When to Extract Cores

By Lihe (John) Zhang

During preconstruction testing and mockups, as well as during shotcrete production, a minimum specified compressive strength is always required in the project specification. The specified compressive strength is used to qualify the concrete mixture, the shotcrete nozzlemen, and the shotcreting equipment, as well as for quality control of the shotcrete production. Compressive strength is commonly tested at 3, 7, and 28 days using 3 or 4 in. (75 or 100 mm) diameter cores (ASTM C1604) from standard shotcrete test panels (ASTM C1140). Compressive strength at other ages, such as 1 or 5 days, might also be required, depending on project application needs. Typically, contractors prefer to evaluate the shotcrete's compressive strength as early as possible, which requires early extraction and testing of cores. When compressive strength tests meet the required strength at 1, 3, and 7 days, shotcrete is considered to have met the quality control requirement, and the construction schedule can be adjusted using an increased production rate. Therefore, it is reasonable for contractors to want to extract cores at the earliest age. However, it is not uncommon to find damage to cores that are extracted too early, such as less than 1 day. Alternatively, when cores are extracted too late, such as more than 2 days, the decision of the production rate and the adjustment of the construction schedule are delayed. The question, at least from the contractor's perspective, is: When should cores be extracted to meet requirements for both quality control testing and the construction schedule?

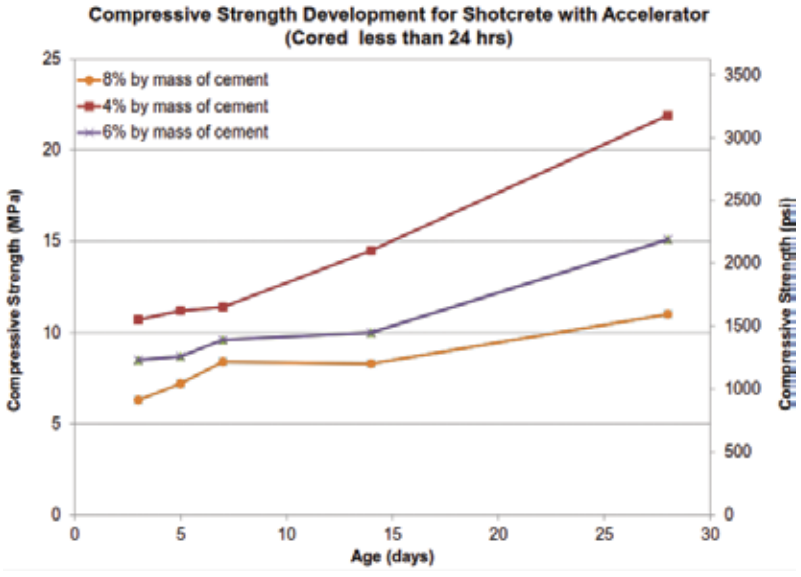

Fig. 1: Compressive strength development for shotcrete with accelerators; cores extracted at less than 24 hours of age

Coring at 1 Day

In a recent underground shotcrete project, cores were extracted at less than 24 hours. The project used silica fume-modified wet-mix shotcrete and added an alkali-free accelerator for overhead application. Shotcrete preconstruction test panels were shot with accelerator dosages of 4, 6, and 8% by mass of cement. Shooting started on Monday afternoon at 2:00 p.m., and a total of six test panels were shot, which allowed two panels for each accelerator dosage. The project took place in May, and temperatures were approximately 59 to 68°F (15 to 20°C). All panels were covered with wet burlap and plastic sheeting for overnight protection. A restricted area was constructed for the test panels, and no rainfall occurred. Coring activity began the next morning at 7:00 a.m. By 10:00 p.m., all cores were extracted and a very dark slurry came from the core drilling water. Cores were delivered to the laboratory for standard curing and were tested at 3, 5, 7, 14, and 28 days. The results are shown in Fig. 1. The 5-day compressive strength test results confirmed that the coring had significantly damaged the cores, which produced low strength results.

Coring at 2 Days

The same ACI Certified Nozzleman shot the same shotcrete mixture using the same equipment, including the shotcrete pump and the accelerator dosing pump with accelerator dosages of 4, 6, and

8%. Panels were left in the field and covered with wet burlap and a plastic sheet for overnight protection. A restricted area was constructed for the test panels, and no rainfall occurred. The cores were extracted 2 days after shooting, and the compressive strength development is shown in Fig. 2, which clearly shows that the compressive strength developed properly when cored at 2 days of age.

Proper Time to Extract Cores from Test Panel

The test results illustrated in Fig. 1 and 2 show that the compressive strength of the cores developed properly when they were extracted at 2 days, instead of less than 1 day. It appears that cores extracted at 2 days produce results representative of the panel or in-place shotcrete. ACI 506.5R-09,[1] Section 8.8, also states that "coring, at an early age, can potentially cause damage to the cores." However, to accelerate the construction schedule and obtain early quality control testing results, contractors always want to extract cores as early as possible. The question then becomes: Do you have to wait 2 days to extract the cores?

The physical grinding and tearing of the shotcrete at the core surface, which is caused by the coring operation, is believed to affect the strength development of shotcrete. This is because the vibration causes internal damage to the weak bond of the hydrating cement, especially at a very early age (hours versus days) when strengths are low. Typically, shotcrete and concrete can be cored or demolded when compressive strength reaches 1800 to 2200 psi (12 to 15 MPa). Most shotcrete mixtures will develop this strength within 1 to 2 days of placing. However, to be confident that early-age coring will not damage cores extracted from a panel or in-place shotcrete, it is critical to establish the shotcrete's compressive strength at an early age of less than 24 hours. The Heere and Morgan[2] end beam testing method is particularly suitable for establishing compressive strength of shotcrete less than 24 hours old (Fig. 3).

Previous project experience[2] reported that when compressive strength reaches 1800 to 2200 psi (12 to 15 MPa) when tested with an end beam tester, coring activity will not cause damage to the cores and will produce representative shotcrete compressive strength.

To further confirm this experience, the author recently carried out a trial dry-mix shotcreting project in which he tried coring at 20 hours. The shotcrete mixture was a silica fume-modified shotcrete mixture with 3% accelerator (in dry powder) by mass of cement. Figure 4 shows the strength development of a dry-mix shotcrete during the first 24 hours.

Compressive strength, tested with an end beam tester, reached 2200 psi (15 MPa) at 16 hours, and cores were extracted at 20 hours. Compressive strength development at 3, 7, and 28 days (Fig. 5) shows that the cores were not damaged by the coring activity at 20 hours.

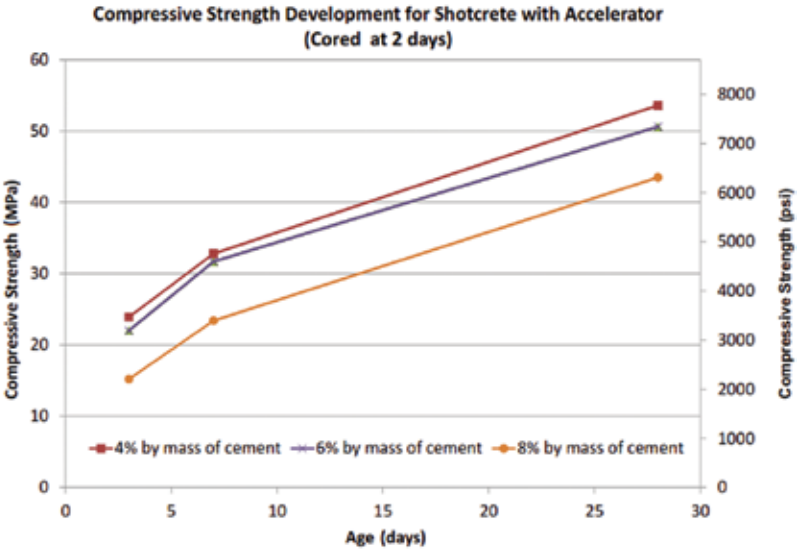

Fig. 2: Compressive strength development for shotcrete; cores taken at 2 days of age

Fig. 3: End beam test equipment to test compressive strength at less than 24 hours

Summary

When an accelerator is used, the shotcrete sets faster at an early age and can sometimes develop strength in only a few hours. However, the accelerator is sensitive to temperature; therefore, strength development varies according to the ambient temperature and the temperature of the shotcrete mixture. The dosing of the accelerator is always dependent on the nozzleman's experience, as well as the accuracy and reliability of the accelerator dosing pump. Therefore, the early-age strength development of accelerated shotcrete will potentially vary more than nonaccelerated shotcrete.

Core extraction should only be done when shotcrete compressive strength has developed sufficiently. Generally, a compressive strength no less than 1800 to 2200 psi (12 to 15 MPa), when tested by an end beam tester, would be sufficient to proceed with coring. This strength level is typically reached between 1 and 2 days. However, if an accelerator is used, this strength level may develop at a much earlier age—often less than 24 hours.

If the early-age compressive strength test (with an end beam tester) is not available, it is recommended to extract cores 2 days after shooting. Any coring activity before 48 hours has a high probability of damaging the shotcrete core, which creates a weaker structure in the shotcrete cement paste matrix and consequently produces compressive strength test results that are lower than the actual compressive strength of the panel or in-place shotcrete sample.

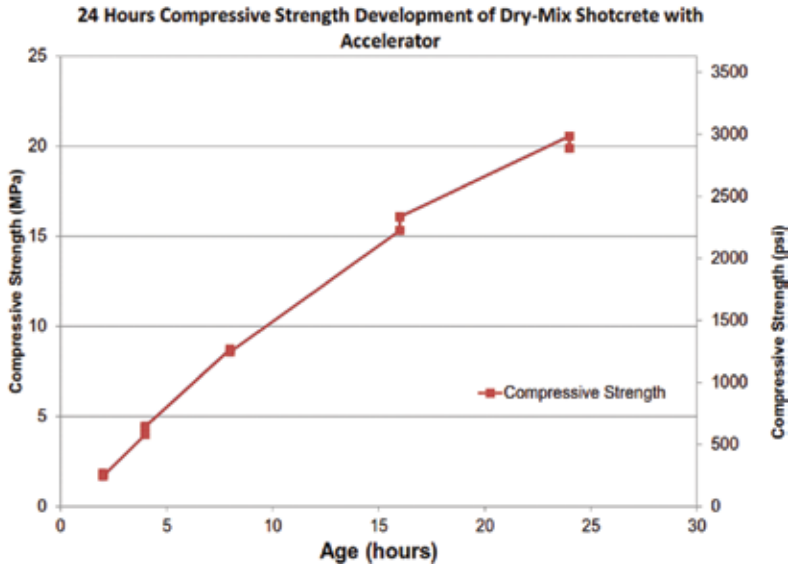

Fig. 4: Early-age compressive strength when tested with end beam tester

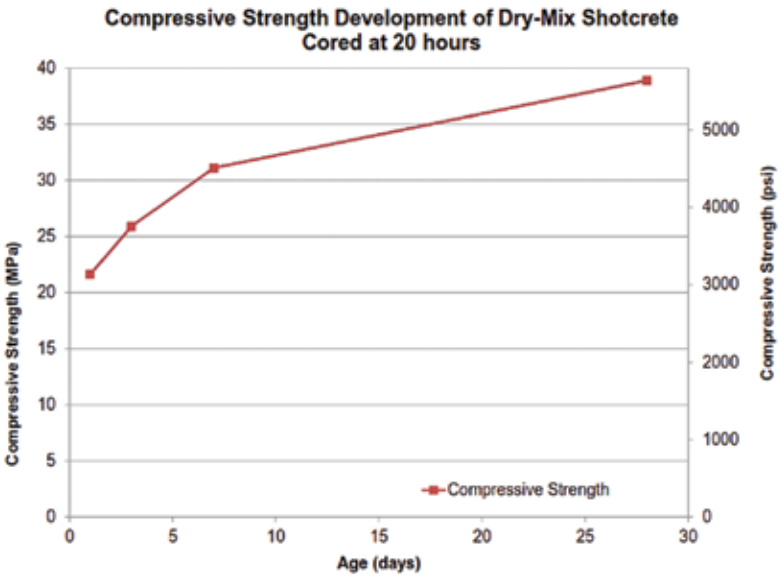

Fig. 5: Compressive strength development through 28 days; cores extracted at 20 hours

References

1. ACI 506.5R-09, "Guide for Specifying Underground Shotcrete," American Concrete Institute, Farmington Hills, MI, 2009, 52 pp.

2. Heere, R., and Morgan, D. R., "Determination of Early Age Compressive Strength of Shotcrete," *Shotcrete*, V. 4, No. 2, Spring 2002, pp. 28-31.

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