Air-Entraining Admixtures

Freeze-thaw weathering is one of the most powerful destructive forces in nature. Over time, this natural erosion process can turn the hardest boulders into pebbles. This process is fairly straight forward: water fills a crack or crevice, temperatures fall, then as water turns to ice, it expands roughly 9% in volume, pushing against the inner walls of the crevice. Over time, this outward pressure will force the crevice open, eventually causing large rocks to separate into countless smaller rocks.

Concrete is no different: Freeze-thaw cycles pose one of the greatest challenges to concrete durability. Protection against this challenge must be included as part of the design of a precast concrete product, and air-entraining admixtures are one part of the solution to preventing damage from freeze-thaw forces. During the 1930s, certain sections of highway were found to be withstanding the effects of freeze-thaw better than others. Studies of the pavement found that the more durable concrete was produced from cement milled at plants using beef tallow as a grinding agent. The beef tallow acted as an air-entraining agent, improving the durability of the concrete.

As water is mixed with cement, the hydration process begins. This process can be thought of as growing interlocking crystals. Hydration leaves capillary cavities (a.k.a. "bleed channels") that become filled with water when a precast product is exposed to the environment. As the water freezes it exerts pressure on the concrete that exceeds its tensile strength, causing cracking and eventual disintegration. Since the 1950s, entrained air has provided a relief system for that pressure by providing avenues for the expansion caused when the water freezes.

It is important to note that entrained air is not the same as entrapped air. Entrapped air refers to the natural 1% - 3% voids that are created during the mixing and placement of the concrete. These voids are irregularly shaped and spread throughout the product. While providing no positive benefits, they can have a negative effect on appearance, strength and durability. Proper vibration techniques can remove entrapped air.Entrained air is usually created by the addition of a liquid admixture specifically designed for that purpose. The goal is to develop a system of uniformly dispersed air voids throughout the concrete. Proper use of air-entraining admixtures ensures the development of the correct spacing, size (usually measured in micrometers) and amount of these voids. These voids

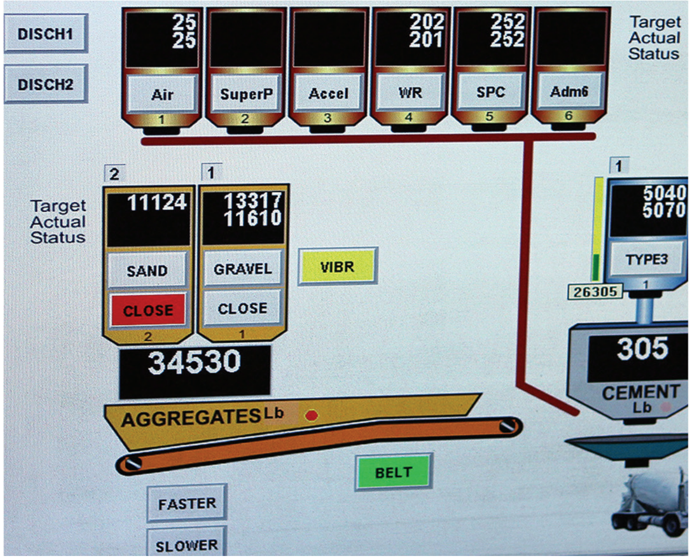

Photo courtesy MPAQ Automation

Computer monitor showing admixture options

basically absorb the pressure created by the expansion of the freezing water.

The criteria for spacing is defined as the maximum distance that the water would have to move before reaching the safety valve of the air reservoir: essentially the halfway point between two bubbles ACI 201 recommends that the "spacing factor" should not be greater than 0.008 in (0.2mm).
The size of these voids is also important. The "specific surface" is the average surface area of the voids in hardened concrete per unit volume of air. The bigger the specific surface, the smaller the bubble size. The specific surface necessary for adequate resistance to repeated freezing and thawing is generally recommended to be greater than 600 in.^{2}/in.^{3} (24mm^2/mm^3).

One of the concerns with the use of air-entraining admixtures is that they can decrease the strength of the concrete. Typically an increase of one percent (1%) in air content will decrease compressive strength by approximately five percent (5%). Therefore, it is important that air content be closely controlled.

The National Precast Concrete Association Quality Control Manual recommends air content tests to be conducted at least daily or for every 150 yards of concrete produced, whichever is most frequent. However, state and local specifications may require more frequent testing. The air content test should be conducted in accordance with either ASTM specification C173 (“roller-meter”) or C231 (“pressure meter”). Note: ASTM specification C172 requires all samples for acceptance testing be taken from the middle portion of the batch.

Per the ACI 318 Building Code Requirements for Structural Concrete, the recommended target air content varies with severity of exposure and aggregate size. For instance, 3/8 in (9.5mm) aggregate with a severe exposure requires 7.5% air content, while the same aggregate with moderate exposure requires 6% air content. A 1 in. (25 mm) aggregate requires 6% for severe and 4.5% for moderate exposure. Air-entraining agents are generally added to the mix in a range from .25 to 3 fluid ounces per 100 lbs. (16-196ml/100kg) of cementitious materials, but higher or lower dosage rates are not unusual. These are large ranges, and usage should be determined after consultation with your admixture supplier, consideration of mix design, materials and conducting trial batches.

There are many factors that affect the air content of concrete when using admixtures. The finer the cement, the lower the air content. Similarly, fine supplementary cementitious materials (SCMs) such as coal ash, particularly those with high amounts of residual carbon or treatment, can reduce the effectiveness of air-entraining admixtures. An increase in fine aggregates passing the Number 100 sieve will lower the air content, as well as dust on coarse aggregates. Lower water content or water/cementitious ratios generally require higher AEA dosages, and hard water and small amounts of detergents will also affect air content. Other chemical or mineral admixtures will have an impact and must be included in any trial batches. The load size, mix rate, mix time and condition of mixers will also have an effect.

Today’s air-entraining admixtures are primarily liquids produced from byproducts of wood resins. However, there are new products made from synthetic detergents, sulfonated lignins, petroleum acids, proteinaceous materials and sulfonated hydrocarbons. There are also particulate air-entraining admixtures, composed of hollow plastic spheres and crushed brick. Although outside the scope of this article, there are air-entraining cements that meet ASTM specifications. These cements have an “A” identifier, e.g. C150 Type IA, C595 Type IL(A) or C1157 Type HE(A).

Microscopic photo of concrete showing air bubbles

The specifications for air-entraining admixtures are covered in the ASTM C260. This specification sets limits on the impact of the admixture on bleeding, set time, strengths, compressive and flexural strengths, freeze-thaw resistance, and length change during drying. The manufacturer of the admixture should certify that its product conforms to this specification.

Entrained air is one of the critical techniques available to precasters to reduce the impact of freeze-thaw processes. It is mandated in most highway applications, particularly where there is heavy use of road salts. However, there are other factors that must be taken into consideration. Correct placement, consolidation and finishing will help ensure the proper air content. The use of any admixture can be a valuable tool to make concrete better and more durable, but it cannot compensate for poor workmanship.

NATIONAL PRECAST CONCRETE ASSOCIATION