Can Dry-Mix Shotcrete Be Air Entrained?

by Jean-François Dufour

Can dry-mix shotcrete be air entrained? Is shotcrete not a proven method of pneumatically placing concrete? The answer to these questions is a resounding yes! In fact, not only can dry-mix shotcrete be air entrained, but in areas of repetitive freezing-and-thawing cycles, dry-mix shotcrete should be air entrained. Air entrainment, except perhaps for some high-performance concrete, is necessary to protect concrete against frost action. In North America, air-entraining admixtures (AEA) are required to entrain air in conventionally placed concrete and have been used for more than 50 years. Over the past 10 years, innovative research in shotcrete technology has proven that dry-mix shotcrete can be air entrained, just as wet-mix shotcrete and conventionally-placed concrete can.

Many structures in North America are exposed to winter conditions and need to be repaired. The main causes of deterioration are the corrosion of the reinforcing steel and the action of frost, or freezing-and-thawing cycles with the presence of deicing salts. Most of these repairs are for surface attacked concrete with a depth varying from 1 to 4 in. (25 to 100 mm). Both shotcrete processes, wet- and dry-mix, are often used to rehabilitate these concrete structures, where bond between the substrate and the shotcrete and shotcrete durability are key elements to improve the overall durability of the repair. Although it seems that more people clearly understand the benefits of air-entrained wet-mix shotcrete, it appears that some are still skeptical as to the possibility of air entraining dry-mix shotcrete.

Two classes of AEAs can be used to entrain air in dry-mix shotcrete: ASTM Class A liquid and Class B nonliquid (or powdered) admixtures. The AEAs used in shotcrete are the same as those used in conventionally-placed concrete. Any concrete mixture that is placed through the shotcrete process needs to be specifically designed to be shot, and the same principle applies when an AEA is used; proper dosage must be selected and compatibility with the cementitious materials used should be verified.

Liquid AEA can be used when introduced with the mixing water on site, which is usually done by adding the AEA into a water tank used for shotcreting. Although many studies have shown the beneficial effect on shotcrete durability of this system, some disadvantages are associated with it. Additional equipment (water tanks and measuring devices) is required and the dosage of the admixture must be precisely controlled and measured by someone on site.

In an effort to improve the current system, nonliquid or powdered AEAs have been proven to be an effective method of entraining air in dry-mix shotcrete. Quality assurance and quality control programs are enhanced when fewer raw materials are added on the job site. When prepackaged dry material is used, powdered AEAs can be preblended with the other dry ingredients of the shotcrete mixture and weigh-batched according to the cement content. This ensures that the admixture is accurately dosed. When the dosage at the source is consistent and not a function of the water introduced at the nozzle to get the desired mixture consistency, a consistent air-void system can then be expected.

Although the scope of this article is not to describe all the theories of frost action in concrete, one must understand the basics of how non-air-entrained concrete deteriorates when exposed to freezing-and-thawing cycles. It is well documented that when temperatures fall below 32 °F (0 °C), water in the concrete capillaries (pores) begins to freeze, causing an increase in volume. If the cement paste is saturated, the capillary pores become full and a certain amount of water is squeezed out because of the inability of the pores to expand. This water must move toward the only available places in which it can freeze without causing any damage (that is, the air voids within the cement paste). When these air voids are absent or the distance between the voids is simply too great for the water to travel, hydraulic pressure within the capillaries is created. If that pressure exceeds the tensile strength of the cement paste, cracking occurs.

The objective when air entraining concrete is therefore to minimize the distance between adjacent bubbles and reduce the distance that freezing water must travel to escape and release hydraulic pressure. When tested, this maximum distance is defined as the spacing factor.

Most literature on the subject considers dry-mix shotcrete durable to freezing-and-thawing cycles with or without the presence of deicing salts when the spacing factor is limited to a maximum of 12 mil (300 μm) as per ASTM C457. One should not be confused between air content and spacing

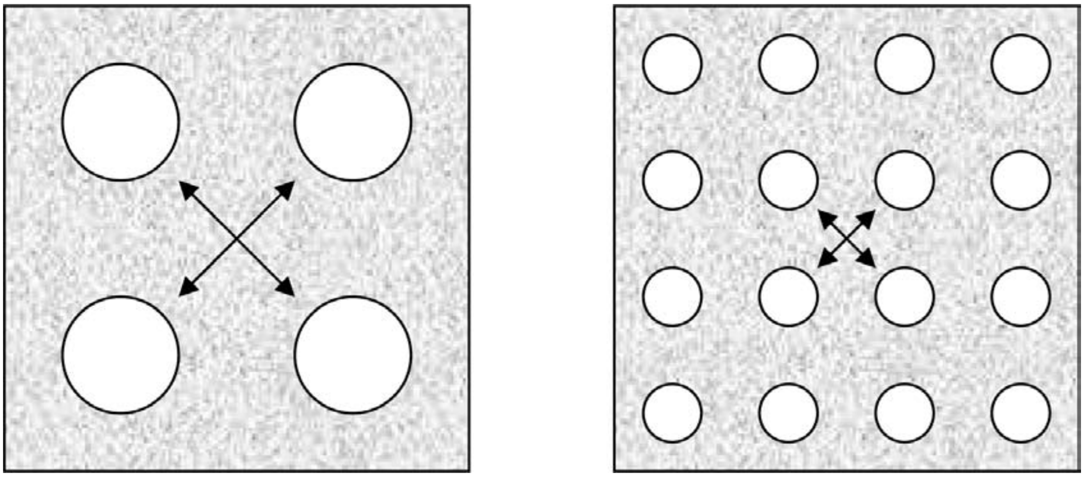

Fig. 1(a) and (b): Illustration of the influence of the size of air voids on the value of the spacing factor for an equivalent air content

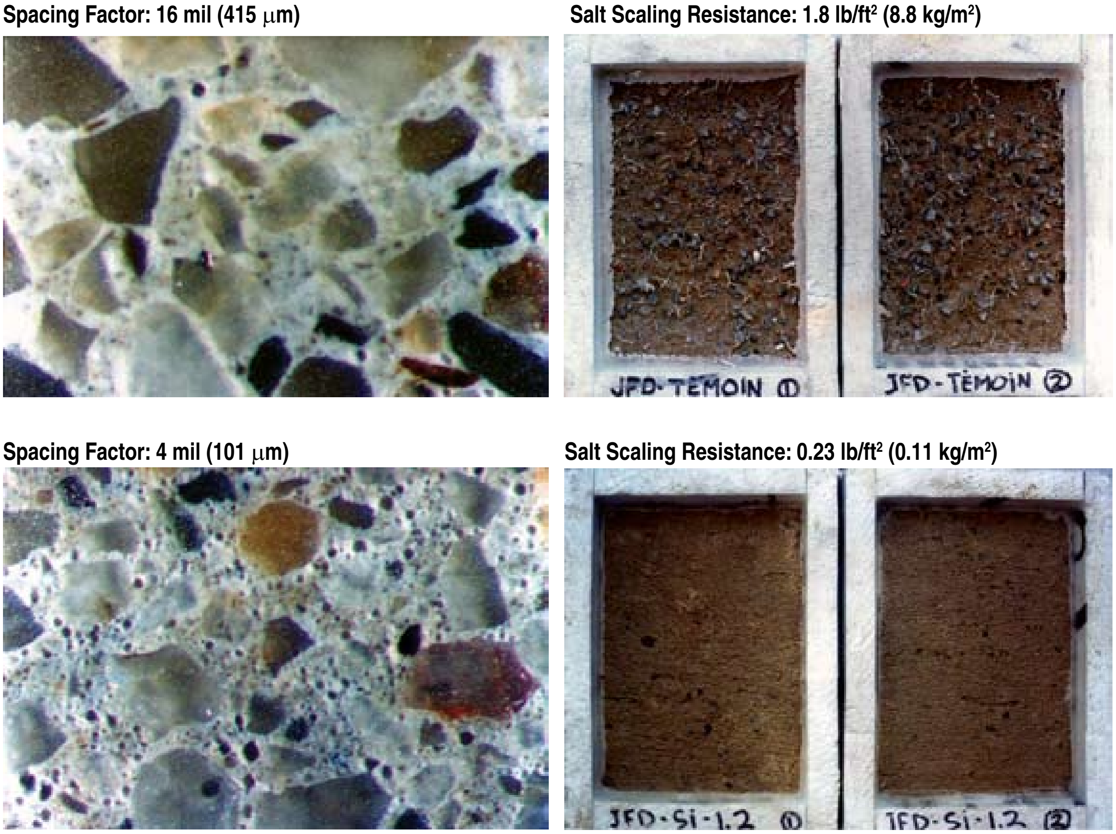

Fig. 2: Non-air-entrained versus air-entrained dry-mix shotcrete—air void system, ASTM C457 (60× magnification) and salt scaling resistance, ASTM C672

factor, as adequate air contents do not necessarily guarantee an adequate spacing factor. Shotcrete with a measured air content of 6% may provide a spacing factor above 12 mil (300 µm), which will not be sufficient to ensure long-term durability (Fig. 1(a)). Low spacing factors will be achieved when a large number of small microscopic air bubbles are retained into the cement paste (Fig. 1(b)).

By the nature of the process, non-air-entrained dry-mix shotcrete mixtures produce entrapped air voids, which are significantly larger than entrained voids. As a result, the presence of larger entrapped voids increase the air content without offering any significant protection against scaling due to freezing in the presence of deicing salts.

In dry-mix shotcrete during the shooting process, a large number of small entrained air voids are created through the presence of an AEA. This process also produces turbulence that promotes the mixing action (both in the nozzle and upon impact of the surface), which also enhances the production of air bubbles in the mixture. The AEA stabilizes these bubbles, just as in conventionally-mixed concrete.

Without presenting all the results from all the available literature on the subject, Fig. 2 illustrates air-entrained versus non-air-entrained dry-mix shotcrete microstructures with the corresponding deicing salt scaling performance as per ASTM C457 and C672, respectively. These photos demonstrate that air entrainment in dry-mix shotcrete offers increased durability performance when shotcrete is exposed to freezing-and-thawing cycles in the presence of deicing salts. The industry standards usually limit salt scaling surface loss to a maximum of 0.2 lb/ft^2 (1 kg/m^2).

In addition to producing durable dry-mix shotcrete, air entrainment also offers great plastic mixture consistency to facilitate reinforcing bar encapsulation. Although this is beyond the scope of this article, more information can be found on the subject in the References.

For many years, ACI 506R, "Guide to Shotcrete," did not recognize the benefits of adding AEA into dry-mix shotcrete. The revised version of the Guide, published in 2005, does. Cold winters are common in many areas of North America. Codes of practice prescribe stringent requirements for concretes exposed to freezing-and-thawing cycles. If these elements are present for concrete construction, they are also present for dry-mix shotcrete repairs. The technology is proven and available. Why not use it?

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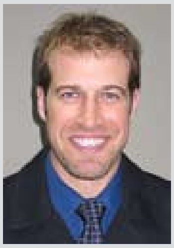

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