**New Developments in Cold-Weather Concreting**

Charles Korhonen[1], M.ASCE

## Abstract

Cold weather inhibits construction productivity in the northern tier of the United States. Over the years the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL) has developed formulations for cold-weather concrete that facilitate economical placement of concrete at mix temperatures well below freezing. Like many other technological advances, the commercialization of this technology has effectively been blocked by a lack of standards. CRREL is working with several State Transportation Departments to develop a near-term cold-weather concreting capability using off-the-shelf technology. Paralleling this effort, the Civil Engineering Research Foundation is spearheading an initiative to develop an acceptance standard for low-temperature admixtures. The world of cold-weather concreting promises to become a bit friendlier within the next few years and beyond.

## Introduction

Cold weather places serious constraints on concrete construction. As temperatures drop, concrete sets more slowly, takes longer to finish, and gains strength less rapidly. If temperatures dip too low, the mix water may freeze and the final product will be irreparably damaged. Because there are times when work must continue despite the weather, the only option available today is to thermally protect the concrete while it cures. This option, though meeting construction's needs, is resource-intensive (labor, time, equipment, and budget). What's needed is a concrete that can be placed and cured in subfreezing weather without thermal protection.

The Cold Regions Research and Engineering Laboratory (CRREL) has made significant progress in developing a technology that will facilitate economical placement of portland cement concrete when its internal temperature is well below the freezing point of water. This is made possible by using chemicals that allow

[1] Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, New Hampshire 03755-1290.
E-mail: korhonen@crrel.usace.army.mil

concrete to develop strength while it is cold—an impossibility for normal concrete. However, because using chemicals to protect concrete against freezing is not supported by acceptance standards in the United States, little has been accomplished to move this technology into general practice. Recently, however, interest from several northern states' departments of transportation (DoT), the Civil Engineering Research Foundation (CERF), and the U.S. Department of Defense (DoD) has rekindled the effort.

This paper reviews today's cold-weather concreting practice, describes the emerging technology, and discusses the work leading up to current efforts to move this technology into the marketplace.

**Current Practice**

Current cold-weather concreting practices have remained unchanged since the 1930s. The primary concerns, then and now, have been to maintain an adequate temperature during curing, protect the concrete from freezing, and avoid large thermal shocks to the concrete when it is exposed to the cold. Basically, the concrete must be delivered to the job site warm, any surface that the fresh concrete comes in contact with must be thawed, and the concrete must be kept warm by insulation or heated enclosures while it cures.

The goal in proportioning mixtures for cold weather is to achieve a concrete that cures rapidly. That is, one that sets more quickly and gains strength more rapidly than it ordinarily would. Figure 1 shows that the time of setting of concrete increases as temperature decreases. Likewise, strength develops more slowly at lower temperatures. Though concrete cured in cool weather ultimately becomes stronger than that cured in hot weather, the construction schedule is slowed down. For example, concrete placed and maintained at 5°C, the lowest temperature allowed by the American Concrete Institute (ACI 1988), could take several hours longer to finish and up to a week or more before forms can be safely removed. Delays such as these can result in significant cost penalties.

ACI recommends three ways to shorten the delays caused by cold weather: (1) use more cement, (2) use Type III cement, or (3) use a chemical accelerator. These options are considered equivalent. They cause the concrete to behave as if it were 10°C warmer than it actually is, which can shave a day or two off the schedule. They do not, however, prevent the concrete from freezing. If the concrete freezes after its initial set, but before it has gained much strength, it may lose half its potential strength. Thus, heated enclosures are the best, though the most expensive, option when ambient temperatures drop below the freezing mark. Adding an enclosure can more than double project costs.

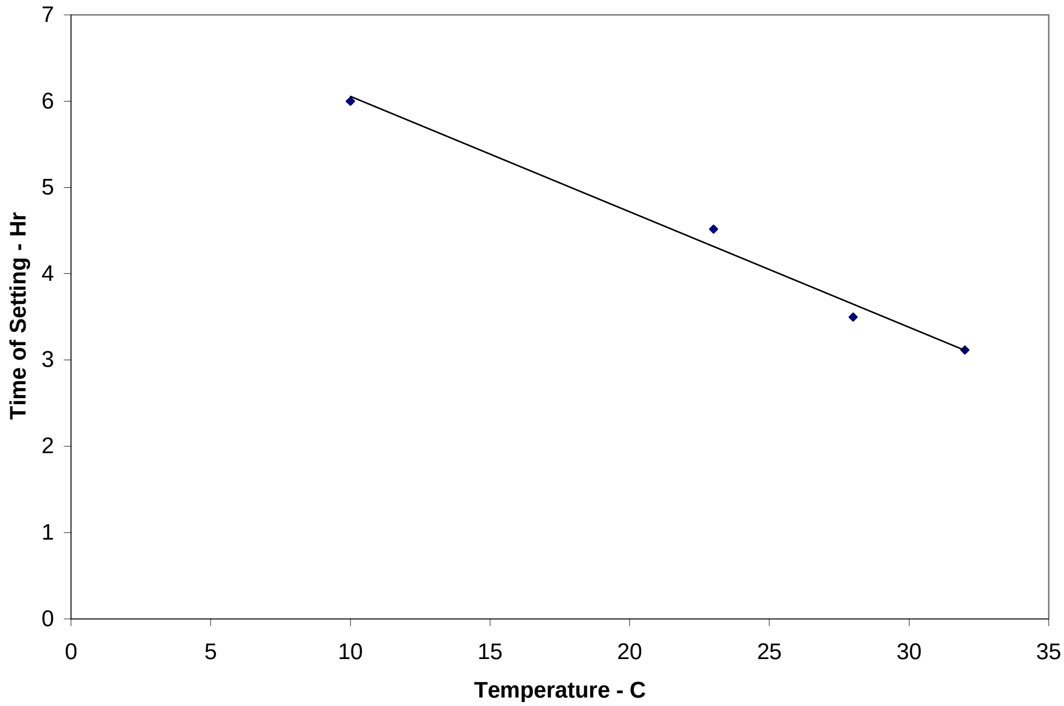


**Figure 1**. Effect of temperature on the initial time of setting of concrete (Dodson 1994).

## Alternate Approach

An alternate approach to cold-weather concreting is to use chemical admixtures that allow concrete to gain strength at subfreezing temperatures. There are numerous chemicals that depress the freezing point of water and many that accelerate the rate of cement hydration—the essential functions of this technology—but the challenge has been to find chemicals that work together.

Figure 2 presents a typical performance of two chemicals in concrete cured at –5°C. The exact chemicals used are not important for this discussion. The intent, rather, is to show the reader what can be expected from low-temperature admixtures, and it is important to know how the concrete was handled. The concrete was prepared at room temperature according to ASTM C192 (1981). After mixing, the concrete was placed into cylindrical molds, vibrated to ensure proper consolidation, and capped with plastic lids to prevent evaporation. Within 40 minutes of the water first contacting the cement, the cylinders were placed into the 20°C and the –5°C curing rooms. The cylinders in the –5°C room reached that temperature well before initial set occurred. Therefore, it is important to recognize that the temperatures shown in Figure 2 represent the internal temperature of the concrete as it gained strength.

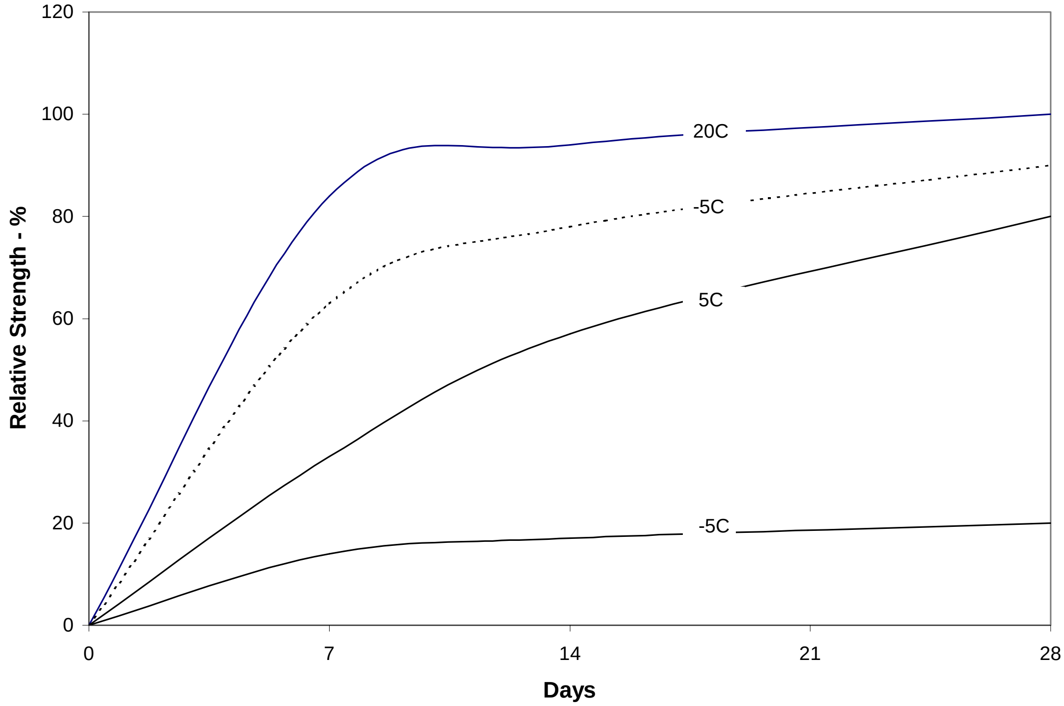


**Figure 2**. Comparison of normal concrete (solid lines) to that made with admixtures (dotted line).

As Figure 2 shows, the concrete made with the two chemicals and cured at –5°C resisted freezing and gained strength as if it was cured at something well above 5°C. Without benefit of the chemicals, ordinary concrete at this same temperature did not fare too well.

As written elsewhere, a –5°C capability translates into a potential extension of the construction season of up to four months in the United States and a cost savings of one-third compared to conventional cold-weather concreting techniques (Korhonen and Ryan 2000). However, for reasons mentioned earlier, cold-weather admixtures are not commercially available today.

## Moving This Technology into the Marketplace

CRREL has spent much of the past decade studying alternate approaches to cold-weather concreting. The first commercial interest in this area occurred in 1992, when CRREL partnered with two major admixture manufacturers in the United States to study low-temperature admixtures. This effort was part of an initiative by the U.S. Army Corps of Engineers to work with private industry on research and development that had potential for advancing the art of construction and for being of value to Corps construction activities.

This cooperative study led to the field demonstration of two prototype low-temperature admixtures in 1994. The first demonstration project was built outdoors at

CRREL, Hanover, New Hampshire, in which a steel-reinforced concrete bin, 3.7 m wide by 4.6 m long with 1.2-m-high walls, 203 mm thick, on a 165-mm-thick slab, was cast in February. In March of that same year, a second field demonstration, conducted in northern Michigan, consisted of replacing several 5.5-m-wide by 6.1-m-long by 150-mm-thick reinforced slabs on grade. In both cases the concrete was easily mixed at low temperature, the admixtures were dosed into the truck during mixing, and the concrete was finished in the usual manner. No special tools or skills were required to work with the concrete and, because external heat was not needed to protect the concrete, a significant amount of non-renewable thermal energy was conserved. The resulting concrete, still in service, is indistinguishable from control concrete.

The prototype admixtures that resulted from the cooperative study were never commercialized, primarily because it was felt that an industry acceptance standard should be in place before this new technology could be opened to general practice.

Though studies continued at CRREL, little happened on the commercial scene until it was discovered that the floors inside the ice condenser rooms of two nuclear power plants had frost-heaved and were close to compromising plant safety. In 1997 CRREL designed a low-temperature concrete mixture made from commercial off-the-shelf admixtures to be placed in the Sequoyah Nuclear Power Plant belonging to the Tennessee Valley Authority. The concrete was pumped more than 100 m horizontally and 10 m vertically and placed, finished, and cured at –8°C. This project showed that it was possible to design and specify low-temperature admixtures from conventional materials without requiring special acceptance standards. This conclusion led to the activity that is discussed below and that continues today.

For the Department of Defense (DoD), it was becoming increasingly clear that there are times when concrete must be placed regardless of the weather, and that insulation or heated enclosures might not be available. This situation presented both a problem and an opportunity. The problem was that any concrete placed unprotected in the cold could be damaged by the cold. The opportunity was that in contingency operations—the battlefield or other emergency—long-term performance may not be a consideration and acceptance standards probably are not important. This allowed a wider scope of chemicals than might otherwise be acceptable for commercial application. In 1999, CRREL evaluated various materials found in a theater of operation for use as expedient concrete admixtures and published a report for the Army for concrete not expected to last more than five years (Korhonen 1999).

More directly related to the success achieved at TVA, low-temperature concrete mixtures were developed at CRREL for the City of New York Department of Design and Construction and Atkinson Construction in Bath, Maine, in 1999 and 2000, respectively. New York wanted the capability to repair its streets and sidewalks later into the fall and earlier in the spring. Atkinson Construction wanted to be able to continue concreting operations during the winter to complete the Naval shipyard it was working on. Neither of these two entities has reported using this technology, as the last two winters have been mild. However, they are ready should the need arise.

Because using chemicals to protect concrete against freezing has been proven technically feasible but is still not practiced in the United States, CRREL embarked on two parallel paths to introduce this technology to a wider audience. The first approach, which began in 2001, is to develop cold-weather admixtures from those that are being used for various purposes in concrete today. This is being done to avoid the necessity of developing a new acceptance standard. It was previously shown that cold-weather admixtures could be formulated by combining existing admixtures, which already comply with industry practice. The goal is to not use more of any single admixture than is recommended by its manufacturer but to use sufficient numbers of admixtures so that the concrete can safely resist freezing down to –5°C. The admixture combination must also force the concrete, when it is cold, to cure as rapidly as control concrete cured at 5°C. Arbitrarily, the initial setting of cold concrete was tentatively established to be not more than twice that of control concrete cured in standard laboratory conditions. This program, started in April 2001, is scheduled to run three years. It is being funded by a consortium of Northern State Departments of Transportation (DoT) and is being monitored by the Federal Highway Association.

The second path has the long term in mind. The Civil Engineering Research Foundation (CERF) is spearheading this one and its intent is to develop a national standard for cold-weather admixtures. As with most emerging technologies, the practice of emplacing fresh concrete in subfreezing weather without the need for heaters has been stymied by the lack of standards. During the fall of 2000, CERF gathered a panel of experts from across the United States to develop a draft of what is hoped will eventually become the standard for cold-weather admixtures. It is recognized that developing new standards, getting them approved, and then accepting them into practice takes time—sometimes, years. Thus, this approach will be a natural follow-on to the DoT effort.

## Conclusions

Though not quite there yet, the world of winter concreting promises to become a bit friendlier within the next few years and beyond. Expectations are that the protocol for using existing admixtures to make "true" cold-weather admixtures should become available to the DoT community within three years of this writing. This will permit immediate use of this technology to protect concrete down to –5°C. Following that, a national standard supporting the commercialization of cold-weather admixtures should become available. This standard will specify how concrete should perform when made with the admixtures, and, equally important, that the admixtures may not harm the concrete in the long term. The timing on developing this standard largely depends on how quickly this process can move through committee. Once this is done, it is expected that commercial admixtures, dedicated to protecting concrete down to perhaps –10°C, will enter the market. At that point, cold-weather admixtures will become readily available.

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