Top Ten Sustainability Benefits of Shotcrete

The United States Green Concrete Council's (USGCC) book, *The Sustainable Concrete Guide—Applications*, includes a list of the top 10 sustainability benefits of shotcrete in its chapter on shotcrete. Over the next 10 issues of *Shotcrete* magazine, this Sustainability column will elaborate on each one of the listed advantages. Previous discussion of advantages from past issues can be viewed on the ASA website at **www.shotcrete.org.** Look in the "Why Shotcrete?" section for "Sustainability."

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1. Formwork savings of 50 to 100% over conventional cast-in-place construction.
2. Formwork does not have to be designed for internal pressures.
3. Complex shapes require very little—if any—formwork.
4. Crane and other equipment savings or elimination.
5. Labor savings of at least 50% in repair applications.
6. New construction speed savings of 33 to 50%.
7. Speed of repair reduces or eliminates downtime.
8. **Better bonding to the substrate enhances durability** (see below).
9. Adaptability to repair surfaces that are not cost-effective with other processes.
10. Ability to access restricted space and difficult-to-reach areas, including overhead and underground.

Better Bonding to the Substrate Enhances Durability

Concrete is, by the definition of sustainability, the perfect construction material. It is the most common construction material on the planet. Concrete can be easily produced from widely available, plentiful natural resources, and it is completely recyclable. History has proven that structural elements made from concrete tend to last longer and require less ongoing maintenance than any other common construction material. History has also proven that all concrete elements eventually deteriorate or need to be reconfigured over time.

New concrete construction currently benefits from an array of material advancements and innovative construction techniques that have substantially improved the sustainability of modern elements constructed from concrete. The use of supplementary cementitious materials such as slag, fly ash, and microsilica and the more recent use of other recycled materials in the production of greener concrete reduce the environmental impact of new concrete construction.

But what about the immense inventory of existing concrete structures? Wear, exposure, deterioration, or obsolescence ultimately mandates the life span of all concrete elements. The ability to repair or reconfigure, rather than replace, existing concrete elements enhances sustainability, as repair methods can significantly extend the structures' useful service life (refer to Fig. 1).

Bonding Becomes the Critical Element

The ability to form a durable bond interface between the existing substrate and the new concrete is critical to nearly every concrete reconstruction or repair. Typical structural designs require both the existing and replacement material to perform as a single cohesive element. Research has proven that durable, permanent bonds can be attained by using properly prepared substrate conditions in conjunction with shotcrete placement methods. Studies focusing on the bond qualities of shotcrete have proven that a sound substrate surface with an adequate roughness profile provides a suitable surface to form a durable bond. Shotcrete applied to a properly prepared substrate offers a significantly stronger and more durable bond than traditional casting placement methods. Other factors, such as surface moisture conditions, impact energy, shrinkage, and the mixture properties of the repair materials, can also affect the long-term bond quality. For many projects, bond quality will have the strongest influence on repair durability (refer to Fig. 2).

Why Shotcrete Placement Methods Increase Bond Quality

Pneumatically applied shotcrete is capable of producing a stronger, more durable bond to cementitious, masonry, or stone substrates than any other common application method. Understanding the reason behind this requires insight into the principles of the shotcrete process. Both wet- and dry-mix shotcrete's superior bond properties are not due to mixture proportion differences between shotcrete and traditional concrete. Bond quality with shotcrete is derived from the very high energy imparted to the surface during shotcrete placement. Traditional casting placement methods rely on new material bonding to an existing substrate, essentially by contact. Conversely, shotcrete placement methods propel material to the substrate at a high velocity. This process significantly modifies the mixture's proportions at the bond plane. As shotcrete material is initially placed, impact energy causes most of the mixture's coarser components to bounce, rather than stick, to the substrate surface. Only the mixture's smallest particles—the fine paste—can accumulate. As the paste layer builds, larger particles become embedded and rebound subsides.

It is shotcrete's high-velocity nozzle stream, through the tendency of fast-moving larger particles to ricochet off a hard surface, which produces a tight, well-compacted paste layer, driven into the surface irregularities at the bond plane. This perfect material arrangement at the substrate surface facilitates an exceptionally strong crystalline connection—the primary element of a durable bond (refer to Fig. 3).

Defining a Durable Bond

Concrete can be designed to possess a very high compressive strength of 4500 to 7500 psi (30 to 50 MPa) or more. Its pull-apart resistance is comparably quite low at 145 psi (1 MPa). Bond strength values between new and existing concrete should be similar to the strength of the existing concrete. Therefore, for a bond to be considered durable, its bond strength should meet or exceed the pull-apart resistance of the underlying material. Typically, pneumatically applied shotcrete, when exposed to pull-apart or tensile loading, does not fail at the bond plane but, rather, within the substrate layer. This proves that the best possible bond has been attained.

Structural designs requiring durable bonding typically specify routine bond pulloff testing. Bond strength is commonly measured by coring through the shotcrete layer and into the substrate. A tensile load is applied to the surface of the core and then increased to the point of failure. The measured load failure divided by the core surface area provides a numerical bond strength. Both wet- and dry-mix shotcrete applications produce very good bond strength, typically 145 psi (1 MPa) or higher.

Bond quality is a primary requirement for repair durability. Shotcrete's unique material arrangement at the substrate surface enhances durability through improved bond strength.

Note: Bonding agents are not recommended for shotcrete applications. Bonding agents interfere with shotcrete's natural bond qualities and can create unreliable bonding.

Resources

ACI CP 60(09), 2009, *Craftsman Workbook*, American Concrete Institute, 92 pp.

Beaupre, D., 1999, "Bond Strength of Shotcrete Repair," *Shotcrete*, V. 1, Spring, pp. 12-15.

Duckworth, O., 2011, "Can Nozzleman Skill Affect Bond Quality?" *Shotcrete*, V. 13, Winter, pp. 30-33.

Fig. 1: Exposed concrete ceiling element has deteriorated beyond its useful service life

Fig. 2: The bond characteristic of shotcrete is an important issue for the engineer because it strongly affects repair durability

Fig. 3: Note fine materials developing a paste layer at leading edge of the nozzle spray pattern. Although larger particles have impacted this area, they cannot embed until a sufficiently thick paste layer develops