

# Watertight Shotcrete for Swimming Pools

Shotcrete is an ideal construction method for a concrete swimming pool. The versatility of shotcrete placement allows for the construction of a concrete pool shell of virtually any size and shape. Standards for shotcrete design and applications can be found in American Concrete Institute (ACI) Committee 506 guides,<sup>1</sup> specifications, and technical notes, as well as ASA position papers.\* Responsible shotcrete contractors specializing in concrete pool construction must use appropriate design, quality materials, and construction techniques to build a fully functional pool with long-term durability that is essentially watertight under normal service conditions. Watertightness of the shotcrete material is a crucial durability and serviceability property of any properly constructed water-holding shotcrete structure. Shotcrete placement that allows water to pass through the concrete of a pool shell is a sign of flawed material or placement techniques.

Pools are complex concrete structures with irregular shapes, varying thicknesses, numerous shell penetrations, and variable soil conditions. The structural requirements for a pool shell must be evaluated by a professional engineer who is qualified for structural evaluation. A proper design will include specifications for subgrade preparation, concrete shell thicknesses, concrete materials, reinforcing steel layout, and pipe and fixture penetration details. With an appropriate design, proper materials, and quality placement, the experienced builder creates a pool that meets loading conditions, provides long-term durability, and is essentially watertight.

The concrete material used to construct the pool shell must meet watertightness requirements. Scientifically defined, watertightness of the concrete material is the result of complex mass transport mechanisms (capillarity, permeability, and water diffusion) that refer to various properties of concrete.<sup>2</sup> A definition of watertightness is “impermeable to [measurable flow of] water except when under hydrostatic pressure sufficient to produce structural discontinuity by rupture.”<sup>3,4</sup> A

proper concrete mixture design is a prerequisite for successful shotcrete application of concrete. A well-designed, shootable mixture should be selected with a proper aggregate gradation, allowing it to pass through a shotcreting system. Special attention should be given to the amount of fine aggregate and cementitious paste necessary to cover the aggregate surface area (minimum 4:1 cementitious-to-aggregate ratio, and ideally 3:1). Sufficient cementitious paste and a low water-cementitious material ratio ( $w/cm$ ) are necessary for producing a dense, watertight final product.

Assuming the correct mixture design, compressive strength of the concrete is generally indicative of the  $w/cm$  (lower  $w/cm$  equates to higher strength) and the potential watertightness of the shotcrete in the pool shell. Complete compaction of the pool shell concrete is a direct result of the velocity (typically 65 to 115 ft/s [20 to 35 m/s]<sup>5</sup>) at which the mixture is shotcreted onto the substrate. The high impact energy produced by proper shotcrete equipment and placement techniques achieve maximum in-place encapsulation and compaction with minimum voids for a given concrete mixture. Compressive strength is measured through core samples taken from in-place material or shotcrete test panels. Because concrete compressive strength is affected by the same physical properties that affect watertightness, it is possible to evaluate the quality of a shotcrete pool shell—both from a structural and a watertightness point of view—by considering the compressive strength of the shotcrete produced. Thus, in this context, compressive strength is an appropriate predictor of watertightness.

Shotcrete made from properly graded aggregates, quality cement, and potable water; properly placed by a qualified shotcrete crew; consolidated at the requisite velocity; and properly cured will easily yield a 28-day compressive strength of 4000 psi (28 MPa). In reality, 5000 psi (34 MPa) is desirable for enhanced durability and is routinely achievable by careful attention to materials and placement techniques. Table 4.2.2 of ACI 350-06<sup>6</sup> (refer to Fig. 1) has requirements for special exposure conditions. The table indicates concrete intended to have low permeability when exposed to water should have a maximum  $w/cm$  of 0.45 with a minimum 4000 psi (28 MPa) compressive strength. However, when the concrete is exposed to chlorides (brackish water, salts, and seawater), ACI 350 requires a  $w/cm$  of 0.40 and compressive values of 5000 psi (34 MPa) to provide protection for embedded reinforcement. Thus, lower

\*NOTE: “Shotcrete” and “concrete” are two distinct terms. Shotcrete is defined as “concrete placed by a high-velocity pneumatic projection from a nozzle.”<sup>3</sup> In other words, concrete is the **material**; shotcrete is the placing **process**. The end result is a *concrete* structure built with the *shotcrete* process. However, many members of the industry will use the terms interchangeably *when the reference to the shotcrete process is implied*. We do the same in this Paper, using “shotcrete” and “concrete” interchangeably. A “shotcrete pool shell” is understood to be comprised of concrete, and a “concrete pool shell” is—in this context—understood to have been placed using the shotcrete process.

Exposure condition	Maximum water-cementitious materials ratio, by weight*	Minimum $f'_c$ , psi*
Concrete intended to have low permeability when exposed to water, wastewater, and corrosive gasses	0.45	4000
Concrete exposed to freezing and thawing in a saturated condition or to deicing chemicals	0.42	4500
Concrete exposed to corrosive chemicals other than deicing chemicals	0.42	4500
For corrosion protection of reinforcement in concrete exposed to chlorides in tanks containing brackish water and concrete exposed to deicing chemicals, seawater, or spray from seawater	0.40	5000

\*A lower water-cementitious material ratio or higher strength may be required for durability of concrete exposed to sulfates (Table 4.3.1).

Fig. 1: Table 4.2.2 of ACI 350-06<sup>6</sup>

$w/cm$  and higher compressive strength provide better protection for embedded reinforcement in water containing structures. Concrete technology and common sense show that watertightness will be improved using a concrete with a low  $w/cm$  with sufficient paste content—that is, well-consolidated by the placement techniques and properly cured and protected after placement—thus creating a dense impermeable concrete.

There are many reasons why a shotcrete placement would not achieve specified minimum compressive strength. These include poor workmanship, defective equipment, undesirable

environmental conditions, or the inadequate selection of ingredients including poorly graded aggregates, soft or deleterious aggregates, expired cement, or contaminated water. In any case, compressive strength values less than 4000 psi (28 MPa) are, in most cases, the result of intentionally or unintentionally ignoring the rules of good practice<sup>7,8</sup> and will result in pool shell shotcrete that is not as watertight.

As with any other concrete structure, shotcrete pool shells must be properly designed—both from a structural and a concrete material perspective. Good quality shotcrete properly designed, manufactured, placed, and cured will produce the desired result—a durable and essentially watertight structure. Experienced pool builders pay attention to all the details of the shotcrete process and building pool shells with watertight shotcrete. Watertightness of shotcrete should be the expectation of all parties: the client, the designer, and the contractor.

## References

1. ACI Committee 506, “Guide to Shotcrete (ACI 506R),” American Concrete Institute, Farmington Hills, MI, 2005, 40 pp.
2. Bolduc, L. S., and Jolin, M., “Shotcrete Boiled Water Absorption,” *Shotcrete*, V. 12, No. 1, Winter 2010, pp. 12-17.
3. ACI CT-13, ACI Concrete Terminology, American Concrete Institute, Farmington Hills, MI, 2013, [http://www.concrete.org/portals/0/files/pdf/ACI\\_Concrete\\_Terminology.pdf](http://www.concrete.org/portals/0/files/pdf/ACI_Concrete_Terminology.pdf).
4. ASA Pool & Recreational Shotcrete Committee, “Position Statement #2, Definitions of Key Shotcrete Terminology,” *Shotcrete*, V. 15, No. 3, Summer 2012, p. 29.
5. Ginouse, N., and Jolin, M., “Material Velocity at the Nozzle,” *Shotcrete*, V. 15, No. 4, Fall 2013, pp. 22-24.
6. ACI Committee 350, “Code Requirements for Environmental Engineering Concrete Structures (ACI 350-06) and Commentary,” American Concrete Institute, Farmington Hills, MI, 2006, 487 pp.
7. Crom, T. R., “Dry-Mix Shotcrete Nozzling,” *Concrete International*, V. 3, No.1, Jan. 1981, pp. 80-93.
8. CP-60, “Craftsman Workbook for ACI Certification of Shotcrete Nozzlemans,” American Concrete Institute, Farmington Hills, MI, 2009, 126 pp.