Shotcrete Testing around the World

By Lars Balck

Charles Hanskat's article on "Shotcrete Testing—Who, Why, When, and How"[1] in the Summer 2011 issue of *Shotcrete* magazine provided us with an excellent overview of shotcrete testing in the United States. As Charles pointed out, the purpose of testing is project quality assurance (QA), which should verify the designer's intent, and quality control (QC), which should confirm the contractor's performance. This article is meant to give the reader an introduction into the world of testing of concrete used for shotcrete outside the United States.

Fifty years ago, concrete was just tested for compressive strength. No thought was given to durability other than the concept that "the stronger the concrete, the longer it will last," and to a degree, compressive strength of concrete is a good rough indicator of durability. Today, however, we have a better understanding of concrete properties affecting durability. To properly evaluate concrete's longevity, specific durability tests are needed to give us a better indication of a concrete structure's longevity for a particular service or environment than just testing for compressive strength alone.

Durability requirements not only give us a better understanding of the service life of a structure but can vary depending on location. In Canada, durability requirements are different than in the Middle East. Due to an extended exposure to freezing conditions, concrete durability in Canada focuses on tests that measure concrete's ability to resist freezing-and-thawing cycles and resistance to deicer salt scaling. In the Middle East, older concrete structures are crumbling from within due to corroding internal reinforcement. The corrosion is caused by salts and sulfates included in the original concrete mixtures. Local cement, aggregates, and even water contain chlorides. To prevent internal corrosion, the Qatar Construction Standard (QCS) 2010 specifies frequent testing for chlorides per ASTM C1218, "Standard Test Method for Water-Soluble Chloride in Mortar and Concrete." This is the same test that ACI 318 specifies for measuring chlorides in concrete, but is seldom measured in the United States. In addition, the QCS 2010 requires a test for durability that is actually four separate tests: water penetration, water absorption, rapid chloride penetration, and absorption.

Testing around the world is really no different than testing in the United States. Project needs and often governing codes are what determine which tests are needed or required on a project, whether the project is in Atlanta, GA, or Shanghai, China. Engineers design structures to carry design loads and endure environmental conditions. So project requirements dictate what tests are required. Mining and tunneling shotcrete projects, whether in Canada or Latin America, are concerned about rapid strength gain, so early-strength tests are conducted, and because most tunnel and mining shotcrete is fiber reinforced, it is appropriate that tests for flexural toughness are typically specified.

What makes testing around the world different is standards and which standard developing organization (SDO) develops those standards. There are many different standards throughout the world to test for basically the same thing. Also, the test results can vary significantly depending on what standards are specified. For example, testing results for water-soluble chloride using the ASTM standards can vary substantially from results using British standards due to far different procedures used in the testing, even though both are supposed to result in determining the percentage of chloride in a material.

Every country wants to control commerce within its borders, so every country specifies its own standards. Fortunately, most countries adopt common national standards developed by independent SDOs that are developed using a consensus process involving owners, suppliers, engineers, and contractors. The most prominent international standards are:

- American Society Testing Materials (ASTM);
- British Standards Institute (BSI);
- Deutsches Institut fur Normung (DIN);

- Canadian Standards Association (CSA)
- Association Francaise de Normalisation (AFNOR); and
- Japanese Industrial Standard Committee (JIS).

In addition, there is the International Organization for Standardization (ISO), which has adopted many of the above standards.

China, as an example, has its own national standards, called GB, from Guo Biao, meaning National Standard. The GB 50086-2001 is specifically design for shotcrete, called "Standard for Rock Anchor Shotcrete Support." It was developed based on BS, EN (European Standard), and ASTM test methods. Many countries like China and Qatar have standards that specify tests from multiple organizations such as BS, EN, and ASTM.

Many countries like Qatar hire design consultants from other countries who specify standards that they know. Thus, a project in Qatar or Singapore may have common ASTM tests specified if the designers are from the United States.

When comparing test results from different parts of the world, it is important to know how tests are performed and the units used. Conversions may be needed, and not just from metric to English. For instance, the British Standards (BS) for concrete compressive strength are much different than the ASTM concrete compressive strength standard. BS concrete compression is done on a concrete cube 6 x 6 x 6 in. (150 x 150 x 150 mm), not a cylinder whose height is twice the diameter (2:1). To compare BS results to U.S. units results requires two conversions. First, a conversion is needed to compare testing a cube to testing a 2:1 cylinder. The second conversion is simply converting from metric to English. As an example, QSC 2010 C40 concrete is 40 N/mm^2 compression on a 6 x 6 x 6 in. (150 x 150 x 150 mm) cube, which is equivalent to 32 MPa 2:1 on a 6 in. wide x 12 in. tall (150 x 300 mm) cylinder, which in turn is equivalent to 4600 psi on a 6 x 12 in. cylinder (40 N/mm^2 [cube] = 32 MPa [cylinder] = 4600 psi [cylinder]).

Summary

Testing provides verification to designers and confirmation to contractors. The driving forces behind testing around the world are specific project needs, and the local codes and standards a project must meet will likely be specified by the local government regulatory agency. Standards chosen by different countries often dictate testing, although more countries are choosing to use nationally recognized standards such as ASTM, BS, and ISO. Be careful when evaluating a test that the proper conversions are done, and that the test results are in line with the specific standards requirements. For example, ACI 318 specifies a maximum of 0.06% water-soluble chloride ion content in a concrete mixture by weight of cement for prestressed concrete and as measured by ASTM C1218. One should not use BS 1881 to meet ACI 318 requirements, for while it also measures chloride content, it does so in a substantially different way than ASTM and with differing results. Standards that seem similar can vary significantly. Know the units and how the tests are conducted.

In the Summer 2013 issue of *Shotcrete* magazine, Charles Hanskat updated readers on U.S. shotcrete standards and tests.[2] Below is a condensed summary of his list.

ACI (www.concrete.org)

- ACI 506.2-13, "Specification for Shotcrete"—recently released
- ACI 506R-XX, "Guide to Shotcrete"—in ballot, needs photos
- ACI 506.1 R-08, "Committee Report on Fiber-Reinforced Shotcrete"
- ACI 506.4R-94, "Guide to Evaluation of Shotcrete"
- ACI 506.5R-09, "Guide for Specifying Underground Shotcrete"

ASTM International (www.ASTM.org)

- ASTM C1140/C1140M-11, "Practice for Preparing and Testing Specimens from Shotcrete Test Panels"
- ASTM C1141/C1141M-08, "Specification for Admixtures for Shotcrete"
- ASTM C1385/C1385M-10, "Practice for Sampling Materials for Shotcrete"
- ASTM C1436 -08, "Specification for Materials for Shotcrete"
- ASTM C1480/C1480M-07, "Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application"
- ASTM C1604/C1604M-05, "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete"
- ASTM C1550-12a, "Test Method for Flexural toughness of Fiber-Reinforced Concrete (Using Centrally Loaded Round Panel)"
- ASTM C1609/C1609M-12, "Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete Using Beam with Third-Point Loading"

In addition, the following tests are frequently used on shotcrete projects:

- ASTM C138/C138M-13a, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete": Plastic density.
- ASTM C143 / C143M-12, "Standard Test Method for Slump of Hydraulic-Cement Concrete": Wet-mix shotcrete only.
- ASTM C231/C231M-10, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method": At pump and as shot.
- ASTM C1604/C1604M-05(2012), "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete": Compressive strength at 7 and 28 Days.

Hardened Shotcrete Properties

- ASTM C642-13, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete": Boiled absorption and volume of permeable voids at 28 days.
- ASTM C1202-12, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration": Rapid chloride penetrability testing.
- ASTM C1556-11a, "Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion": Apparent chloride diffusion (chloride ponding) testing.
- ASTM C1585-13, "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes": Rate of water absorption testing.
- STADIUM Ionic Migration test.
- STADIUM Drying test: flexural toughness for fiber reinforced shotcrete
- RILEM TC-162 TDF

References

1. Hanskat, C., "Shotcrete Testing—Who, Why, When and How," *Shotcrete*, V. 13, No. 3, Summer 2011, pp. 8-12.

2. Hanskat, C., "US Shotcrete Standards Update," *Shotcrete*, V. 15, No. 3, Summer 2013, pp. 44-46.

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