Testing Air Content of Dry-Mix Shotcrete

By Lihe (John) Zhang

It has been well-established that the freezing-and-thawing resistance of concrete is improved by air entrainment. Air-entraining admixtures are often added to both wet- and dry-mix shotcrete primarily for durability considerations.[1-4] If shotcrete is required to have freezing-and-thawing resistance, a typical engineering specification will require:

- As-shot air content: 2.5 to 5.5%; and
- As-batched air content: 4 to 7%, 5 to 8%, or 6 to 9%, depending on exposure condition and maximum size of the aggregates.

It is a common practice to add air-entraining admixture into the wet-mix shotcrete because it is often batched as ready-mix concrete.

However, the question has been raised, from time to time, on whether dry-mix shotcrete should be air-entrained. About two decades ago, researchers and engineers originally developed the concept of air-entrained dry-mix shotcrete,[1-3] and its use is well-proven today.

It is widely recognized in the shotcrete industry that the air content of the as-batched shotcrete will drop during the shooting process. This results from high-velocity impact from the shotcrete process tending to "knock out" air from the mixture and thus reduce the air content of the in-place shotcrete. The as-shot air content in the in-place shotcrete is typically below 6% regardless of how high the as-batched air content was before shooting.[4] Testing for air content in the hardened shotcrete can be conducted by air voids analysis using the ASTM C457 test procedure. However, this test is time consuming and expensive and is thus not often used as a quality control (QC) test. This article provides project testing data for the as-shot air content for the dry-mix shotcrete.

An air meter is used to measure the air content of the plastic shotcrete or concrete. For the purposes of this article, air content measured at the point of discharge from the truck or at the end of the pump hose is referred to as-batched air content. Air content measured by shooting directly into the air meter base, or shot against a wall, into a wheelbarrow, or even into a basket, and then scraped out to fill the air meter, is called as-shot air content. Sometimes, the terminology of "air content at nozzle" is also used (erroneously) for the as-shot air content.

Air Content for Steel Fiber-Reinforced Dry-Mix Shotcrete

During a recent project in British Columbia, Canada, steel fiber-reinforced dry-mix shotcrete was applied for rock stabilization (Fig. 1).

The project specification required:

- 7-day compressive strength: at least 4400 psi (30 MPa);
- 28-day compressive strength: at least 5800 psi (40 MPa);
- Boiled absorption: maximum 8%;
- Volume of permeable voids: maximum 17%; and
- As-shot air content: 2.5 to 5.5%.

To meet the project specification and the durability requirement for freezing-and-thawing resistance, air-entraining admixture was added—in a powder format—into the pre-bagged materials of dry-mix steel fiber-reinforced shotcrete.

As-shot air content was tested to ASTM C231. The dry-mix steel fiber-reinforced shotcrete was shot on the ground in a pile. The shotcrete sample was taken from the piled shotcrete and tested for as-shot air content. The resultant as-shot air content is plotted in Fig. 2. Results show that the as-shot air content ranges from 2.7 to 5.0%. The average as-shot air content is 3.7%, with a coefficient of variation (COV) of 14.5%, and standard deviation of 0.5%.

Plot Air Content versus Compressive Strength

A typical air-entrained shotcrete dry-mix design will have an as-shot air content of approximately 3 to 5%. It is generally known that higher air content will generally reduce the compressive strength for cast-in-place (CIP) concrete.[5]

The correlation for as-shot air content versus 28-day compressive strength is plotted in Fig. 3 for the dry mix previously introduced in Fig. 2. As expected, there is no clear relationship between the two properties as opposed to CIP

Fig. 1: Steel fiber-reinforced dry-mix shotcrete

concrete. Indeed, the mechanisms behind the formation of an air bubble during placement of dry-mix shotcrete as well as those involved in rebound are all leading to a final in-place composition, where different factors (such as water-binder ratio, binder content, and air content) can have opposite effects on the resulting compressive strength. What is clear, however, is that even the highest air content measured allowed (4.8%) reached more than satisfactory compressive strength results.

Discussion

Why Do We Use Air Entrainment?

Entire papers could be written and research conducted as to the effect of different shotcrete-related parameters (including water content, velocity, and process) on the as-shot air content. However, the real question is whether or not we are able to generate a dense enough network of small air bubbles in the hardened shotcrete to protect it from freezing-and-thawing damage (that is, a small enough spacing factor). Unfortunately, the real answer comes from a test usually conducted only when qualifying a specific mixture design (ASTM C457, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete"); its relevance in QC is little because the test has to be conducted on hardened concrete/shotcrete samples, usually after more than 28 days. When an air-entraining admixture is incorporated in the mixture, the as-shot air content is an indirect measurement of the level of success we have in creating the dense small

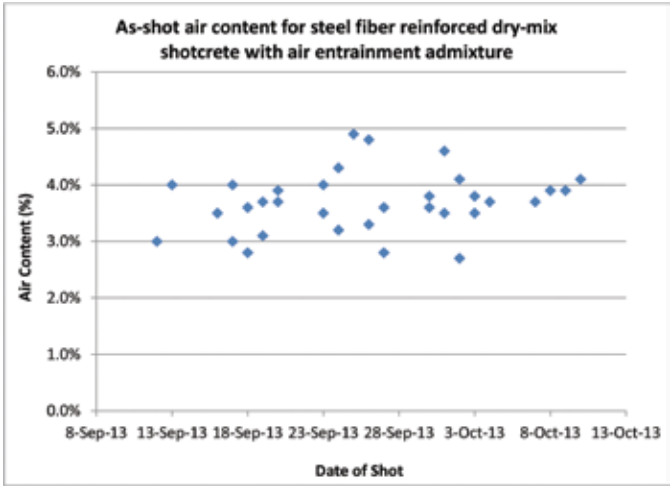

Fig. 2: As-shot air content for dry-mix steel fiber-reinforced shotcrete (air-entrained)

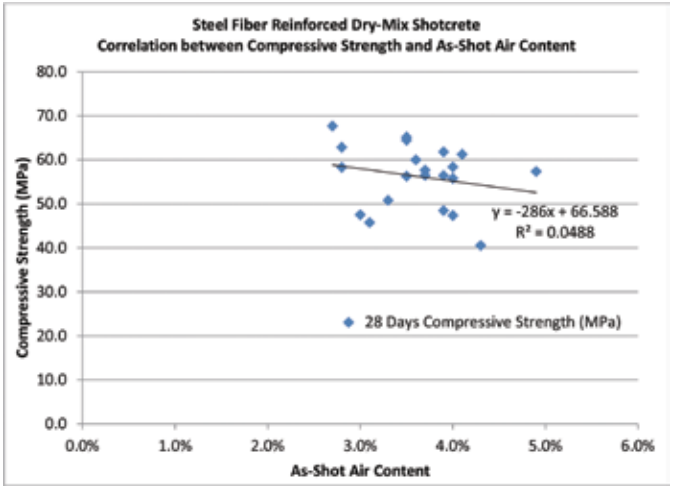

Fig. 3: Correlation between 28-day compressive strength and as-shot air content

bubble network; the as-shot air-content is therefore an excellent QC test.

Is It Possible To Test Air Content For Dry-Mix Shotcrete?

As water is added into the nozzle during the dry-mix process, the as-batched air content for dry-mix shotcrete cannot be tested. The as-shot air content for dry-mix shotcrete can be tested by shooting a pile to the ground or to the wall—samples can be taken from the as-shot shotcrete and tested in the air meter. Shooting directly into the air meter is not recommended, as that might damage the air meter.

References

1. Vezina, D., and Bertrand, J., "The Development of Air Entrained Durable Shotcrete for Structural Repairs," *Proceedings, Shotcrete for Underground Support VII*, Telfs, Austria, June 11-15, 1994.

2. Seegebrecht, G.W.; Litvin, A.; and Gebler, S.H., "Durability of Dry-Mix Shotcrete," *Shotcrete*, V. 8, No. 2, Spring 2006, pp. 32-35.

3. Dufour, J.F., "Can Dry-Mix Shotcrete be Air Entrained?" *Shotcrete*, V. 10, No. 4, Fall 2008, pp. 28-30.

4. Zhang, L., "Air Content in Shotcrete: As-Shot vs. As-Batched," *Shotcrete*, V. 14, No. 1, Winter 2012, pp. 50-54.

5. Neville, A.M., *Properties of Concrete*, fourth edition, Pearson, New York, 1995, pp. 559-561.

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