CRREL-ERDC

Technical Brief

April 2026

Effect of Freezing Temperature and Duration of Exposure on Compressive Strength of Concrete with Additive-Based Freeze Protection

Background

Cold-weather concreting occurs whenever ambient temperatures fall to or below 4 °C during the early protection period, slowing hydration and delaying setting, and leaving concrete vulnerable to internal ice formation and microcracking if it freezes before adequate strength develops. Additive-based freeze protection (ABFP) admixture systems reduce reliance on costly, energy-intensive heating by depressing the freezing point of mix water and promoting early hydration at subfreezing temperatures, enabling placement in remote locations, urgent repairs, and military operations. However, even with ABFP, deep-freeze exposure during early-age development can still reduce strength and stiffness, and the risk depends on both when freezing occurs relative to setting and how long it persists. This research quantifies how deep-freeze exposure timing and duration jointly govern mechanical property loss in cold-cured, ABFP-protected concrete, providing the evidence base needed for event-driven, verifiable cold-weather protection decisions.

Research Objectives and Approach

This research quantifies the combined influence of deep-freeze exposure timing and duration on cold-weather concrete produced with an ABFP admixture system and continuously cured at −5 °C. Two coordinated phases isolate each factor: the timing study exposes specimens to −10 °C, −20 °C, and −40 °C for 24 hours with onset defined relative to initial set, final set, and 24 hours after mixing (via ASTM C403 penetration resistance); the duration study holds onset constant at final set while varying exposure from 1 to 7 days at the same temperatures. Mechanical performance was evaluated using compressive strength (ASTM C39), static modulus of elasticity (ASTM C469), and resonant frequency (ASTM C215) at ages of 7 through 90 days, normalized to age-matched controls. Embedded temperature logging linked cooling curves to mechanical outcomes, enabling direct comparison of the relative sensitivity of timing versus duration.

Direct Benefit to Military Engineering

This research gives military and cold-region construction agencies the evidence needed to protect concrete placed in subfreezing conditions more efficiently and reliably. It supports event-driven protection planning, replacing calendar-driven protection periods with thresholds tied to actual freezing risk relative to setting and exposure duration. Linking cooling-curve indicators to mechanical outcomes provides a framework for using embedded sensors and temperature logging to confirm in-field exposure severity rather than relying on assumptions, reducing reliance on external heat by supporting targeted heating or insulation rather than blanket heating of every placement. For military engineers, this translates directly into the ability to place and cure concrete in remote or forward locations without extensive heated enclosures, enhancing safety and efficiency while supporting rapid repair of pavements, runways, and other mission-critical infrastructure even during multi-day cold-weather events.

Conclusions and Recommendations

The main takeaway is timing, not just temperature: deep-freeze exposure before final set is the high-risk window, with initial-set exposure cutting normalized compressive strength to as low as 0.74 at −40 °C, while exposure after final set or 24 hours performed at or near control levels regardless of how cold it got. Duration compounds this risk under fixed onset, since a single day of exposure caused little lasting damage, but 3 to 7 days of exposure produced substantial early-age strength loss (as low as 0.66–0.77) with only partial recovery by 90 days, meaning ABFP protects against a brief cold snap but not a sustained one. In practice, this means protection should prioritize the window through final set above all else, and multi-day cold snaps should be treated as high risk even after the first 24 hours. Embedded temperature monitoring is recommended to verify actual exposure history and confirm when protection can safely be removed.

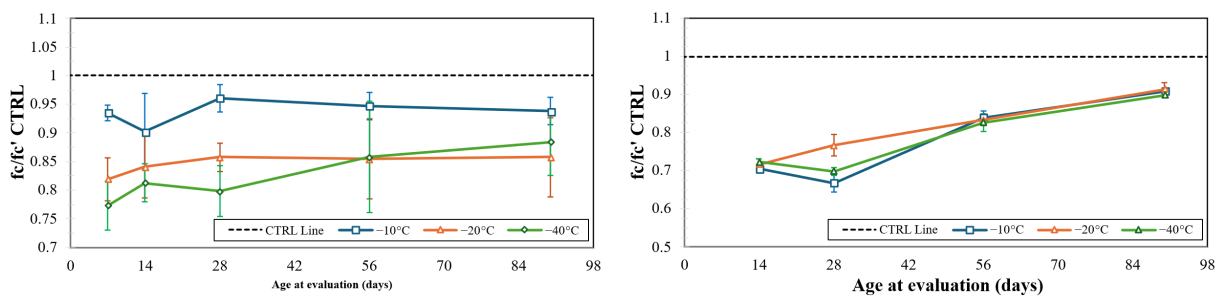

Figure 1. Normalized compressive strength versus age for the most vulnerable condition in each study: (a) initial-set exposure across the timing study; (b) 7-day exposure across the duration study.

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