



Effects of chloride and chloride-free accelerators combined with typical admixtures on the early-age cracking risk of concrete repair slabs



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HIGHLIGHTS

- Ca(NO₃)₂ based accelerator showed increased shrinkage, restraint stresses, and strength.
- Increase in temperature had a larger effect on setting time of CaCl₂ based accelerator.
- Ca(NO₃)₂ and CaCl₂ based accelerators showed similar cracking tendencies at studied dosages.
- HIPERPAV modeling showed evening and nighttime placements to decrease cracking risk.

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ABSTRACT

Accelerators are commonly added to concrete mixtures used for concrete repair slabs due to high early strength requirements. This study compared the effects of a calcium chloride-based accelerator and a calcium nitrate-based accelerator in rapid strength concrete mixtures on the early age cracking potential of concrete repair slabs. The results showed more shrinkage, higher restraint stresses, and higher strength for the calcium nitrate-based accelerator mixture. HIPERPAV simulated a lower cracking risk for the calcium nitrate-based accelerator mixture during evening and nighttime placements. Calorimetry, free shrinkage, and rigid cracking frame testing were used with the modeling software to observe trends in these mixtures.

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1. Introduction

Early-age cracking in concrete repair slabs is a recurring problem which limits the repair serviceability and increases maintenance costs. Change in volume due to shrinkage and thermal contraction could contribute significantly to early age-cracking in repair slabs. As the subbase and adjacent slabs restrain the concrete, the decrease in volume due to shrinkage and thermal effects induces tensile stresses. When these stresses surpass the tensile strength of the concrete, which is relatively low at early ages, cracking probability increases.

Repair construction typically requires concrete repair materials to retain workability during placement, harden quickly, and maintain ultimate strength capacity. In order to meet these requirements, combinations of admixtures are often used in the concrete mixture. To reach high compressive strengths, a low water-to-cement (w/c) ratio is typically used since it lowers

porosity [1]; however, a low w/c ratio decreases the workability of the concrete. Often times water-reducing and retarding admixtures are used to maintain the workability of concrete mixtures that are batched with low w/c ratios or at high temperatures to accelerate strength gain. However, retarders delay the setting time, so accelerators are added to speed up the hydration process. The effects of using a combination of accelerators with water-reducers/retarders on cracking probability were studied here to represent realistic repair mixtures.

Accelerators decrease the setting time and increase the early strength gain rate once the concrete begins to harden [2]. This encourages the concrete to meet high early strength requirements, and reduces time to opening-to-traffic thus avoiding potential delays to the traveling public. However, higher hydration rates increase the temperature rise during hardening which can potentially increase autogenous deformation [3]. The consequent increased rate of volume change can lead to higher stresses and increased cracking probability.

Different types of accelerators have been studied to determine their effectiveness as a setting or hardening accelerator. The most

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commonly used accelerator today is calcium chloride. However, calcium chloride promotes corrosion of reinforcement by breaking down the passive oxide layer of steel [4,5]. Due to this, chloride-free accelerators have been developed. Some common chloride-free accelerators include soluble inorganic salts – such as nitrates, nitrites and thiocyanates [6].

To ensure that both setting and hardening properties are attained, accelerator blends have been manufactured. Researchers have performed many tests on different accelerator blends and their effects on hydration, setting, and strength development [4,7–10]. However, little research has been done on how these accelerators in combination with typical water-reducing and retarding admixtures affect the overall cracking potential of concrete. Experimental tests using a free shrinkage frame and rigid cracking frame were conducted and compared to cracking prediction software to show the effects of different chemical admixture combinations on the early age cracking potential of high early strength concrete repair slabs.

2. Materials

Four concrete mixtures were prepared for this study [11]. Two of the mixtures compared a calcium chloride-based accelerator with a calcium nitrate-based accelerator, with both accelerators in compliance with ASTM C494 – Type E [12]. To represent field mixtures, the mixtures containing two different accelerators also included a water-reducing/retarding admixture meeting ASTM C494 – Type D, and an air-entraining admixture (AEA) which complied with ASTM C260 [13]. For this reason, two control mixtures without accelerator were used: the first control, C, did not have any admixtures, while the second, CNA, included the water-reducing/retarding admixture and an air-entraining admixture without any accelerator additions. The same Type I/II cement was used for all mixtures, and its composition and physical properties are shown in Table 1. The mineralogical composition was determined using X-ray diffraction and Rietveld refinement in accordance with ASTM C1365 [14], and the fineness was determined using a Blaine apparatus and Method A of ASTM C204 [15].

Both accelerators used in this study were commercially developed for use where accelerated set and hardening properties of concrete are needed. Although the principle active ingredient in each accelerator was either calcium chloride or calcium nitrate, the accelerators used were based on a mixture of chemicals. Table 2 shows the composition of each admixture based on their respective material safety data sheets. The calcium nitrate-based accelerator included small amounts of calcium nitrite, sodium thiocyanate, and triethanolamine (TEA) for their hardening properties. The calcium chloride-based accelerator included small amounts of potassium chloride, sodium chloride, and TEA. Calcium nitrite has been a very popular chloride-free accelerator

Table 1

Cement phase composition (Rietveld refinement) and fineness.

| Cement phase | TYPE I/II |
|--|-----------|
| Tricalcium silicate, C ₃ S (%) | 52.0 |
| Dicalcium silicate, C ₂ S (%) | 20.7 |
| Tricalcium aluminate, C ₃ A (%) | 10.2 |
| Tetracalcium aluminoferrite, C ₄ AF (%) | 5.7 |
| Gypsum | 4.4 |
| Hemihydrate | 1.6 |
| Anhydrite | 0.2 |
| Calcite | 2.1 |
| Lime | 0.1 |
| Portlandite | 2.0 |
| Quartz | 0.9 |
| ASTM C204-blaine fineness (m ² /kg) | 442 |

Table 2

Admixture compositions.

| | Component | Percent (max) |
|-------------------------------------|--|---------------|
| Calcium-nitrate based Type E | Calcium nitrate | 30–50% |
| | Calcium nitrite | 2–5% |
| | Sodium thiocyanate | 2–5% |
| | TEA | 0.1–1% |
| Calcium-chloride based Type E | Calcium chloride | 25–50% |
| | Potassium chloride | 1–10% |
| | Sodium chloride | 1–10% |
| | TEA | 1–10% |
| Calcium-lignosulfonate based Type D | Sulfite liquors and cooking liquors, spent, alkali-treated | 25–50% |
| | Molasses | 10–25% |
| | TEA | 1–10% |

since patented in 1969 [16]. Calcium nitrites have been shown to be a very effective form of protection from corrosion [16–19] and have shown strength developments comparable to calcium chloride [20]. Sodium thiocyanate is a hardening accelerator. Justnes described it as possibly the “most promising single compound” as a hardening accelerator, resulting in an increase in compressive strength of 121% after 1 day at 20 °C and 113% at 2 days at 5 °C [8]. Calorimetry measurements by Abdelrazig et al. [19] showed sodium thiocyanate to have a small effect on the induction period but a large increase in the main hydration peak. Small dosages of TEA are usually used with other accelerators and rarely by itself. TEA has been shown to accelerate C₃A reaction while retarding C₃S hydration [4]. The water-reducer/retarder contained a large amount of calcium lignosulfonate-based material and also included TEA which is known to cause retardation of C₃S hydration when present at high concentrations [20].

An Oolitic limestone, in accordance with ASTM C33 #57 stone [21], was used as coarse aggregate with specific gravity (SSD) of 2.49 and an absorption capacity of 3.04%. Siliceous sand was used as fine aggregate having a specific gravity (SSD) of 2.64, an absorption capacity of 0.34%, and a fineness modulus of 2.35.

Table 3 shows the four concrete mixture designs. The dosage for the calcium-nitrate accelerator was based on a similar set time at 38 °C as the calcium chloride-based accelerator since many repair slabs are mixed at higher temperatures to gain early strength quickly. In order to maintain the water-cement ratio (w/c) constant for all mixtures at 0.38, the amount of mixing water was adjusted for the water present in the accelerating admixtures. The calcium chloride-based accelerator had a water content of 61%, while the calcium nitrate-based accelerator had a water content of 46%. The contribution of AEA and Type D admixtures to the mixing water was low and not taken into account.

Table 3

Mixture design.

| Materials | Mixture | | | |
|--|---------|------|------|------|
| | C | CNA | CA | CAD |
| Cement (kg/m ³) | 534 | 534 | 534 | 534 |
| Coarse Agg (SSD) (kg/m ³) | 997 | 997 | 997 | 997 |
| Fine Agg (SSD) (kg/m ³) | 492 | 492 | 492 | 492 |
| Mixture water (kg/m ³) | 206 | 206 | 195 | 190 |
| AEA (mL/100 kg cement) | – | 22 | 22 | 22 |
| Type D (mL/100 kg cement) | – | 326 | 326 | 326 |
| Type E (chloride-based) (mL/100 kg cement) | – | – | 2782 | – |
| Type E (nitrate-based) (mL/100 kg cement) | – | – | – | 4173 |
| w/c ratio | 0.38 | 0.38 | 0.38 | 0.38 |

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