Shotcrete Doesn't Have Cold Joints

By Charles Hanskat

A typical question on projects using shotcrete placement is, "How do you deal with cold joints when shotcrete placement is interrupted?" The brief answer is that we don't have cold joints — when we properly prepare the joint. To produce a monolithically acting placement, the receiving surface must be rough, clean, and brought to a saturated surface dry (SSD) moisture condition. A previous article in *Shotcrete* magazine, "**Shotcrete Placed in Multiple Layers does NOT Create Cold Joints**," explains the reasons we get excellent bond strength between shotcreted layers to create a final section that acts monolithically. This article explores more of the research that points to why shotcrete placement done properly does not create cold joints between placements.

Fig. 1: Prominent cold joint in a form-and-pour wall

WHAT IS A COLD JOINT AND WHY IS IT A PROBLEM?

Let's look at what a "cold joint" is. The American Concrete Institute (ACI), in Concrete Terminology (ACI CT-25), defines it as:

> "A joint or discontinuity resulting from a delay in placement of sufficient duration to *preclude intermingling and bonding of the material*, or where mortar or plaster rejoin or meet."

In form-and-pour concrete, this generally happens when concrete delivery is interrupted and the previously placed concrete has hardened such that the fresh concrete can't be vibrated into the hardened concrete. There is no intermingling and bonding of the fresh concrete to the hardened surface. The fresh concrete just sits on top of the original placement. You can see in Fig. 1 the distinct interface between the two placements in a form-and-pour wall.

This creates a poorly bonded disruption in the concrete, preventing the overall section from acting monolithically. Cold joints are often detrimental to the mechanical performance of the section. Here are the impacts commonly experienced with cold joints.

- **Impact on Structural Integrity and Strength:** Cold joints can significantly lower the compressive and flexural strength of the concrete. Depending on the location in the section, a cold joint can impact the designed load-transfer characteristics and overall load-carrying ability. The cold joint is essentially a tight crack that may degrade the stability of the section
- **Durability and Permeability Impact:** Because a cold joint is essentially a seam in the concrete, it creates a path for external exposure to penetrate the concrete. This increases liquid permeability, allowing moisture to seep deeper into the structure. When corrosive liquids penetrate through the joint, corrosion of the embedded reinforcement may further weaken the structure or require earlier repairs.
- **Aesthetic and Surface Impact:** While engineers consider cold joints a structural issue, they also have visual consequences for concrete surfaces intended to be left as cast concrete surfaces exposed to view. As seen in Fig. 1, there are visible seams that appear as distinct lines or "discolorations" on the finished surface. This is often unacceptable in architectural concrete and may require unplanned coatings to produce a uniform surface appearance.

WHEN IS A SHOTCRETED CONSTRUCTION JOINT NOT A COLD JOINT?

The simple answer is when it's a strong enough bond for the two surfaces to work together. But what is "strong enough?"

Earl Felt with the Portland Cement Association (PCA) Research and Development Laboratories published research[1] in 1956 evaluating the properties needed to have a bonded overlay on a concrete pavement act monolithically. This research concluded that the flexural strength (modulus of rupture) of beams cast in two layers with a bonded topping was equal to the strength of monolithically cast beams if the *shear strength* at the bond interface was at least 200 psi (1.4 MPa).

Evaluating the bond shear strength of a two-layer system is difficult, generally requiring laboratory testing. Using a bond tensile strength test is generally much easier and can be routinely accomplished in the field[2]. ASTM C1583 *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)* is commonly used for testing bond tensile strength, and the test equipment is readily available from a variety of suppliers. However, how do you equate the results of a bond tensile strength test to the bond shear strength?

Fortunately, research has provided the correlation between bond tensile and bond shear strengths. Johan Silfwerbrand with the KTH Royal Institute of Technology evaluated the bond shear strength in repaired concrete structures[3] using cast-in-place concrete test samples. He found that the ratio of the average shear bond strength and the direct tensile bond strength ranged from between 1.9 and 3.1 for cast-in-place samples.

In 2016, Michael Sprinkel, with the Virginia Transportation Research Council, published research[4] on the bond strength between a shotcrete overlay and reinforced concrete substrate on a Florida concrete cooling tower. He concluded, "The ratio between shear and tensile bond strength is about 3 to 4 for surfaces with a macro texture of 0.06 in. (1.5 mm) and increases as the macro texture increases to a ratio as high as 7." The macro texture was the surface profile.

If we consider an interface shear strength of 200 psi as the minimum recommended bond shear strength and use the surface profile of 0.06 in. (from Sprinkle's research), the direct tensile bond pull-off strength would need to be at least 67 psi (0.5 MPa). to ensure that the bond at the interface allows the overall section to act monolithically.

WHY DOES SHOTCRETE PLACEMENT CREATE ENOUGH BOND TO ACT MONOLITHICALLY?

What makes shotcrete placement different than cast-in-place? First, high velocity. The shotcrete material stream exiting the nozzle and impacting the receiving surface travels at 60 to 80 mph (100 to 130 kph). The material is fully mixed concrete when it impacts. For an analogy of the impact we get with shotcrete placement, imagine driving at 60 mph and hitting a concrete wall. That is the impact we get with shotcrete placement. In effect, we are blasting concrete onto the surface and, in effect, sandblasting as we place concrete (Fig. 2). This opens up the pores in the existing concrete surface and drives cement paste into the pores.

Second, there is a very cement paste-rich environment right at the interface. When we are first shooting against a hard concrete surface, much of the coarse aggregate bounces off as rebound, as there is no bed of cement paste to embed into (Figs. 3 and 4). Thus, the shotcrete process inherently creates a paste-rich layer right at the interface.

Fig. 2: High velocity shotcrete placement in a wall

Fig. 3: Initial paste-rich shotcrete placement without coarse aggregate

Fig. 4: Removed sample of initial shotcrete placement

For decades, engineers have specified a scrub coat of a paste-rich grout to help bond fresh concrete to existing concrete. Shotcrete accomplishes this with the high-velocity placement process. No extra work involved!

Third, ACI and ASA shotcrete documents stress that when shotcreting on a hardened concrete substrate (like a construction joint), we need three things to get the best bond:

- **A roughened surface:** The roughness should be established when the first placement is not fully hardened. Roughening techniques can include raking or using a stiff broom. We generally want to see at least the +/- 0.06 in. or an ICRI CSP (International Concrete Repair Institutes' Concrete Surface Profile) Level 5[5]. The roughened profile gives increased shear resistance and increases the surface area for the fresh concrete to bond to.

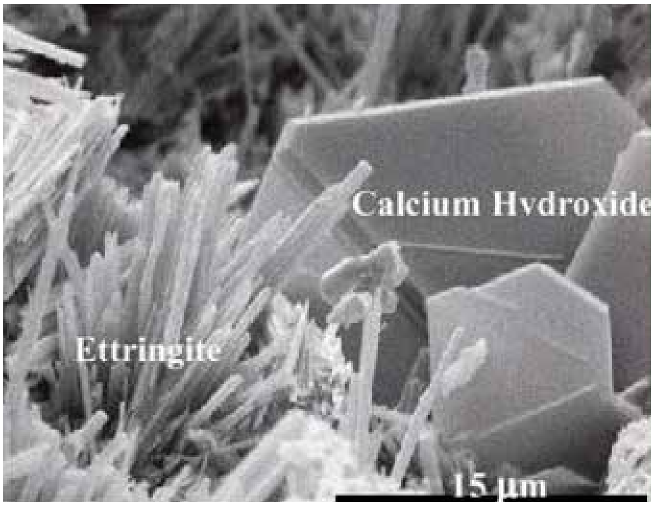

Fig. 5: Microphotograph of cement hydration products

- **The surface is clean:** Any contaminants on the surface can reduce the bond. We never want to use a bonding agent on the surface, as it will interfere with the process of driving cement into the pores of the concrete.
- **The surface is saturated surface dry (SSD):** SSD means we don't have standing water on the surface, but we have filled the surface pores with moisture.

With this preparation, we have a clean, roughened, and dampened concrete surface. We then drive fresh cement paste into the surface at over 60 mph (100 kph). The impact drives the cement particles into the pores. When the cement and water react and create hydration products (Fig. 5) an interlock is formed between the new and existing concrete. In most evaluations when taking cores or sawing samples, identifying the location of the interface is difficult to impossible (Fig. 6).

WHAT BOND TENSILE STRENGTHS DO WE GET WITH SHOTCRETE PLACEMENT?

In the aforementioned article[6], I detailed results of a study on shotcrete bond to concrete repair surfaces that included work on multi-layer shotcrete bond conducted at Laval University[7]. Table 1 summarizes the testing from the Laval University research. The results showed a bond tensile strength of 260 to 300 psi (1.8 to 2.1 MPa). Using a conservative factor of bond shear to bond tensile strength of 3 yields an effective bond shear strength of 780 to 900 psi (5.4 to 6.2 MPa)

Sprinkel's results[4] showed the tensile bond strength is about the same for both hydro-blasted and mechanically blasted methods of surface preparation at 142.0 psi (0.98 MPa) and 139.8 psi (0.96 MPa), respectively. A specific surface profile wasn't noted, just the surface


Fig. 6: Intimate contact and full bond of new shotcrete placement (right, gray) with old concrete (left, beige)

	Type of Finish Between Layers in psi (MPa)			
Time	**None**	**Scratch**	**Scratch + wood**	**Broom roughen**
4 hours	300 (2.1)	260 (1.8)	300 (2.1)	275 (1.9)
1 day		300 (2.1)	300 (2.1)	
28 days		260 (1.8)		290 (2.0)

Table 1: Multi-layer bond strength in psi (MPa) (Boupré 1999)

preparation using either mechanical or hydro blasting. It was noted that an increased surface profile could raise the ratio of shear to tensile strength as high as 7. The bond shear strength was similar for both hydro-blasted and mechanically blasted methods of surface preparation: 1047.7 psi (7.22 MPa) and 972.7 psi (6.71 MPa), respectively. All these bond shear values far exceeded the 200 psi minimum to act monolithically.

THAT'S WHY SHOTCRETE DOESN'T HAVE COLD JOINTS

Full attention to the essentials of surface preparation (roughened, clean, SSD) is mandatory to produce the best bond of shotcreted concrete onto previously shotcreted or cast concrete. With the required surface preparation, proper concrete materials, and equipment, along with placing techniques, shotcrete can routinely achieve a bond tensile strength of 150 psi (1 MPa), providing bond shear strength of at least 450 to 1000 psi (3.1 to 6.9 MPa) of bond shear strength, and far exceeding the required 200 psi to act monolithically. No bonding agents or added polymers are needed to create a section that performs well. Shotcrete placement inherently creates an excellent bond to properly prepared concrete substrates whether the concrete is 100 years old or shot yesterday.

Charles Hanskat *is the current ASA Executive Director. He received his BS and MS in civil engineering from the University of Florida, Gainesville, FL. Hanskat is a licensed professional engineer in several states. He has been involved in the design, construction, and evaluation of environmental concrete and shotcrete structures for over 35 years. Hanskat is also a member of ACI Committees 301, Specifications for Structural Concrete; 350, Environmental Engineering Concrete Structures; 371, Elevated Tanks with Concrete Pedestals; 372, Tanks Wrapped with Wire or Strand; 376, Concrete Structures for Refrigerated Liquefied Gas Containment; 506, Shotcreting; and Joint ACI-ASCE Committee 334, Concrete Shell Design and Construction. Hanskat's service to the American Society of Civil Engineers (ASCE), the National Society of Professional Engineers (NSPE), and the Florida Engineering Society (FES) in over 50 committee and officer positions at the national, state, and local levels was highlighted when he served as State President of FES and then as National Director of NSPE. He served as a District Director of Tau Beta Pi from 1977 to 2002. He is a Fellow of ACI, ASCE, and FES and a member of ACI, NSPE, ASTM International, AREMA, ICRI, and ASCC.*

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