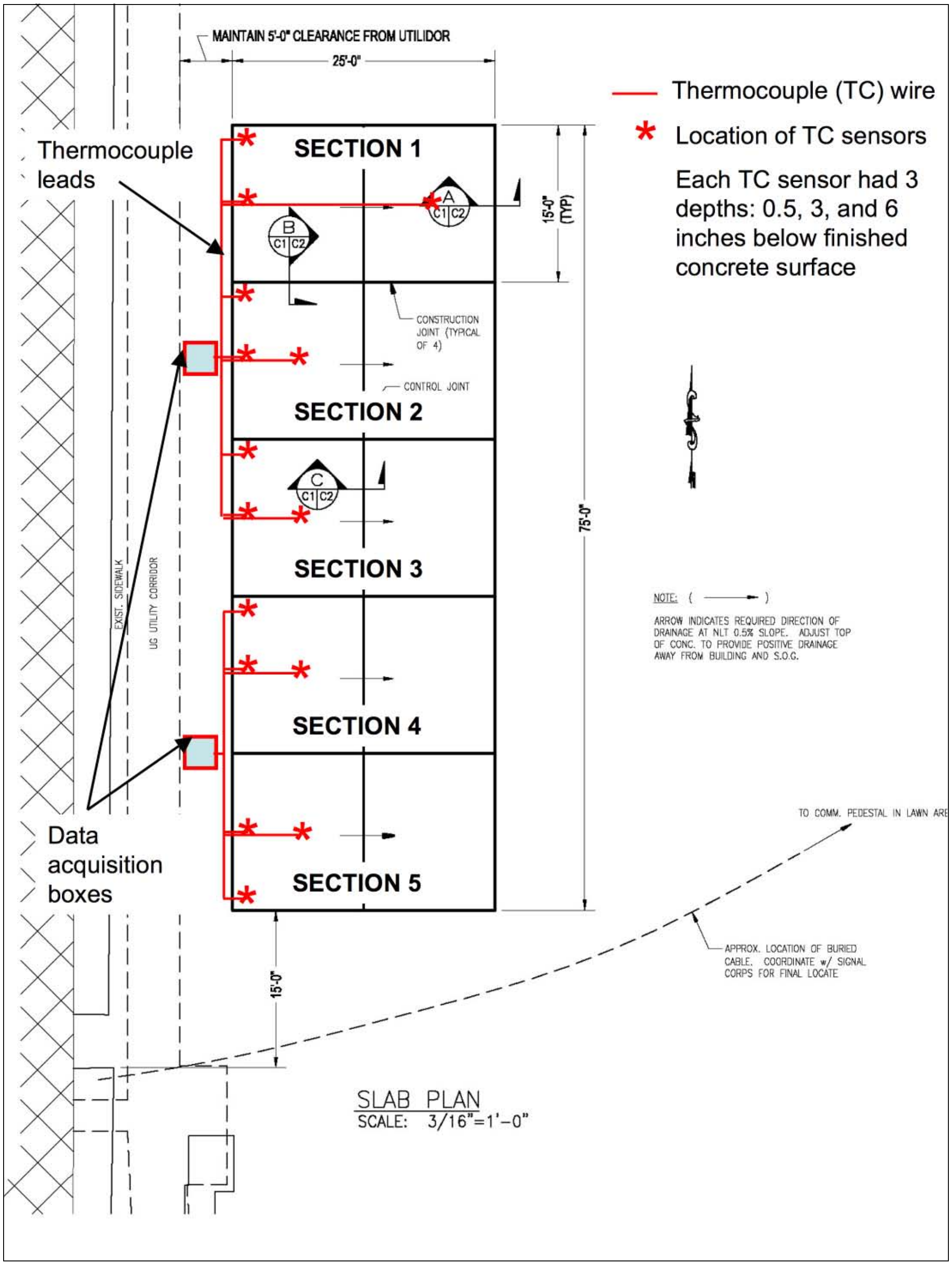

Figure 2. Test area layout.

Figure 3. Preparation of the base material prior to compaction testing.

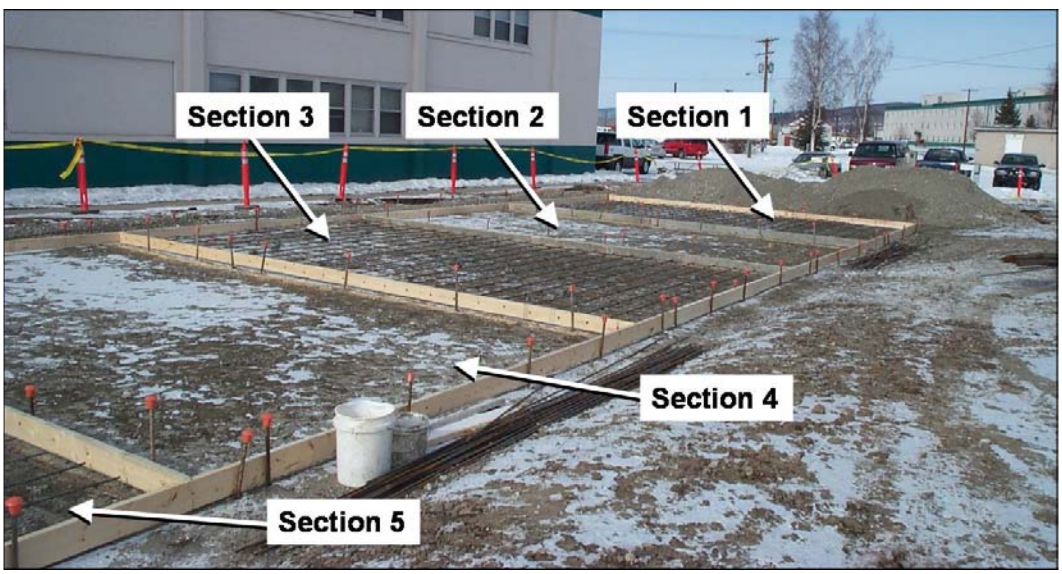

Figure 4. View of test area prior to concrete placement.

Instrumentation

All five test sections were instrumented prior to placing the concrete so the internal concrete temperature could be monitored during the curing period. Temperatures were monitored for a total of 29 days beginning from the time the concrete was placed. Ambient air temperature at the site was also recorded. The temperature sensors consisted of Type T (copper-constantan) thermocouples connected to a data acquisition system consisting of Campbell Scientific CR10X dataloggers to record the measurements.

Each test section was instrumented at three locations in the slab and at three depths: the center, an edge, and a corner (Figure 2). A total of nine readings were collected for each test section. Additional temperature sensors were installed in the base and subgrade layers in Test Section 1. The temperatures at the center of the slab were expected to be warmer, due to their location at the center of mass. The critical locations were the edge and the corner, as they were more exposed. These sensor locations provided a range of temperatures to characterize the curing conditions in the slab in areas progressively more exposed to the outside environment.

Within the 6-in.-thick slab, sensors were mounted at 0.5, 3, and 6 in. below the finished surface to represent the top, middle, and bottom levels, respectively (Figure 5). The thermocouple sensors were mounted to a plastic dowel rod at the selected depth. The dowel rod was affixed to the rebar using plastic wire ties. The thermocouple wires were run over the surface of the base course material and connected to the dataloggers located outside the test area in weather-resistant enclosures (Figure 2).

Figure 5. Typical mounting of thermocouple sensors in the formwork.

At the center location in Test Section 1, three additional temperature sensors were installed in the base course and subgrade below the slab. The sensors were used to monitor the influence of the curing concrete on ground temperatures. An auger was used to make a hole in the prepared substrate into which was placed a dowel rod with thermocouples affixed to it. The sensors were located at 9 and 17 in. below the finished surface of the concrete to measure temperatures in the base layer, and at 21-in. deep to monitor the subgrade.

Concrete mixture

The concrete specifications called for a 28-day compressive strength of 4,000 psi, with 5 to 7% entrained air. Chemical admixtures from BASF were used to formulate the antifreeze mixtures. Table 1 lists the admixtures in this study, along with the dosage rates. All of the chemical admixtures were dosed within the maximum allowable manufacturer recommended levels. The base concrete mixture used 658 lb of Type I/II cement per cubic yard.

The types of admixtures used in antifreeze concrete are commercially available and either approved for use under ASTM C494 or accepted for use in the industry. Glenium® 3000 NS is a high-range water reducer (BASF 2007a). This type of admixture aids in reducing the amount of water needed while maintaining the workability of the mixture. In antifreeze concrete mixtures, high-range water reducers contribute to freezing-point depression. The dosage rate of Glenium® 3000 NS is based on the cement content (on a per hundred weight basis). The manufacturer's recommended dosage rate range for Glenium® 3000 NS is 4–12 fluid ounces per hundred weight of cement (fl oz/cwt).

Pozzutec® 20+ is a non-chloride based accelerating admixture, suitable for use at low temperatures (BASF 2008). Accelerating admixtures are used to speed the set time and promote early-age strength gain. The dosage rate of Pozzutec® 20+ is based on the cement content (on a per hundred weight basis). The manufacturer's recommended dosage rate range for Pozzutec® 20+ is 60-90 fl oz/cwt.

Rheocrete® CNI is a corrosion inhibiting admixture (BASF 2007b). While corrosion inhibitors are used to protect embedded steel members, they also contribute to freezing-point depression in antifreeze mixtures. The dosage rate of Rheocrete® CNI is based on the volumetric size of the mixture, per cubic yard. The manufacturer's recommended maximum dosage rate for Rheocrete® CNI is 6 gal/yd^3.

Mixture 5 was the only one that used Rheomac® VMA, an admixture that enhances concrete viscosity and provides stability against segregation (BASF 2007c). This admixture had not previously been used in antifreeze concrete formulations. Table 1 lists the components in each of the five mixtures used to construct the hardstand.

Table 1. Concrete mix proportions used in the demonstration.

	Trial	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Date Batched	25 March	26 March	26 March	26 March	27 March	27 March
Placement Location	N/A	Section 1	Section 3	Section 5	Section 2	Section 4
Cement (lb/yd^3)	655	658	659	660	658	656
¾ in. aggregate, ssd† (lb/yd^3)	1,777	1,762	1,776	1,766	1,762	1,758
Sand, ssd (lb/yd^3)	1,383	1,350	1,383	1,352	1,365	1,375
Batch water‡ (gal/yd^3)	23.5	19.0	20.1	24.0	20.4	24.5
Glenium® 3000NS (fl oz/cwt)	6.0	8.0	7.0	4.9	6.0	--
Rheomac® VMA (fl oz/cwt)	--	--	--	--	--	4.0
Pozzutec® 20+ (fl oz/cwt)	34.2	68.0	45.0	22.0	34.0	34.1
Rheocrete® CNI (gal/yd^3)	2.3	4.0	3.0	1.5	2.3	2.3
Extra water added at batch plant (gal/yd^3)	--	3.8	5.0	3.0	5.9	8.7
Water added at job site (gal/yd^3)	--	1.6	1.2	0.4	--	--
Final w/c* ratio	0.34	0.39	0.39	0.38	0.38	0.47
% total solids	7.3	11.8	8.3	4.4	6.6	5.3

† saturated surface dry. Describes the condition of water-soaked aggregate where excess water that has not been absorbed into the aggregate pore structure is removed from the surface

‡ includes free water contribution from aggregate and sand but not admixtures

* water-cement ratio. The desired w/c ratio for typical concrete exposed to freezing and thawing should be 0.45, but not greater than 0.50 (Korhonen et al. 2004). In antifreeze concrete mixtures, the target w/c ratio should be 0.45 or less (USAF 2005).

3 Results

Quality control testing

Standard testing procedures

Properties of the fresh concrete were measured onsite from a sample taken from the truck during the placement of each slab. The temperature of the concrete delivered to the site was measured according to ASTM C1064, slump according to ASTM C143, and the volumetric air content with the pressure air method according to ASTM C231. Table 2 shows results for each section. Target values are included for each of these properties. Target air content range was specified by the owner. Slump range was based on the ready-mix producer's concrete design. Target range for initial mixture temperature is based on past experience with these mixes. A lower mixture temperature retains workability over time and is more important as the admixture dose increases.

For each mixture, 6 x 12 in. test cylinders were cast for compressive strength testing according to ASTM C31. A total of 23 strength cylinders were cast for each concrete mix, except for Section 1, which had 22. Twelve cylinders from each concrete mix were transported to an indoor laboratory and cured at standard room temperature. The remaining cylinders were cured in an unheated insulated box onsite to represent the field conditions (Figure 6). The compressive strengths from both curing conditions are used to develop a strength-maturity relationship used with the temperature data, to estimate the in-place strength gain. All cylinders remained in their molds until the time of testing. The laboratory-cured cylinders were tested in groups of three at 1, 2, 3, and 28 days after placement. The field-cured cylinders were tested in groups of three at 2, 3, and 7 days after

Table 2. Measurements of fresh concrete properties.

Mix	Placement Location	Temperature (˚F)	Slump (in.)	Air Content (% vol.)
Mix 1	Section 1	60	9	5.8
Mix 2	Section 3	66	6	5.4
Mix 3	Section 5	50	9	5.7
Mix 4	Section 2	53	8.5	5.2
Mix 5	Section 4	52	9	5.5
N/A	Target Value	40 to 50	5 to 8	5 to 7 ± 1

Figure 6. Field-cured cylinders kept onsite in insulated box.

placement, with the remaining two cylinders (only one in the case of Section 1) tested 28 days after placement.

Figures 7 and 8 show unconfined compressive strength testing results for all five mixtures. All compressive strength data are presented in full detail in Appendix A. Strengths for test cylinders cured at standard room temperature are given in Figure 7. Curing at room temperature, all of the mixtures attained the target strength of 4,000 psi after 2 days, with the exception of Mixture 5 (Test Section 4), which required a total of 11 days. No peculiarities were noted during the strength testing. It is unclear what caused the additional time needed for strength gain. After curing for 28 days, the strength of Mixtures 1–4 exceeded 7,000 psi, while the 28-day strength of Mixture 5 neared 5,500 psi.

Figure 8 shows strengths for field-cured cylinders. All of the mixtures, including Mixture 5, attained 4,000 psi within 5 days of curing. However, little strength gain occurred beyond the 7-day test age, and it reached roughly 5,500 psi at 28 days. Mixtures 1–4 continued to gain strength and reached comparable strengths after curing for 28 days under field conditions (7,000 psi) as the set that cured at room temperature.

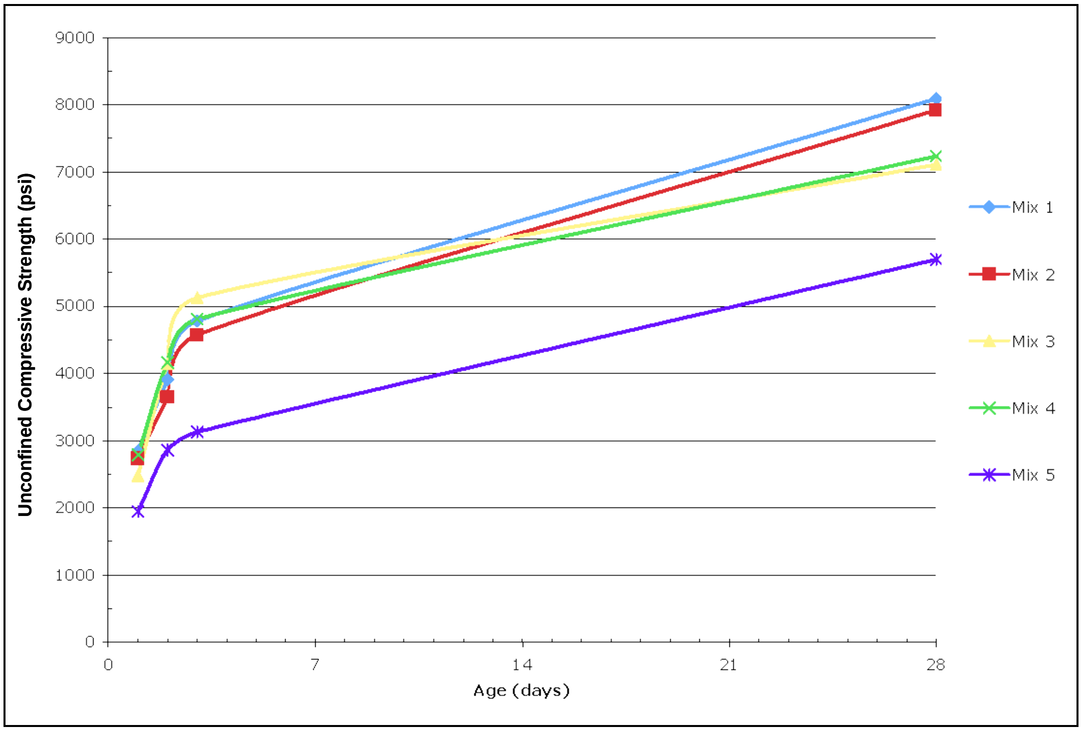

Figure 7. Comparison of compressive strength gain for room-temperature-cured cylinders for all five mixes.

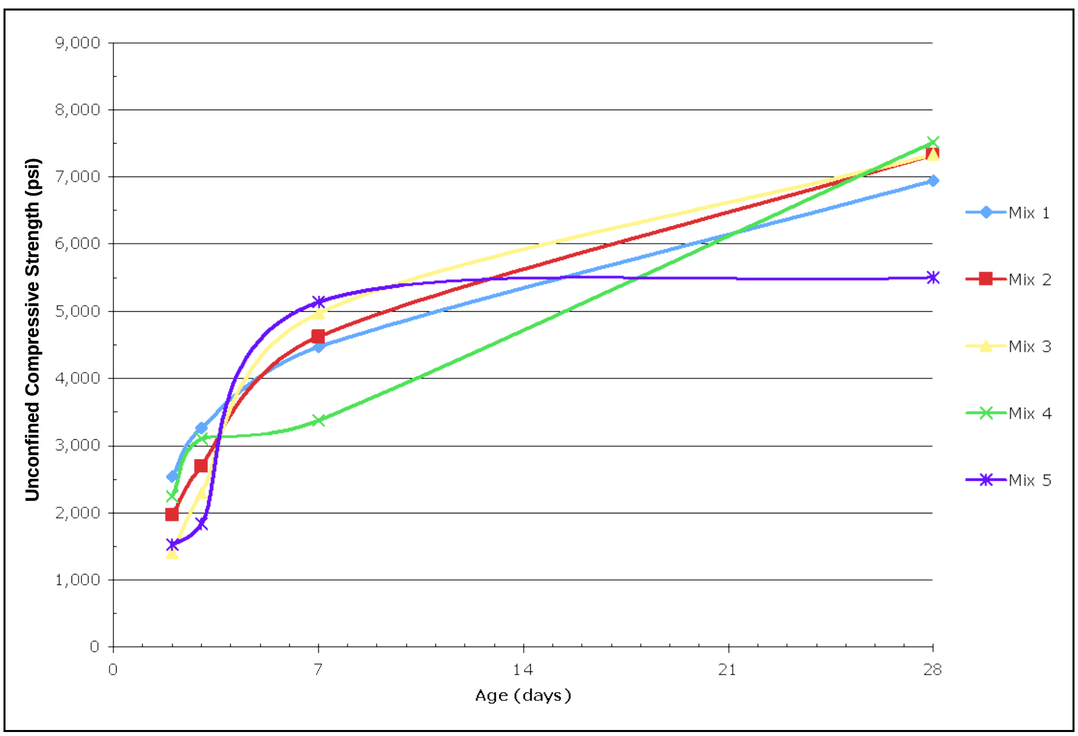

Figure 8. Comparison of compressive strength gain for field-cured cylinders for all five mixes.

Freezing-point measurements

In addition to the standard quality control tests conducted at the job site, the initial freezing point of the fresh concrete was measured by ERDC-CRREL. Previous field work demonstrated the importance of measuring the initial freezing point to verify that the mix arriving on site meets the temperature protection limit specified in the design. The freezing-point measurement has also been shown to be a valuable method of determining the water-cement ratio in the actual mix. Korhonen et al. (2004) provides additional background on the development of the initial freezing point.

For each of the five mixes used to construct the hardstand, small samples were collected concurrent with the other quality control testing (slump, air content, etc.). The initial freezing-point field setup consisted of a portable cold chamber (standard chest cooler), dry ice, small sample cylinders, temperature sensors, and a data collection system connected to a laptop computer (Figure 9). The purpose of the portable cold chamber was to have a very cold environment to expediently freeze the concrete samples. A thin layer of dry ice was placed on the bottom of the cooler. Fresh concrete was spooned into three small (2 in. x 4 in.) cylinders, embedded with a temperature sensor, and placed in the portable cold chamber to freeze (Figure 10). The temperature sensors consisted of type T (copper and constantan) thermocouples wired to a datalogger. Temperature measurements were collected at 1-sec intervals and monitored real-time with the laptop computer.

The temperature readings from each sample produced a freezing-point curve. Figure 11 shows a representative freezing-point curve for each mixture. The initial freezing-point values summarized in Table 3 for each mixture were averaged from the three samples. Mixes 3 through 5 clearly show a characteristic cooling curve as heat from the sample is removed. The bump, or slight temperature increase in the curve, is due to the remaining latent heat released as the phase changed from liquid water into ice. This is the initial freezing-point temperature.

A linear relationship exists between the concentration of dissolved solids from the chemical admixtures in the concrete mix water (percent solids), and the resulting initial freezing point (Korhonen et al. 2004). The initial freezing-point temperature becomes warmer as the concentration of chemical admixtures decreases. The percent solids, based on water weight, was calculated for Mixtures 1 through 4 and plotted against the initial freezing-point temperature (Figure 12). These mixtures are comparable since they used the same suite of admixtures, and only the admixture dosages were changed. Mixture 5, used in Test Section 4, is not included as it used a different admixture, the Rheomac® VMA.

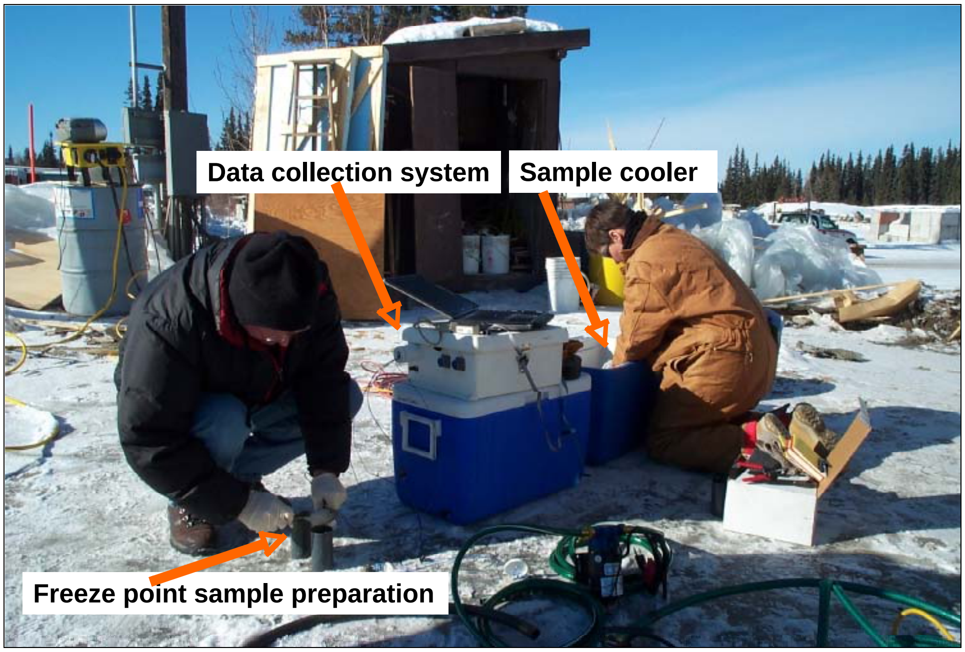

Figure 9. Initial freezing point field setup (photo by C. Haenel).


Figure 10. An example of the freeze-point field setup showing samples of fresh concrete with embedded temperature sensors freezing in the portable cold chamber.

Table 3. Summary of initial freezing-point measurements collected in the field.

Initial Freezing Point (°F)					
Mix Design	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Placement Location	Section 1	Section 3	Section 5	Section 2	Section 4
Sample 1	25.2	29.7	30.3	28.9	29.8
Sample 2	25.4	30.0	30.7	29.4	30.4
Sample 3	25.5	*	30.5	29.3	30.4
Average	25.4	29.8	30.5	29.2	30.2

* 30.5°F measured but the cooling curve was uncharacteristic. This reading was dropped to determine the average.

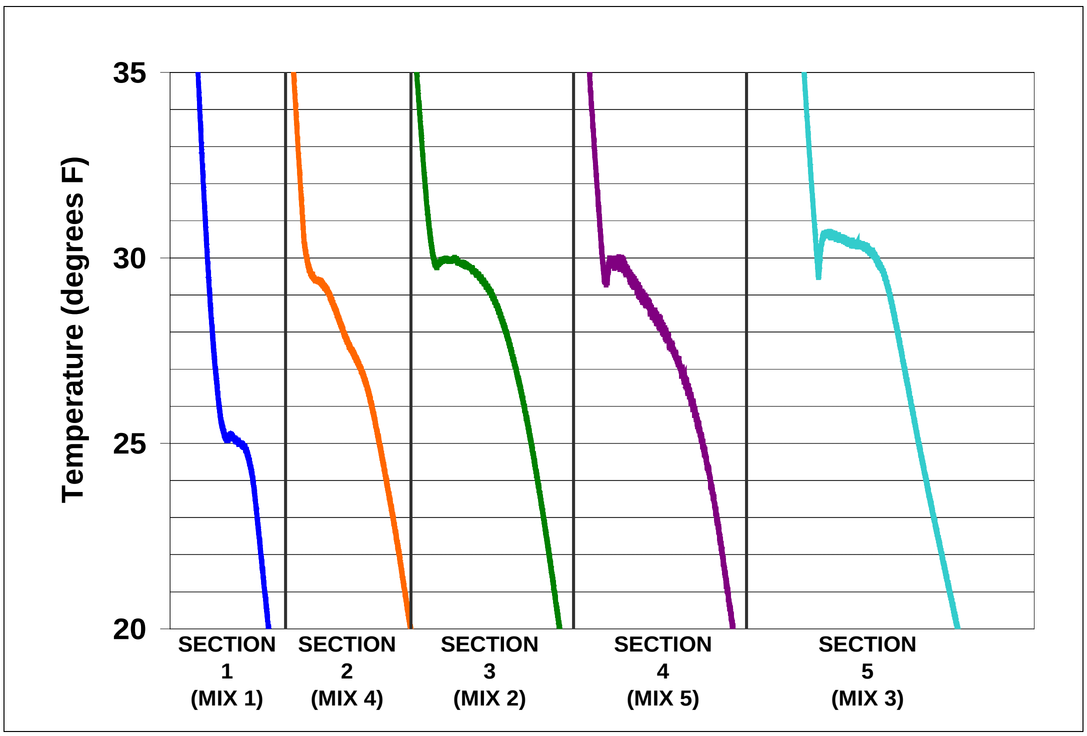

Figure 11. Initial freeze-point curves from each of the five concrete mixes.

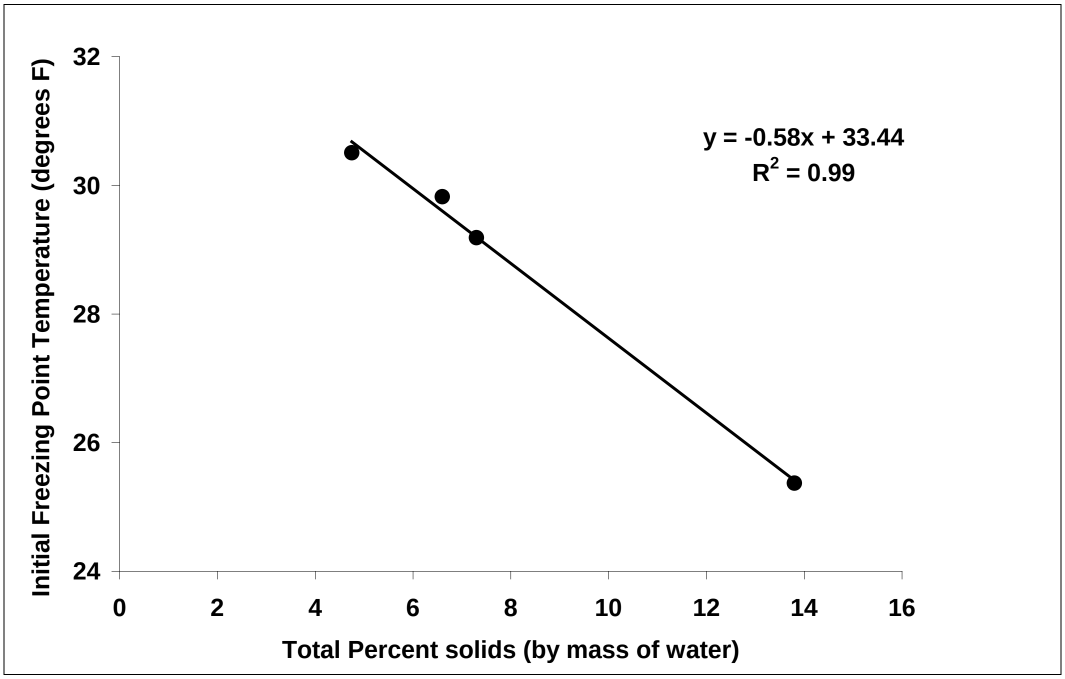

Figure 12. Relationship between freezing-point temperature and percentage of solids.

Strength development

Temperature readings

Recording the temperatures in the structure serves two purposes. Knowledge of the time-temperature history of the curing concrete allows an estimate of the strength development using the maturity method, as explained in the following section. Temperature measurements can also be used to monitor whether any locations approach the freezing point of the concrete mix at an early age. If this were to happen, alternate protective measures (e.g., insulation) could be taken to prevent freezing and strength loss.

Ambient temperatures and conditions prior to, during, and after the placement of the concrete have a strong influence on the internal concrete temperatures. The ambient temperatures from the time the concrete was placed through the first 7 days of the demonstration are included in Figures 13 and 14. During the concrete placements on 26 and 27 March, the air temperatures were between 32 to 23°F, sky conditions were clear to partly cloudy, and there was a very light breeze of 2 to 3 mph. After the test sections were placed, the ambient air temperature overnight lows reached 5°F with daily highs around 32°F until 29 March when a warming trend began. By the end of 7 days, daytime highs topped 60°F with overnight lows around freezing.

Figures 13 and 14 show the concrete temperatures for Mixtures 1 and 3 placed in Test Sections 1 and 5, respectively. Mixture 1 had the highest dose of admixture chemicals in this demonstration, while Mixture 3 had the lowest dose. Mixture 1 was warmer than Mixture 3 when delivered to the site. This was likely due to differences in water and material temperatures used in the batching process, or maybe due to the higher admixture dosage in Mixture 1 generating more early heat in the concrete.

For both Test Sections 1 and 5, the location with the highest temperature reading was at the upper surface in the center of the slab. The coldest location in Test Section 1 was at an exposed corner in contact with the ground. In Test Section 5, the coldest location was at an exposed edge also in contact with the ground. This difference in temperature readings may be due to the placement of the temperature sensor in Section 5 deeper into the base course layer. The ground temperature was approximately 32°F, and it may have had a greater influence in cooling the concrete than the air. The coldest temperatures in the sections occurred where the slab was in contact with the cold ground, while the top surface of the concrete remained relatively warmer. Using the temperature readings, along with the compressive strength test results, the in-situ strength of the slab was estimated using the maturity method.

Temperature readings for the dummy cylinders fabricated for Test Sections 1 and 3 are shown in Figure 15 and Figure 16, respectively.

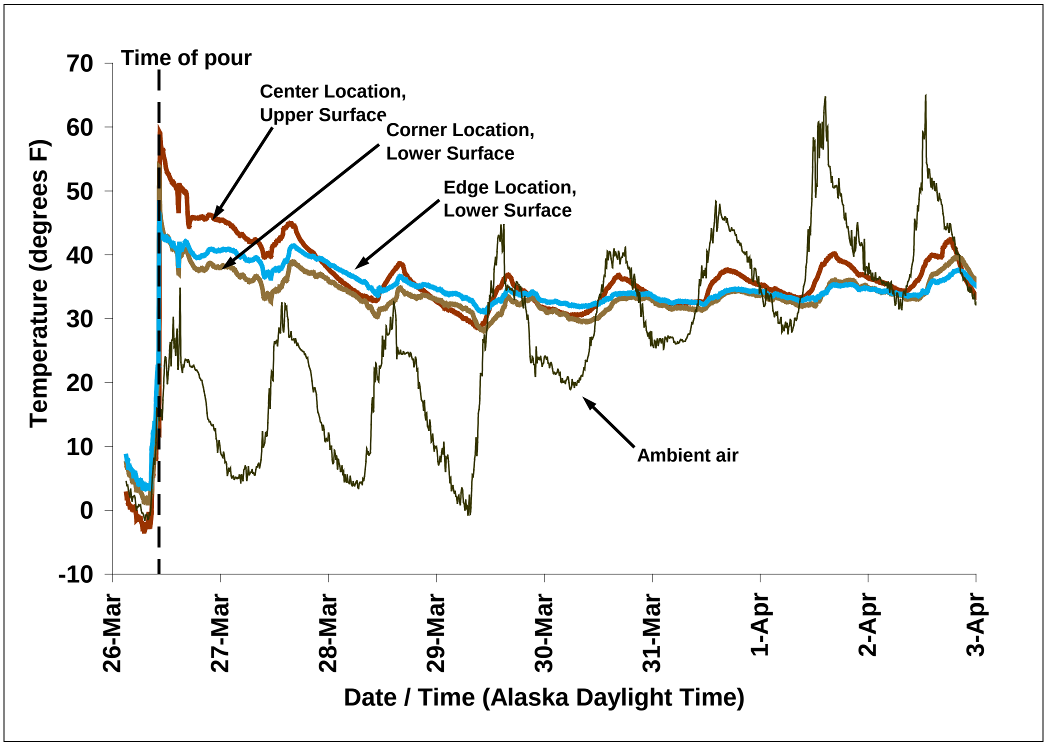

Figure 13. Temperature history of Mixture 1 in Section 1 at the warmest, coldest, and mid-range locations in the structure.

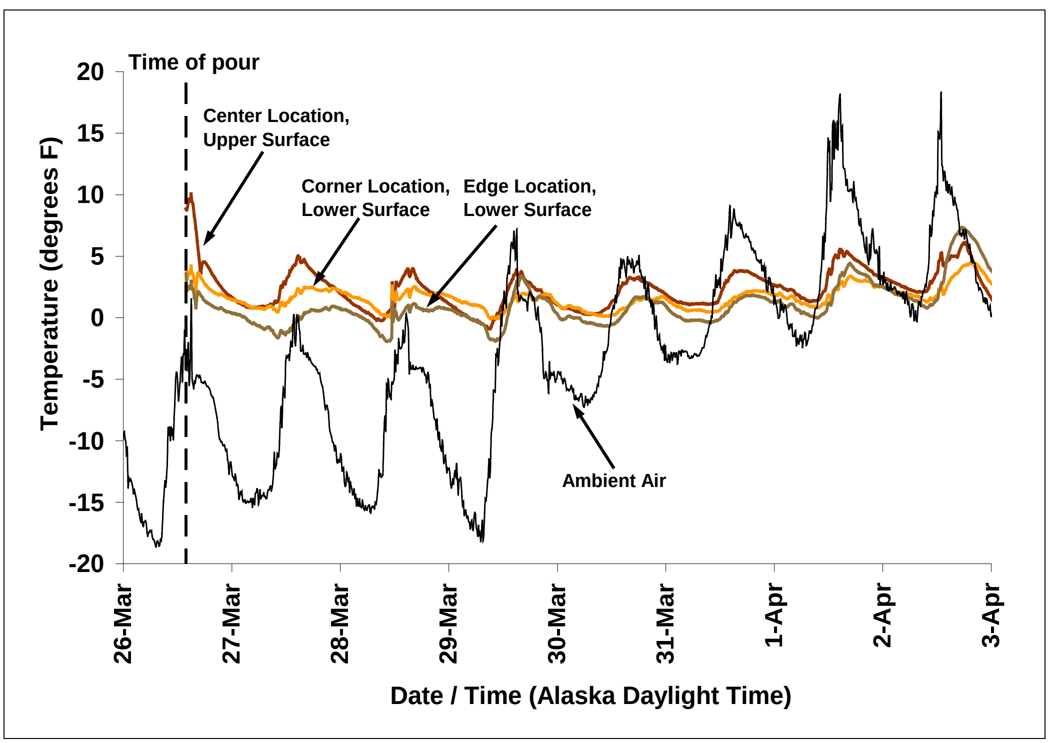

Figure 14. Temperature history of Mixture 3 in Section 5 at the warmest, coldest, and mid-range locations in the structure.

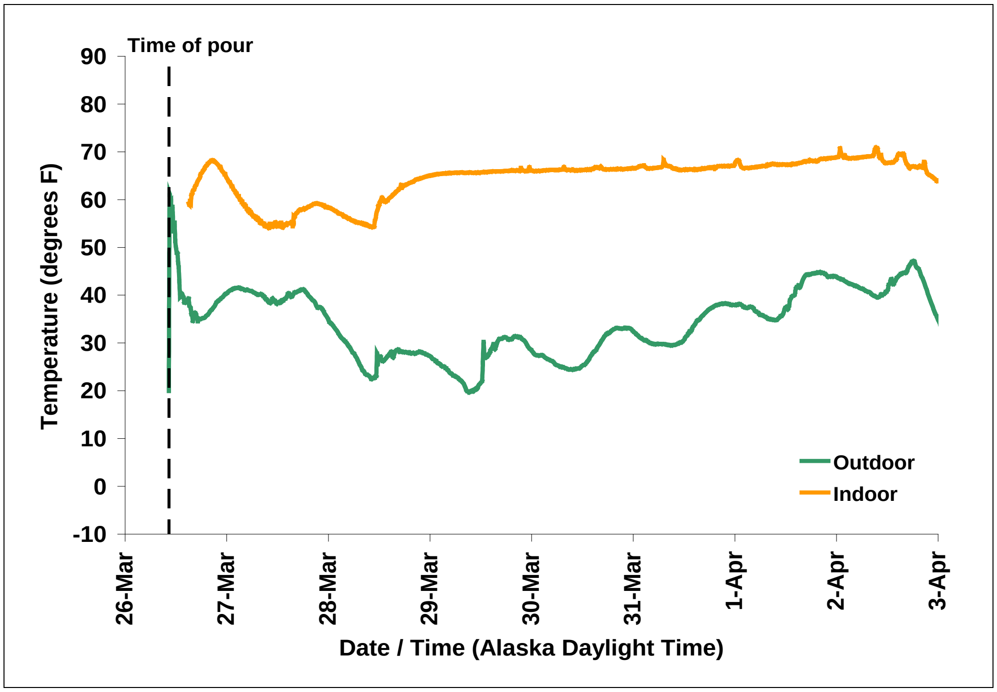

Figure 15. Temperature history of the dummy cylinders for Mixture 1 in Test Section 1.

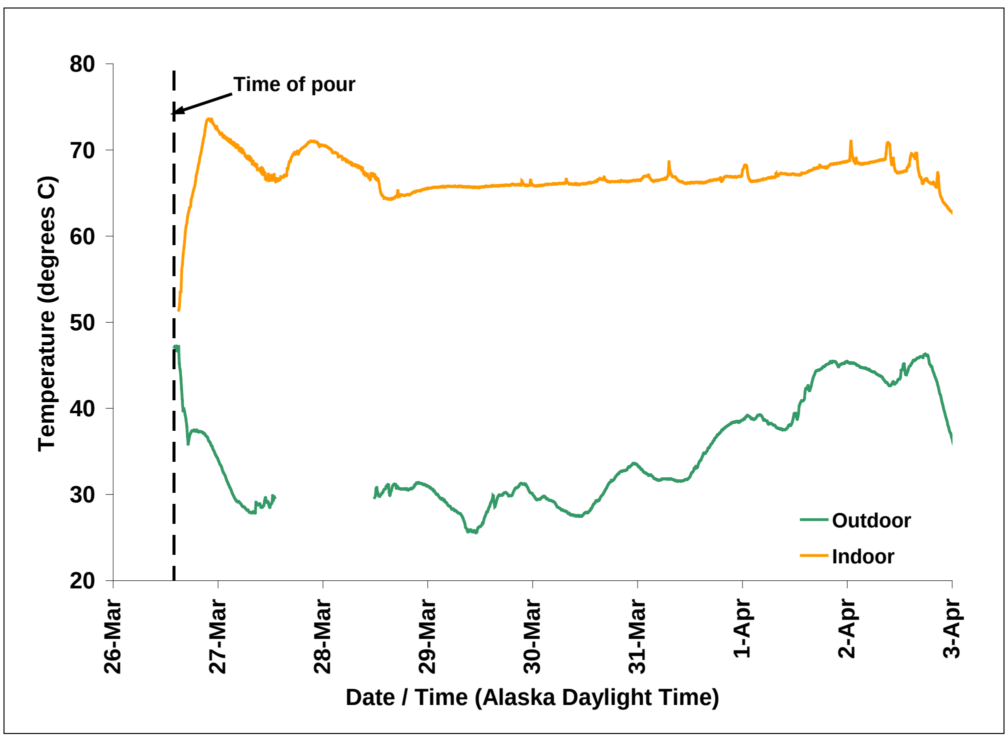

Figure 16. Temperature history of the dummy cylinder for Mixture 3 in Test Section 5.

Maturity method

The maturity method was used to estimate strength development in the sections by establishing a relationship between compressive strength and the time-temperature history of the concrete. For each set of compressive strength cylinder samples cast during the placement operation, an additional companion "dummy" cylinder was instrumented with a thermocouple. This cylinder was used to record a representative temperature history of the samples as they cured and was not tested for strength. A relationship between strength and maturity was developed using the temperature-time factor method (ASTM C1074) with 19.4°F as the datum temperature. In previous work, this approach was found to work well for concretes with a freezing point down to 23°F (Korhonen et al. 2004). The maturity curves for the five mixes are presented in Figure 17.

The maturity curves to estimate the strength gain for each mixture are easily developed using the temperature history data in the slab along with the compressive strength data. In general, locations to monitor in structures should be chosen to meet several objectives. Ideally, the range of temperatures measured should span from the warmest to the coldest points in the structure. Critical locations, such as those that are more exposed (corners

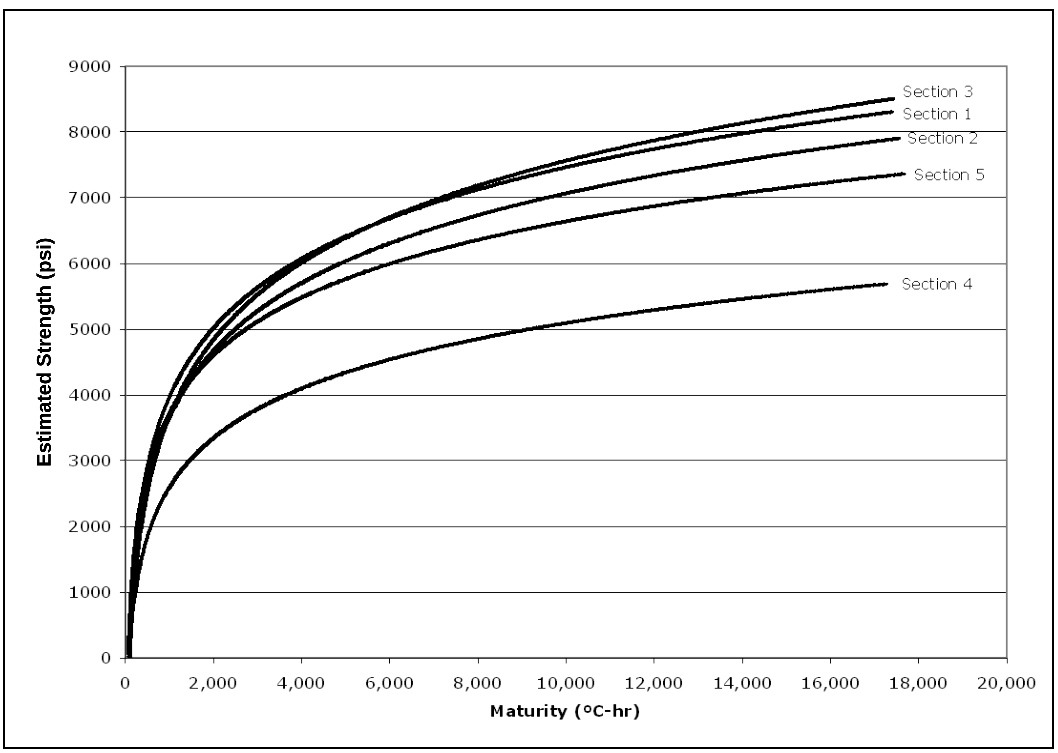

Figure 17. Comparison of maturity curves developed for the five concrete test mixes.

and edges), are areas of great interest for strength monitoring. The bottom of the slab is important to monitor the strength gain, as this will impact the flexural strength.

In Figure 17, the estimated strength gain in Test Sections 1-3 and 5 (mixtures 1-4) are similar. Test Section 4 (Mixture 5) was slower. The lower strength gain was also observed in the laboratory compressive strength cylinders. This mixture used the Rheomac® VMA in the place of the Glenium® 3000 NS. The difference in the performance may be attributed to the different chemical admixture.

Figures 18 and 19 show the estimated compressive strength development in Sections 1 and 5 using the maturity method. Mixture 1 achieved the 4,000 psi strength target within 4–5 days, depending on location in the slab. Mixture 3, with a lower admixture dosage, took an additional 2 days to reach target strength.

The temperature histories for Mixtures 1 and 3 (Figure 13 and Figure 14, respectively) show decreasing temperatures not long following placement. The temperature at the coldest location, the lower surface corner, of Mixture 1 in Test Section 1 neared 32°F at 1120 hr on 27 March (approximately 24 hr after placement). Using the maturity method, the estimated in-situ strength was 2,441 psi. Early-age concrete that reaches a strength of 500 psi is capable of resisting 1 freeze-thaw cycle (ACI 1988). A higher strength gain allows concrete to resist multiple freeze-thaw cycles. The estimated strength of Mixture 1 in Test Section 1 illustrates that the concrete has developed sufficient strength to resist multiple freeze-thaw cycles.

Even with a reduced admixture dosage, Mixture 3 in Test Section 5 neared 32°F at 0350 hours on 27 March. The estimated in-situ strength at the coldest location (lower surface edge) was 948 psi — capable of withstanding at least one freeze-thaw cycle. The temperature continued to decrease, reaching 29.1°F at 1000 hours later the morning of 27 March. The average initial freezing-point reading of Mixture 3 was 30.2°F. Although the temperature at this location dipped below the freezing-point temperature, this is not a concern. As the hydration process uses up available water, this increases the concentration of admixtures in the remaining water, resulting in an increasingly lower freezing-point temperature. Therefore, the freeze protection limit is a lower temperature, especially when the concrete has gained some early-age strength.

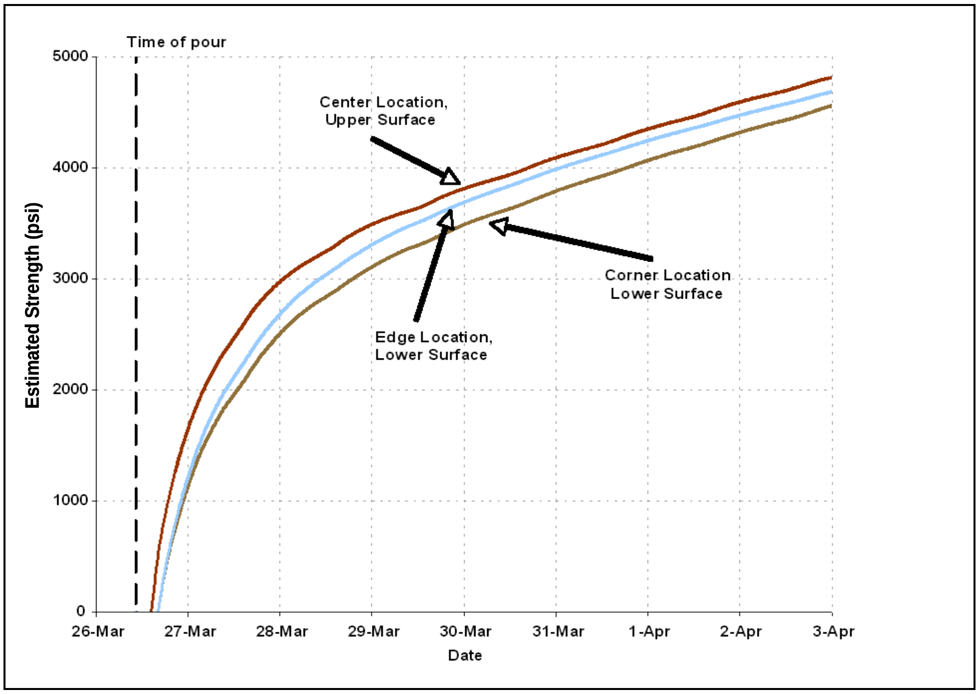

Figure 18. Estimated compressive strength development for Mixture 1 in Section 1 at upper center, lower edge, and lower corner locations in structure.

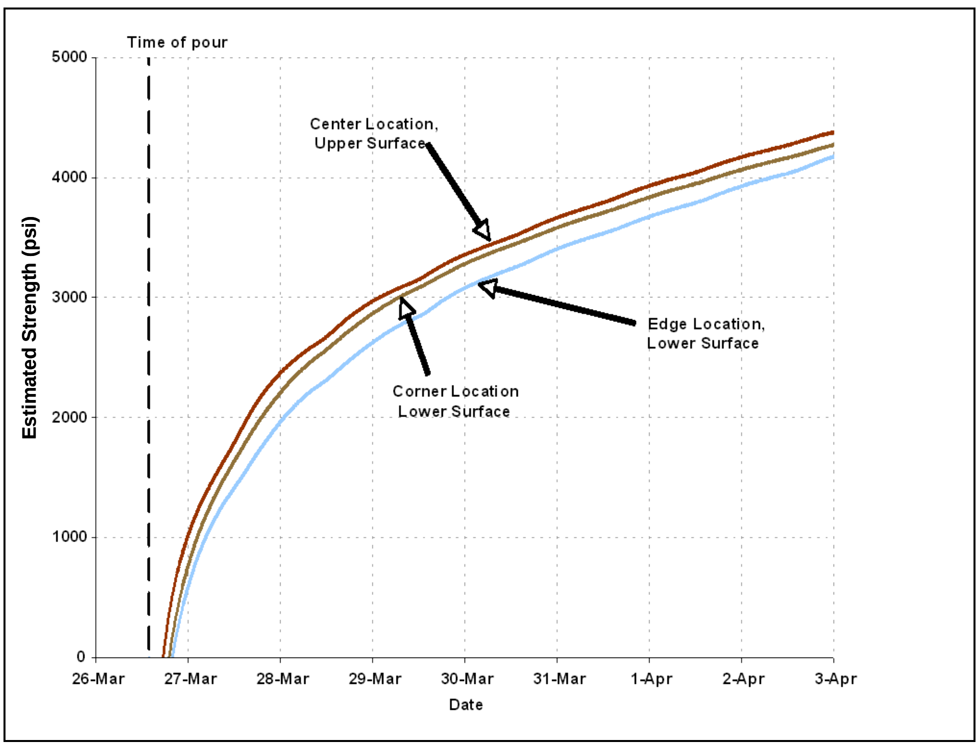

Figure 19. Estimated compressive strength development for Mixture 3 in Section 5 at upper center, lower edge, and lower corner locations in structure.

4 Conclusions

A full-scale field demonstration was conducted at Fort Wainwright, Alaska, using the CWAS approach to construct a rigid hardstand. The concrete placement occurred during early spring from 26–27 March 2008, typically a time when thermal protection (external tenting and heating of the structure) would be required under conventional concrete practices. Using the CWAS approach of incorporating suites of chemical admixtures eliminated the need for additional protection. This demonstration project showed the utility of adding chemical admixtures to the concrete to allow placement of the concrete at low temperatures, provide protection to resist freezing, and promote early strength gain.

The test area consisted of five test sections. A separate mix was used to complete each section. The same base mix was used in the concrete formulations. However, the admixture dosages were varied to investigate the characteristics of the mix. Each of the mixes placed in the hardstand met the specified design criteria and gained acceptable strength, even when the air temperature was at or below freezing. This demonstration also illustrated that the CWAS approach to cold weather concreting does not require any special tools or procedures. It is an approach that may be immediately incorporated into standard practice.

At this point, the CWAS formulations are a “one-size-fits-all.” The ability to optimize the admixture dosage to design mixes based on site-specific conditions and forecasted weather conditions would greatly add value to the user and make CWAS concrete mixes cost competitive. This project provided an opportunity to investigate the effects of varying the admixture dosage, and this issue needs to be investigated further. The results of this test will be used in future work to develop a better understanding of the interactions of the effects of admixture combinations used in the CWAS formulations, the geometry of the structure, and the specific site conditions, with the goal of developing the tools needed to design and tailor CWAS formulations for a variety of applications.

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Appendix A: Compressive Strength Cylinder Data

Table A1. Mix 1 room temperature curing compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
1	8-5723	79,055	6.00	2,795	4	
1	8-5724	81,410	6.01	2,870	2	
1	8-5725	81,615	6.01	2,875	2	2,847
2	8-5726	109,845	6.00	3,885	2	
2	8-5727	112,635	6.00	3,980	4	
2	8-5728	109,270	6.00	3,865	2	3,910
3	8-5729	136,325	6.00	4,820	3	
3	8-5730	135,385	5.99	4,800	5	
3	8-5731	133,625	6.00	4,725	4	4,782
28	8-5732	230,665	5.99	8,185	2	
28	8-5733	229,605	5.99	8,145	3	
28	8-5734	224,050	5.99	7,950	2	8,093

Table A2. Mix 1 field-cured compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
2	8-5736	70,255	5.99	2,490	2	
2	8-5737	72,225	5.99	2,560	4	
2	8-5738	72,505	5.99	2,570	2	2,540
3	8-5739	99,885	6.01	3,520	5	
3	8-5740	89,115	6.00	3,150	6	
3	8-5741	88,340	6.00	3,120	5	3,263
7	8-5742	129,475	6.01	4,560	4	
7	8-5743	126,180	6.00	4,460	6	
7	8-5744	124,160	6.00	4,390	6	4,470
28	8-5745	195,815	5.99	6,945	4	
28						
28						6,945

Table A3. Mix 2 room temperature curing compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
1	8-5747	77,795	6.00	2,750	2	
1	8-5748	76,560	6.00	2,705	1	
1	8-5749	77,980	6.00	2,755	4	2,737
2	8-5750	106,695	6.00	3,770	2	
2	8-5751	99,280	6.00	3,510	2	
2	8-5752	103,545	6.00	3,660	2	3,647
3	8-5753	129,480	6.00	4,575	4	
3	8-5754	128,930	6.00	4,560	6	
3	8-5755	129,585	5.99	4,595	5	4,577
28	8-5756	221,170	5.99	7,845	2	
28	8-5757	206,475	5.98	7,350	2	
28	8-5758	240,685	5.98	8,570	2	7,922

Table A4. Mix 2 field-cured compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
2	8-5760	56,040	6.00	1,980	2	
2	8-5761	61,500	6.00	2,175	2	
2	8-5762	49,405	6.00	1,745	2	1,967
3	8-5763	76,135	6.00	2,690	6	
3	8-5764	74,790	6.00	2,645	5	
3	8-5765	77,785	6.00	2,750	5	2,695
7	8-5766	131,565	6.00	4,650	3	
7	8-5767	127,820	5.98	4,550	6	
7	8-5768	132,285	6.00	4,675	6	4,625
28	8-5769	207,885	5.99	7,375	4	
28	8-5770	205,755	5.99	7,300	5	
28						7,338

Table A5. Mix 3 room temperature curing compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
1	8-5772	70,215	6.00	2,480	2	
1	8-5773	69,580	6.00	2,460	4	
1	8-5774	70,400	6.00	2,490	4	2,477
2	8-5775	114,380	5.99	4,055	2	
2	8-5776	116,240	6.00	4,110	2	
2	8-5777	120,875	6.00	4,275	2	4,147
3	8-5778	145,065	6.00	5,130	3	
3	8-5779	144,350	5.99	5,120	4	
3	8-5780	144,325	5.98	5,135	6	5,128
28	8-5781	206,120	5.99	7,310	4	
28	8-5782	225,005	5.99	7,985	3	
28	8-5783	169,875	5.98	6,045	3	7,113

Table A6. Mix 3 field-cured compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
2	8-5785	37,075	5.99	1,315	5	
2	8-5786	40,650	6.00	1,435	2	
2	8-5787	41,335	6.00	1,460	2	1,403
3	8-5788	63,925	6.00	2,260	5	
3	8-5789	59,955	6.00	2,120	5	
3	8-5790	71,180	6.01	2,505	6	2,295
7	8-5791	140,080	6.00	4,950	5	
7	8-5792	137,470	5.99	4,875	3	
7	8-5793	144,445	6.00	5,105	3	4,977
28	8-5794	205,135	5.99	7,275	4	
28	8-5795	207,810	5.98	7,395	4	
28						7,335

Table A7. Mix 4 room temperature curing compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
1	8-5797	79,650	6.00	2,815	2	
1	8-5798	69,485	6.00	2,455	2	
1	8-5799	87,615	5.99	3,105	2	2,792
2	8-5800	119,210	6.00	4,215	5	
2	8-5801	114,545	6.00	4,050	5	
2	8-5802	119,210	6.00	4,215	3	4,160
3	8-5803	133,335	6.00	4,715	5	
3	8-5804	139,685	6.00	4,940	5	
3	8-5805	134,100	5.98	4,775	5	4,810
28	8-5806	242,700	6.00	8,580	2	
28	8-5807	202,545	6.00	7,160	4	
28	8-5808	169,450	6.01	5,970	1	7,237

Table A8. Mix 4 field-cured compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
2	8-5810	68,895	5.99	2,445	6	
2	8-5811	62,285	6.01	2,195	4	
2	8-5812	59,520	6.01	2,095	6	2,245
3	8-5813	88,385	6.01	3,115	2	
3	8-5814	85,845	6.00	3,035	5	
3	8-5815	89,245	6.00	3,155	2	3,102
7	8-5816	93,315	6.00	3,300	2	
7	8-5817	94,060	5.99	3,335	3	
7	8-5818	98,895	6.00	3,495	4	3,377
28	8-5819	216,255	5.99	7,670	5	
28	8-5820	207,635	5.99	7,365	4	
28						7,518

Table A9. Mix 5 room temperature curing compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
1	8-5822	53,905	6.00	1,905	4	
1	8-5823	53,475	6.00	1,890	2	
1	8-5824	57,715	6.00	2,040	2	1,945
2	8-5825	79,555	5.99	2,820	5	
2	8-5826	80,625	5.99	2,860	5	
2	8-5827	81,375	5.98	2,895	6	2,858
3	8-5828	85,610	6.00	3,025	5	
3	8-5829	91,510	6.00	3,235	2	
3	8-5830	88,745	6.01	3,125	6	3,128
28	8-5831	161,450	5.99	5,725	4	
28	8-5832	155,815	6.00	5,510	4	
28	8-5833	165,905	6.00	5,865	5	5,700

Table A10. Mix 5 field-cured compressive strength.

Age (d)	Sample ID	Maximum Load (lb)	Diameter (in)	Strength (psi)	Fracture Type	Average Strength (psi)
2	8-5835	45,950	6.00	1,625	5	
2	8-5836	42,485	6.00	1,500	5	
2	8-5837	40,990	5.99	1,455	6	1,527
3	8-5838	52,410	5.99	1,860	3	
3	8-5839	55,320	6.00	1,955	3	
3	8-5840	47,420	5.98	1,685	5	1,833
7	8-5841	146,495	6.00	5,180	4	
7	8-5842	143,525	6.00	5,075	3	
7	8-5843	146,035	6.00	5,165	6	5,140
28	8-5844	154,100	5.99	5,465	4	
28	8-5845	156,485	5.99	5,550	4	
28						5,508

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14. ABSTRACT

Cold Weather Admixture Systems (CWAS) is a new approach to cold weather concreting that incorporates suites of commercially available chemical admixtures in concrete mixes. When used in combination, these admixtures depress the freezing point of the concrete mix water, protect the fresh concrete down to an internal temperature of 23°F, and promote early strength gain. In stark contrast to conventional winter concreting operations, no external heat is required in the CWAS approach. As a result, the construction and heating of temporary shelters is not required, as dictated by current practice. Given the significant cost of energy associated with external heating, a real advantage of the CWAS approach is the cost saving potential for cold weather concreting as compared to current practice. In March 2008, a full-scale field test was conducted at Fort Wainwright, Alaska. This field test provided an opportunity to apply the CWAS approach to an infrastructure project on an Army installation. This report describes the placement of a concrete hardstand using the CWAS approach and the monitoring of the structure after construction to estimate the strength gain.

15. SUBJECT TERMS
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compressive strength

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