Much is written about the requirements for materials (sand, aggregates, cement and admixtures), equipment, placement methods (wet versus dry), and personnel with respect to the shotcrete process. But, how do we check the quality of the finished product in place after installation?

When testing shotcrete in place, which performance criteria matter the most? Generally, with most shotcrete applications, the density, strength in compression, good resistance to weathering (freezing-and-thawing durability) and bond to substrate materials matter the most. Preconstruction testing of the shotcrete materials used can yield predetermined values for the first three. Performance parameters in job-site testing, however, are required to assess the quality of bond.

Laboratory testing of prepackaged materials to be used at a specified water-cement ratio ($w/c$) can produce results that closely correlate with test results on actual shotcrete in the field. These laboratory test results will depend on the $w/c$ being consistent with that achieved in the field and the weather conditions at the job site not being drastically different. Obviously, the best testing method for the shotcrete is to conduct tests on samples cut or cored from actual shot panels (or the in-place shotcrete) rather than specimens cast in the laboratory. What meaningful results do we actually receive from shotcrete test panels?

- Compressive strength (ASTM C 42);
- Density absorption and permeable voids (ASTM C 642);
- Freezing-and-thawing durability (ASTM C 666);
- Flexural strength (ASTM C 78); and
- Modulus of elasticity (ASTM C 465).

In the installation of hand-applied concrete repair materials, the bond test frequently referenced for many years has been the slant shear test, better defined as ASTM C 882 or ASTM C 1042. For both of these test methods, blanks of concrete are cast with a 60-degree angle and a base 4 in. (100 mm) in diameter. The blanks are then normally cured for 28 days. The surface of the blank is prepared to facilitate good bond between the 28-day-old blank and the new material. The repair material is placed in the mold on the blank. At the desired age (1, 7, 14, and 28 days), the 4 x 8 in. diameter (100 mm x 200 m) cylinder receives a compressive load and the resulting failure determines the bond strength. With respect to both ASTM C 882 and C 1042, both tests’ original function was to identify the effectiveness of a bonding agent applied to the surface. Because the use of bonding agents is not recommended for shotcrete applications, and casting the repair shotcrete against the concrete blank does not provide the same quality of bond as shooting, this test method is not recommended for shotcrete.

In recognition of the limitations of the slant shear test method as it relates to the bonding of new shotcrete material to a substrate, the International Concrete Repair Institute (ICRI) developed its own test for measuring the quality of bond of new concrete to existing concrete surfaces. The resulting ICRI Technical Guideline No. 03739 provides a direct tensile test for in-place testing for the purpose of evaluating bond in concrete structures. The differences between this test and the previously referenced slant shear test are obvious. ICRI has determined that tensile loading can provide a meaningful reflection of the ability of a concrete material to bond to a substrate. ICRI Technical Guideline No. 03739 is similar to the tensile bond strength test shown in ACI 506.4R, Fig. 3.2, and the just-published ASTM C 1583-04, “Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Methods by Direct Tension (Pull-off Method).”

When applying concrete/shotcrete to existing concrete, the intent is to create a composite system, that is, a combination of multiple materials that result in a monolith. Effective and lasting bond between the materials is required to properly create the single composite system.

Creating proper bond requires:

- Proper surface preparation including creating an adequate surface roughness profile (refer to ICRI Technical Guideline No. 03732) and proper moisture preconditioning of the substrate;
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- Good compaction between the new material and the existing substrate;
- Similarity/compatibility of materials;
- Controlled curing of the new material; and
- Controlled job site conditions, particularly with respect to shotcrete substrate and ambient temperature conditions.

Proper adherence to the previous requirements creates a composite of the new material and existing substrate. In-place bond testing can then commence at appropriate ages.

The direct tensile test method requires coring of the composite concrete sample by using a core bit to drill through the newly applied shotcrete and the substrate concrete. Once the core has been cut, a rigid steel disk is attached to the top of the core using a high-strength adhesive (epoxy).

The testing device applies a tensile load perpendicular to the bond line. The testing device applies the load at a constant rate until failure. The failure load is reported and divided by the cross sectional area to determine the tensile bond strength at failure in lb/in.² (MPa).

This direct tension test method measures the bond of shotcrete to concrete and other substrates in a credible way. It is important to note that the results of the slant shear test will generally be much higher, as stated in lb/in.² (MPa), than the results obtained from the direct tension test. Thus, performance requirements between the two test methods will differ substantially and should not be confused. Commonly specified direct tensile bond strength values for shotcrete to properly prepared concrete substrates tend to range from 100 to 150 in lb/in.² (0.69 to 1.00 MPa).

In summary, the direct tensile bond strength test method provides the best means of evaluating the bond of in-place shotcrete. For detailed information on ICRI Technical Guideline No. 03739, go to www.icri.org.

**Calculating the tensile bond strength:**

<table>
<thead>
<tr>
<th>U.S. units</th>
<th>Metric units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pull-off force = 1500 lb</td>
<td>6672 N</td>
</tr>
<tr>
<td>Core diameter = 3.5 in.</td>
<td>88.5 m</td>
</tr>
<tr>
<td>Core area = (\pi(D)^2/4 = 3.14(3.5)^2/4 = 9.61) in.²</td>
<td>(\pi(88.9)^2/4 = 6204) mm²</td>
</tr>
<tr>
<td>Tensile bond strength = 1530/9.61 = 159 psi</td>
<td>6672 N/6204 mm²</td>
</tr>
</tbody>
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