BENEFITS OF AIR ENTRAINMENT IN HPC

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The development of air-entrained concrete in the mid-1930s was one of the greatest advances in concrete technology. Air-entrained concrete contains small and stable air bubbles that are uniformly distributed throughout the cement paste. Air-entrained concrete is produced through the use of either air-entraining portland cement or air-entraining admixtures. Benefits of entrained air are apparent in both the fresh and hardened concrete. The most important benefit in concrete is the improved freeze-thaw resistance of hardened concrete that is exposed to freezing and to deicing chemicals while critically saturated. In fresh concrete, workability is improved and bleeding is reduced.

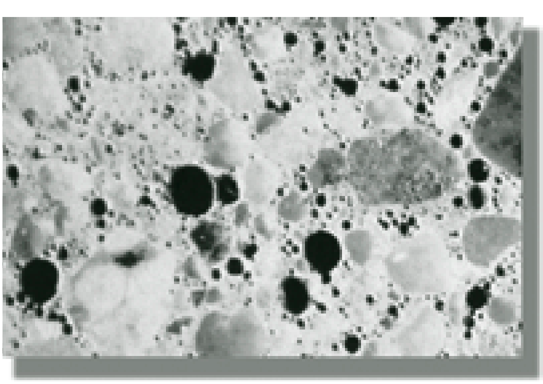
Total Air Content

Current U.S. field quality control practice usually involves the measurement of only total air volume in freshly mixed concrete. The most common test methods are the pressure method (AASHTO T 152) and the volumetric method (AASHTO T 196). It is important to note that these tests refer only to the total air content and do not address the air-void size in any way. The AASHTO Bridge Specifications for Class A(AE) concrete require a total air content of 6 percent with a tolerance of ± 1.5 percent and a maximum aggregate size of 1 in. (25 mm). For Class P concrete, the air content is to be specified in the contract documents.

Air-Void System

The total air content can be misleading. Spacing, size, and number of air voids are very important factors. They determine the quality of the air-void system. As the water in concrete freezes, it needs to find an empty space in a bubble within a short distance. Thus, as the water freezes, it can expand freely, eliminating any buildup of internal pressure—the principal cause of freeze-thaw damage such as scaling. Therefore, properly air-entrained concrete needs to have closely spaced air voids that are extremely small in size. The majority of voids in normal air-entrained concrete are between 10 μm and 100 μm in diameter.[1]

Cross-section of an air-entrained concrete.



Spacing Factor and Specific Surface

The following two air-void characteristics are considered a prime requirement of a good air-void system: [1, 2]

1. Calculated spacing factor, $\bar{L}$, (an index related to the distance between bubbles but not the actual average spacing in the system): less than 0.008 in. (0.200 mm)
2. Specific surface, a, (surface area of the air voids): 600 in.^{2}/in.^{3} (24 mm^2/mm^3) of air-void volume, or greater

The standard test for air-void parameters is ASTM C 457, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.

Durability vs. Strength

Air entrainment greatly increases concrete durability but reduces concrete strength. Compressive strength is generally reduced by 2 to 9 percent for each percentage point increase in air content.[3] Therefore, adequate strength and maximum durability are achieved by establishing optimum air contents and spacing factors.

Air Entrainment for HPC

For bridge decks, piles, piers, and parking structures, where durability in a freeze-thaw environment is required, air entrainment is mandatory. However, for certain high performance concretes with low water-cement ratios, the requirements for total air content might be too conservative.[2] Certain high strength concretes do not need as much air as conventional strength concretes to be frost resistant due to reduced porosity and less freezable water within the high strength concrete. Pinto and Hover found that non-air-entrained concretes had good frost and deicer-scaling resistance at a water to portland cement ratio of 0.25.[2] Other research has indicated excellent durability of certain non-air-entrained high performance concretes to freeze-thaw damage and salt scaling.[3]

Attention should be paid to air-entraining admixture types and their dosage rates, since certain properties of supplementary cementing materials used in HPC, such as the carbon content of fly ash, greatly influence air-void system stability. Trial mixes to ensure adequate concrete air entrainment are important.

While high performance concrete with very low water-cementitious materials ratio is widely believed to be resistant to scaling and physical breakup due to freezing and thawing, it is still considered prudent to use air entrainment.[3] No well-documented field experiments have been made to prove that air entrainment is not needed in HPC. Until such data are available, current practice for air entrainment should be followed for all concrete—conventional and high performance.

References

1. Whiting, D. A., and Nagi, M. A., "Manual on Control of Air Content in Concrete," EB116, National Ready Mixed Concrete Association and Portland Cement Association, 1998, 42 pp.
2. Pinto, R. C. A. and Hover, K. C., "Frost and Scaling Resistance of High-Strength Concrete," RD122, Portland Cement Association, Skokie, Illinois, 2001, 75 pp.
3. Kosmatka, S. H., Kerkhoff, B., and Panarese, W. C., "Design and Control of Concrete Mixtures," EB001, Portland Cement Association, Skokie, Illinois, 2002, 368 pp.

Editor's Note

This article is the eighth in a series that addresses the benefits of specific materials used in HPC. The benefits of silica fume, lightweight aggregate, different cements, slag cement, fly ash, corrosion inhibitors, and chemical admixtures were discussed in previous issues of HPC Bridge Views.