# Concrete Technology in Focus

## Successful Cold Weather Concreting

### Introduction

Cold weather can lead to many problems in mixing, placing, and curing of concrete that can have an adverse effect on its properties and service life. This guide has been developed by Master Builders Solutions to assist the entire construction team (owners, specifiers, contractors, and ready-mixed concrete producers) in the design, manufacture, delivery, placement, and curing of quality concrete in cold weather.

In ACI PRC-306, "Guide to Cold Weather Concreting," it is stated that: "The conditions of cold weather concreting exist when the air temperature has fallen to, or is expected to fall below, 40 °F (4 °C) during the protection period. The protection period is defined as the amount of time recommended to prevent concrete from being adversely affected by exposure to cold weather during construction."

Setting time of concrete as shown in Table 1 is increased approximately one-third for each 10 °F (5 °C) reduction in temperature. Low temperatures slow down the hydration process and significantly retard concrete setting time, which results in reduced compressive strength at early ages, and increased strength at later ages (see Figure 1).

Table 1: *Setting Time of Concrete at Various Temperatures*

(Source: "Concrete Construction," March, 1990)

| Temperature | Approximate Setting Time |
|---|---|
| 70 °F (21 °C) | 6 Hours |
| 60 °F (16 °C) | 8 Hours |
| 50 °F (10 °C) | 11 Hours |
| 40 °F (4 °C) | 14 Hours |
| 30 °F (-1 °C) | 19 Hours |
| 20 °F (-7 °C) | Set does not occur-concrete will freeze |

The beneficial impact that low temperatures can have on hardened concrete properties is recognized by ACI Committee 306, and in ACI PRC-306 it is stated that: "Take advantage of the opportunity provided by cold weather to place low-temperature concrete. Concrete placed during cold weather protected against freezing, and properly cured for a sufficient length of time, has the potential to develop higher ultimate strength and greater durability than concrete placed at higher temperatures. It is susceptible to less thermal cracking than similar concrete placed at higher temperatures."

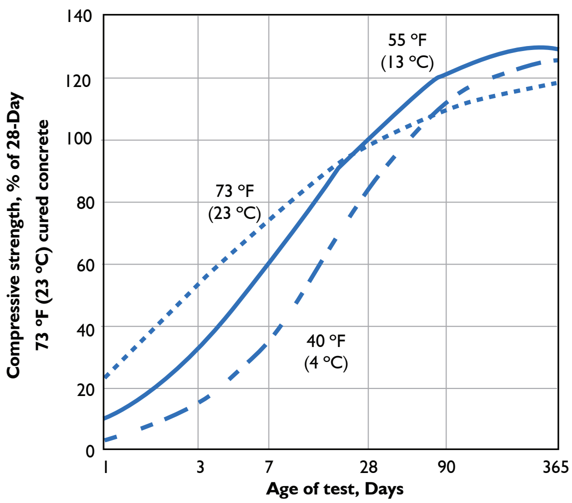


**Figure 1.** *Effect of Low Temperature on Concrete Compressive Strength*

(Source: PCA, "Design and Control of Concrete Mixtures")

In sub-freezing weather conditions, setting time, strength development and durability characteristics of concrete that is not adequately protected will be severely affected.

For example, concrete:

- Should not have water-cementitious materials ratio exceeding the limits recommended in ACI PRC-201.2, "Guide to Durable Concrete"

- Exposed to cycles of freezing and thawing while in a saturated condition or in service, should be properly air-entrained (see ACI PRC-201.2)
- In the plastic state will freeze when the mix temperature falls below 29 °F (-2 °C), and is left undisturbed for sufficient time for ice to form. Once ice has formed, normal hydration will not occur and concrete setting time will be seriously impaired
- That has frozen during the first 24 hours can experience up to 50% loss in compressive strength at 28 days (see Figure 2)
- That is protected from freezing until it has attained a compressive strength of at least 500 psi (3.5 MPa) will not be damaged by exposure to a single freezing cycle
- Should not be allowed to freeze and thaw in a saturated condition before developing a compressive strength of 3,500 psi (24 MPa)

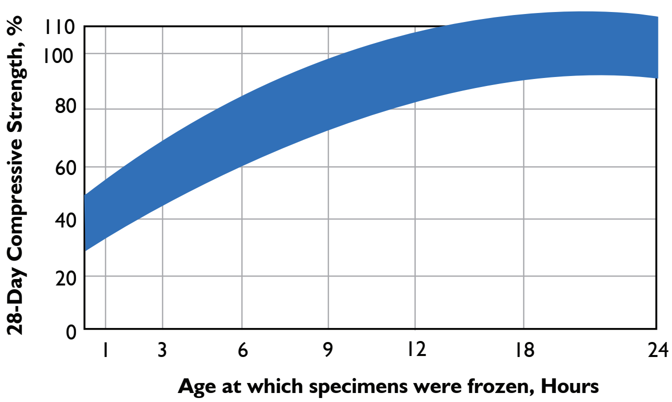


**Figure 2.** *Effect of Freezing on 28-Day Compressive Strength of Concrete*

(Source: ACI Publication SP-39, "Behavior of Concrete Under Temperature Extremes")

There are established cold weather concreting practices that will ensure satisfactory concrete performance. The objectives of these practices are to:

- maintain curing conditions that foster normal strength development
- assure that the concrete develops the required strength for safe removal of forms
- prevent damage to concrete due to freezing at early ages
- limit rapid concrete temperature changes to withstand induced thermal stresses
- provide protection with the intended serviceability of the structure

## Concrete Temperature Control

During cold weather, the concrete mixing temperature should be controlled so that when the concrete is placed, its temperature is not below the values shown in Table 2 for normal weight concrete.

**Table 2:** *Recommended Concrete Temperatures*

(Source: ACI PRC-306, "Guide to Cold Weather Concreting")

| | | **Section size, minimum dimension, in. (mm)** | | | |
|---|---|---|---|---|---|
| | | <12 in. (300 mm) | 12-36 in. (300-900 mm) | 36-72 in. (900-1800 mm) | >72 in. (1800 mm) |
| Line | Air Temp. | | | | |
| | | **Minimum concrete temperature as placed and maintained** | | | |
| 1 | – | 55 °F (13 °C) | 50 °F (10 °C) | 45 °F (7 °C) | 40 °F (5 °C) |
| | | **Minimum concrete temperature as mixed for indicated air temperature*** | | | |
| 2 | Above 30 °F (-1°C) | 60 °F (16 °C) | 55 °F (13 °C) | 50 °F (10 °C) | 45 °F (7 °C) |
| 3 | 0 to 30 °F (-18 to -1°C) | 65 °F (18 °C) | 60 °F (16 °C) | 55 °F (13 °C) | 50 °F (10 °C) |
| 4 | Below 0 °F (-18 °C) | 70 °F (21 °C) | 65 °F (18 °C) | 60 °F (16 °C) | 55 °F (13 °C) |
| | | **Maximum allowable gradual temperature drop in first 24 hr after end of protection** | | | |
| 5 | – | 50 °F (28 °C) | 40 °F (22 °C) | 30 °F (17 °C) | 20 °F (11 °C) |

** For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.*

*Note 1: For Line 1, maximum placement temperature is minimum temperature in the table plus 20 °F (11 °C).*

*Note 2: For Lines 2-4, maximum temperature is minimum temperature in the table plus 15 °F (9 °C).*

As recommended in ACI PRC-306, the mixing temperature should not be more than 15 °F (8 °C) above the values in Lines 2, 3, and 4.

The temperature of concrete at the time of placement should always be near the minimum temperatures given in Table 2. Placement temperatures should not be higher than these minimum values by more than 20 °F (11 °C).

High concrete temperatures do not offer significantly longer protection time against freezing because heat loss is more rapid when concrete temperatures are higher than ambient temperatures. High concrete temperatures require more mixing water to attain a given slump, increase the rate of slump loss and thermal shrinkage, as well as the possibility of plastic shrinkage cracking, because moisture loss through evaporation is greater.

Concrete temperature at the time of mixing is influenced by temperature, specific heat and quantity of its ingredients. The approximate temperature of concrete can be calculated from the following equation:

$$T = \frac{[0.22(T_s M_s + T_a M_a + T_c M_c) + T_w M_w + T_s M_{ws} + T_a M_{wa}]}{[0.22\,(M_s + M_a + M_c) + M_w + M_{ws} + M_{wa}]}$$

where:

$T$ = final temperature of the concrete mixture

$T_c$, $T_s$, $T_a$ and $T_w$ = temperature of cement, fine aggregate, coarse aggregate and water, respectively

$M_c$, $M_s$, $M_a$, $M_w$, $M_{ws}$ and $M_{wa}$ = mass of cement, saturated surface-dry fine aggregate, saturated surface-dry coarse aggregate, mixing water, free water on fine aggregate and free water on coarse aggregate, respectively

The temperature of concrete can be increased by 1 °F (0.5 °C) by increasing:

- cement temperature by 8 °F (4 °C)
- water temperature by 4 °F (2 °C)
- aggregate temperature by 2 °F (1 °C)

Of all the concrete-making materials, water is the easiest and most practical to heat. The mass of aggregates and cement in a concrete mixture is much greater than the mass of water. However, water can store five times as much heat as can solid materials of the same mass.

## Concrete Materials

The use of faster setting cements may improve the rate of hardening of concrete in cold weather. A 10 to 15 °F (5 to 8 °C) temperature rise per 100 lb (45 kg) of cement occurs from cement hydration. The temperature increase from cement hydration is directly proportional to the cement content of the concrete.

Type III (high-early strength) cement can be used to achieve faster setting time and higher early strength. The principal advantages from Type III cement occur during the first 7 days.

Fly ash and other pozzolans and slag cement are used as partial replacements for portland cement. These materials can be used in conjunction with accelerating admixtures to obtain desired concrete performance in cold weather concreting.

The requirements for good results in placing and curing concrete in cold weather are not different from that for other seasons. Concrete should be placed where it is to remain and in shallow layers to allow adequate vibration; use wind breaks, cure and protect freshly-placed concrete from moisture loss and freezing.

## Chemical Admixtures

Chemical admixtures conforming to ASTM C494/C494M Types C, accelerating, and E, water-reducing and accelerating, are beneficial for concrete placed during cold weather. Benefits obtained from these admixtures include:

- lower water demand – by a minimum of 5%
- improved workability during placing
- faster rate of setting (see Figure 3)
- increased early compressive strength
- earlier stripping and reuse of forms

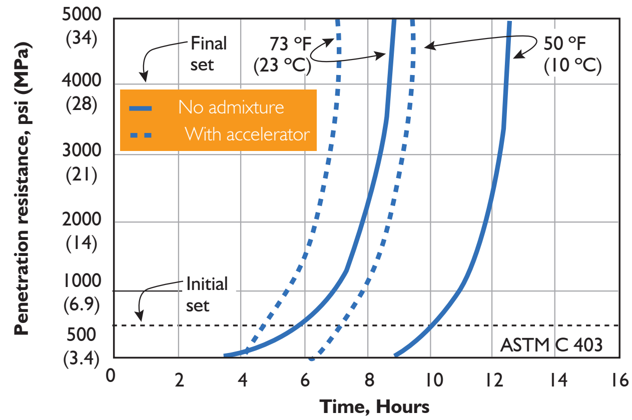


**Figure 3.** *Effect of Concrete Temperature and Accelerating Admixture on Setting Time*

(Source: Master Builders Solutions)

Master Builders Solutions offers a complete family of accelerating admixtures (chloride-based and non-chloride) that conform to ASTM C494/C494M requirements.

In cold weather, MasterSet® AC 122, MasterSet FP 20 and MasterSet AC 534 admixtures can be used to obtain accelerated setting time and increased early strength performance. In sub-freezing weather, MasterSet FP 20 admixture can be used to allow concrete placement at ambient temperatures as low as 20 °F (-7 °C), without the concrete freezing in its plastic state.

**Table 3:** *Typical Performance Data*

Concrete at Ambient Temperature of 50 °F (10 °C)

| Product | ASTM C494/C494M Designation | Dosage, fl oz/cwt (mL/100 kg) | Setting Time Acceleration vs. Plain Concrete (h:min) |
|---|---|---|---|
| MasterSet AC 122[1] | C & E | 16 (1,040)<br>32 (2,080) | – 2:45<br>– 4:15 |
| MasterSet FP 20[2] | C & E | 10 (650)<br>20 (1,300) | – 3:00<br>– 4:00 |
| MasterSet AC 534[3] | C | 13 (850)<br>26 (1,700) | – 3:06<br>– 4:43 |

[1]MasterSet AC 122 is a chloride-based water-reducing and accelerating admixture
[2]MasterSet FP 20 is a non-chloride water-reducing and accelerating admixture
[3]MasterSet AC 534 is a non-chloride accelerating admixture

Your local sales representative will help you select the formulation that best serves your needs.

## Control of Plastic Shrinkage Cracking

MasterFiber® microsynthetic fibers reduce the formation of plastic shrinkage cracks and plastic settlement. In addition, these fibers:

- hold cracks together
- reinforce against abrasion
- are compatible with all surface treatments
- will not change the required mixture proportions

## Curing

Curing is the maintenance of satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop (see Figure 4). The minimum recommended curing period is 7 days. Inadequate curing can cause plastic shrinkage cracking and impair strength development and durability.

Freshly-placed concrete in cold weather must be protected from drying so that adequate hydration can occur. Normally, measures must be taken to prevent evaporation of moisture from concrete.

Methods of curing include the use of:

- Impervious paper and plastic sheets.
- Membrane-forming curing compounds.

***Note: Water curing is not recommended in freezing weather.***

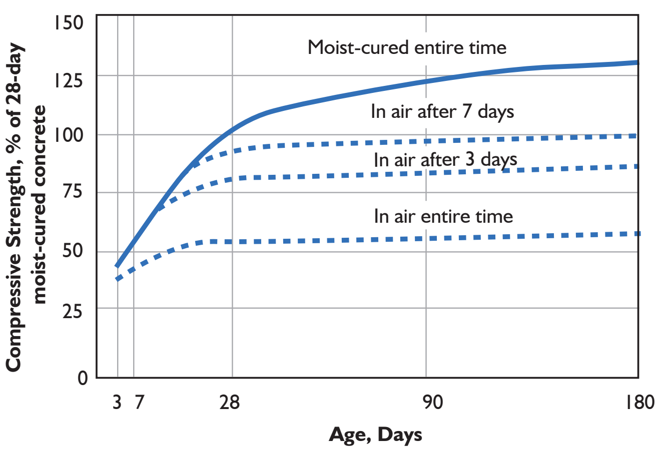


**Figure 4.** *Effect of Curing on Compressive Strength of Concrete*

(Source: ACI PRC-306, "Guide to Cold Weather Concreting")

## Summary

Cold weather concreting difficulties are chiefly caused by low ambient temperatures, and by not protecting concrete from freezing. These conditions adversely affect the quality of concrete since the rate of setting is extended, early strength development is reduced and the potential for plastic shrinkage cracking may be increased.

Desired setting time, strength, durability and other properties of concrete can be obtained in cold weather by adhering to the following recommended practices:

- plan ahead for cold weather concrete placements
- use warm concrete ingredients and accelerating admixtures
- avoid placing concrete on frozen subgrade
- prevent concrete from freezing
- limit rapid concrete temperature changes

If all precautions and recommended ACI concreting practices are followed, successful cold weather concreting can be achieved.

### About Master Builders Solutions

Master Builders Solutions is a leading global manufacturer of concrete admixtures, as well as other sustainable solutions for the construction industry, focussed on delivering its vision: **Inspiring people to build better**. Master Builders Solutions provides value-added technology and market-leading R&D capabilities to improve the performance of construction materials and to enable the reduction of CO2 emissions in the production of concrete. Founded in 1909, Master Builders Solutions has ca. 1600 employees operating 35 production sites globally, supporting their customers in mastering their building challenges of today – for a decarbonised future.


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