National Concrete Pavement Technology Center

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Freeze-Thaw Durability of Low-Permeability Concrete

tech transfer summary

Water-binder ratio, cementitious materials, and air entrainment affect the freeze-thaw durability of low-permeability concrete.

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RESEARCH PROJECT TITLE
Investigation into Freezing-Thawing Durability of Low-Permeability Concrete with and without Air Entraining Agent

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The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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Objectives

- Investigate whether low-permeability concrete made with reduced water-binder ratios (w/b) and/or supplementary cementitious materials (SCMs) need air entrainment to achieve freeze-thaw (F-T) durability.
- Determine the value of the limiting w/b, or the w/b value below which air entrainment becomes unnecessary for good concrete F-T durability.
- Examine the effects of cement type and SCMs on the effectiveness of air entrainment and the limiting w/b or permeability values.

Problem Statement

In cold climates, cyclic freezing and thawing can lead to pavement deterioration. Several concretes have been designed to avoid F-T damage. For example, impermeable concrete that minimizes the amount of freezable water, such as very low w/b mixes that use all water for cement hydration, are theoretically less susceptible to F-T damage. High-strength concrete should also avoid F-T damage because the concrete's very fine pores greatly lower the freezing point of any trapped water. Adding SCMs, especially silica fume, can reduce pore size and thus make water unable to freeze at ambient temperatures.

In most concrete, proper air entrainment provides micro-air bubbles where freezing water can expand. However, it is unclear whether very low permeability or high-strength concrete needs air entrainment to maximize F-T durability. Moreover, the limiting w/b value, or the value below which air entraining admixture (AEA) is unnecessary for good F-T durability, has not been definitively established.

Research Methods

Sixteen concrete mix samples were made with the following variables:

- Type I cement (with 15% class C fly ash) or Type IP cement (with 25% class F fly ash)
- w/b of 0.25, 0.35, 0.45, or 0.55
- With or without air entraining admixture

All concrete mixtures were given a similar slump using different dosages of high-range water reducing agent.

The following concrete properties were tested:

- Air void structure, (AVA, RapidAir, and ASTM C642 porosity tests)
- General properties: slump, air content (ASTM C231), unit weight, 28-day compressive strength
- Rapid chloride permeability (ASTM C1202)
- F-T durability (ASTM C666A)

Key Findings

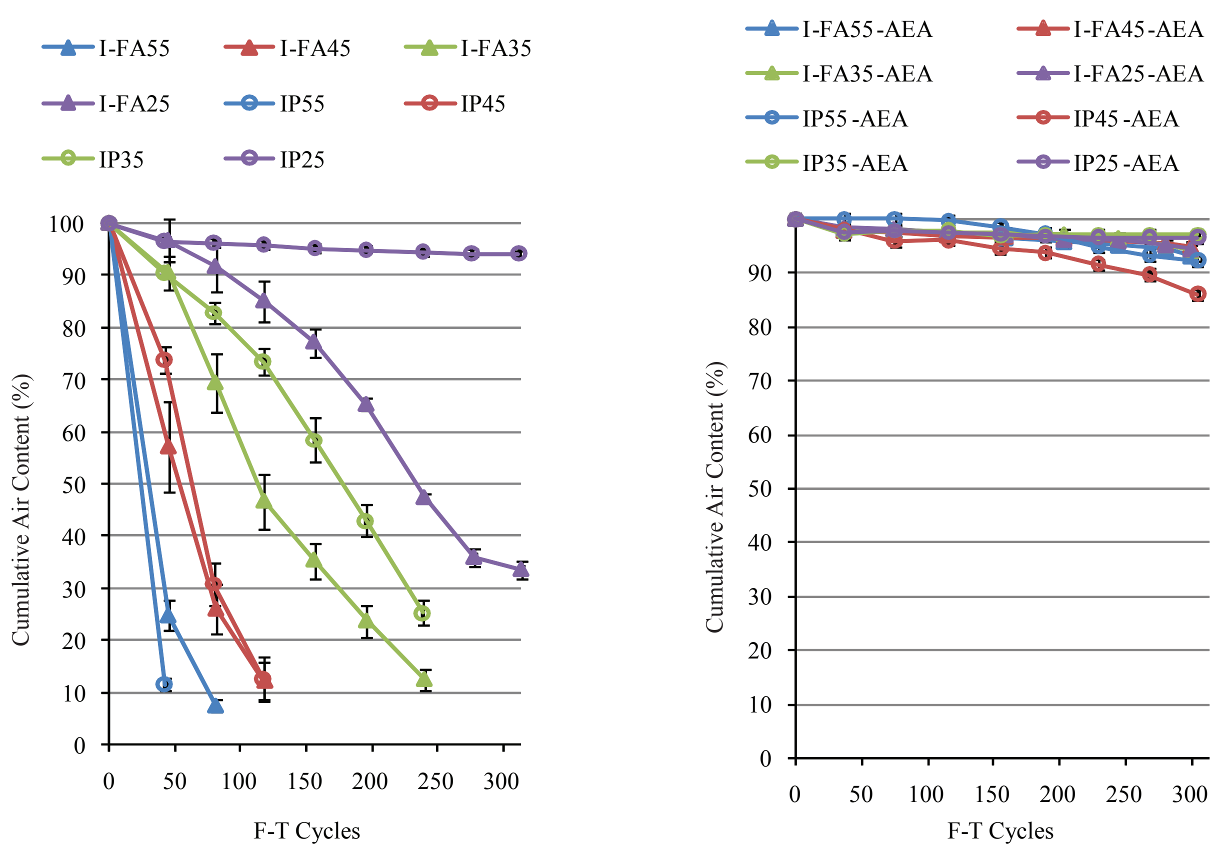
- All of the mixes with proper air entrainment (air content ≥ 6%) showed good F-T resistance (durability factor ≥ 85%). All mixes without AEA showed poor F-T resistance (durability factor < 40%), except for one mix made without fly ash and with a w/b of 0.25.
- To achieve a durability factor of 85% or greater, the limiting w/b of concrete with Type IP cement without AEA was estimated to be 0.26. For concrete with Type I cement and 15% class C fly ash but without AEA, the limiting w/b was estimated to be 0.19. These thresholds either cannot be achieved in the field or are impractical.
- The F-T durability of concrete without air entrainment increases as both permeability decreases and strength increases.
- For concrete without AEA, F-T durability was clearly related to hardened concrete properties. Such relationships were not evident in concrete with AEA.
- For concrete with AEA, good F-T durability was associated with an air void spacing factor ≤ 0.28 mm (measured by AVA) or ≤ 0.22 mm (measured by RapidAir).

Implementation

Even for high-performance concrete, it is quite common to use air entrainment when the concrete will experience freezing and thawing conditions. In this project, good concrete F-T durability was associated with a proper air system, especially the proper amount of small air voids and spacing factor. Without air entrainment, the combination of low permeability and high strength makes concrete F-T durable. Though it is difficult to achieve in the field, such low-permeability, high-strength concrete can be made with the following methods and materials:

1. Supplementary cementitious materials, such as fly ash, slag, metakaolin, or silica fume
2. An increased degree of hydration via longer moist-curing periods
3. A lower water-to-cement ratio

Additionally, aggregate properties and gradation must be considered carefully.



Relative dynamic modulus values for concrete samples without AEA (left) and with AEA (right), showing that samples without AEA deteriorate quickly during freeze-thaw cycles