Quality and Shotcrete

by Edward Brennan

Many factors affect the quality of shotcrete. The shotcrete process itself provides a unique and effective placement technique for portland cement concrete. For the shotcrete process to yield the highest possible quality product, however, many factors must be considered. The shotcrete process has both obvious and not-so-obvious factors that affect the quality of the end product.

First, the obvious:

- Materials selection, aggregate gradations, cement sources, proportioning of materials;
- Moisture content of aggregates;
- Preconditioning of the materials for temperature and moisture prior to placement;
- Temperature and related ambient conditions at the time of placement;
- Preparation and placement of reinforcing steel;
- Thorough premixing of the aggregates and cement prior to placement;
- The mechanical placement of the material; and
- Skill of the personnel in the shotcrete crew.

Use the proper aggregate and portland cement, which should meet ASTM C 33 and C 150, respectively. This may sound simple, but on some jobs, the aggregate gradation used is much too fine to provide a high-quality finished product. Using very fine sand outside of the gradation specified in ACI 506R may yield a shotcrete that places easily. Very fine aggregates in a concrete may present many problems in the finished product, including:

- The increased surface area requires more water to wet out the entire mixture; this increases the shrinkage and hence the cracking potential of the shotcrete;
- The increased water-cement ratio (*w*/*c*) will have a deleterious effect on the strength and density of the mixture; and
- The lack of distributed aggregate sizes does not provide the proper matrix of particle sizes needed to produce shotcrete of good quality.

The problem with using aggregate with too fine a gradation is not exclusive to field-mixed shotcrete. Be sure to confirm with any prepackaged supplier of shotcrete that the aggregate used meets the requirements of ACI 506R and/or ASTM C 33.

The temperature at the time of placement also plays a critical role when placing shotcrete. The ambient temperature of shotcrete produced with ordinary portland cement at the time of placement, and within 24 h after placement, must be above 40 °F (5 °C). If shotcrete is placed when the temperature falls below 40 °F (5 °C), or soon thereafter, the portland cement may not achieve the proper hydration characteristics and the shotcrete may be slow to develop compressive strength. In colder temperatures, it is essential to warm the substrate to ensure that the temperature of the substrate is above 40 °F (5 °C) at the time of placement.

Extreme heat can also adversely affect the final quality of shotcrete. When working in temperatures exceeding 90 °F (28 °C), or in high winds, protect the freshly placed shotcrete using water curing techniques or curing compounds. Failure to protect the freshly placed shotcrete from extreme temperature and/or drying can result in premature desiccation of the shotcrete and subsequent cracking.

Proper surface preparation is critical to achieving good mechanical bond between the freshly placed shotcrete and the substrate. The International Concrete Repair Institute (ICRI) provides detailed surface preparation guidelines for concrete substrates. Nothing, including the use of bonding agents, replaces good surface preparation. Using bonding agents can actually be detrimental to facilitating good mechanical bond between shotcrete and the substrate. Many common bonding agents can cure before shotcrete application and actually function as a bond breaker. Their use is thus not recommended. One of the best attributes of the shotcrete process is the good bond provided by high-velocity impact of the material.

Preparation of reinforcing steel plays a critical role in maintaining a quality shotcrete placement. All steel must be cleaned to remove any loose mill scale or rust and be free of surface contaminants such as paints and form oil. Care must be taken when placing steel reinforcing bar to ensure that it is properly spaced, so that when the shotcrete is applied, proper encasement around the bar does not present a problem.

Whether using the dry-mix or wet-mix shotcrete process, thoroughly and consistently blending the aggregates and cement prior to and during application is important. At some job sites, the need for productivity can sometimes override the proper and consistent blending of the materials on site. This can result in sand pockets and non-uniform shotcrete in areas. This can contribute to defects and ultimately compromise the final quality of the shotcrete.

While all these issues may seem obvious, proper attention to these items is critical for maintaining the quality of shotcrete. Equally important as any one of the aforementioned factors, individually or together, is proper mechanical placement of the material. Unlike ordinary concrete placement techniques, shotcrete has it own equipment and techniques that determine the final quality of the in-place product.

Good nozzling technique and proper shotcrete velocity at the time of placement do as much to determine the final quality and outcome of shotcrete as do the previous factors.

The shotcrete operation, whether wet or dry, and the ensuing quality strictly depend on the competence of the gun/equipment operator and the nozzleman. Their support crew and related experience also play a critical role in the outcome of the shotcrete. First, the crew needs to ensure that the machinery operates in a consistent and reliable fashion. When material application starts, consistency in mixing and placing cannot be compromised.

The final physical properties of the shotcrete rely heavily on both the velocity of the impacting material at time of placement and the orientation of the nozzle to the substrate. The velocity of the shotcrete should remain consistent from start to finish, ensuring even compaction and uniform shotcrete quality. Shotcrete, wet or dry, relies on the impact of the material on the substrate and, when placed in multiple lifts, on itself, to ensure the quality of the material in place.

After velocity, nozzle technique also plays a key role in assuring the quality of the shotcrete. In vertical and overhead applications, both wet-mix and dry-mix shotcrete can be applied in layers. The nozzleman builds each layer to the point where the material will not sag or slough off. Each layer can be placed at typical depths of 2 in. (50 mm). Admixtures such as silica fume may allow the placement of greater thicknesses in a single pass. The permissible thickness is that which prevents sagging or sloughing (fall out). Much greater thicknesses in a single pass are possible when using the "bench-gunning" technique. Thicknesses as much as 20 in. (500 mm) in a single pass are achievable with this method, with suitable shotcrete mixture designs and application procedures.

The angle of the nozzle to the substrate also plays a role in the final product. The nozzle should be held at a 90-degree angle to the receiving surface. When reinforcing steel is encountered, the angle is varied slightly to ensure proper encasement of the steel. Too flat an angle will result in "rolling" or excessive rebound. The nozzle is typically held approximately 30 in. (760 mm) from the face of the concrete substrate for the dry-mix process and about 18 in. (457 mm) for the wet-mix process to ensure maximum compaction and to aid in the placement of the shotcrete, although the optimal distance from the receiving surface will depend on the particular equipment being used.

One process sometimes used—"low-pressure shotcrete"—better describes a placement technique for hand patching mortars rather than shotcrete itself. This process employs a rotor stator or progressive cavity pump. The material is premixed with water and pumped slowly through a line and low air pressure projects the material against the substrate. Low pressure does not employ the high velocity used by typical shotcrete and so, strictly speaking, this process does not produce "shotcrete."

In summary, the production of quality shotcrete depends on a combination of proper surface preparation, proper shotcrete mixture designs and consistency, good nozzling practice and the experience of the entire shotcrete crew.

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