Technical Tip

Using Accelerators for Shotcreting

By Dan Millette

Are you shooting overhead and need to build up a 6 in. (154.2 mm) layer in a single pass? Do you have a difficult pumping situation that requires a looser material—say an 8 in. (200 mm) slump—and you need to stick that on a wall at a few inches of thickness? Then you should be looking at using a shotcrete accelerator to shoot it. Accelerators have been successfully used for years in shotcreting operations for mining and tunneling where overhead applications are commonplace. Accelerators are used in both dry- and wet-mix shotcreting.

The most common method of accelerating dry-mix shotcrete is by purchasing a packaged mixture that contains an accelerator; but you can also add a powdered accelerator to the mixture. Using an accelerator with a system that includes a predampener requires extra attention on the part of the operator. You do not want to get ahead of loading the gun hopper because the accelerator can harden the mixture pretty quickly once moisture is introduced, which can cause problems going through the gun.

Fig. 1: HPS nozzle with separate accelerator port

Fig. 2: ACME nozzle with integrated air/accelerator port

Another method of using an accelerator with dry-mix shotcrete is to add a liquid admixture at the nozzle along with the nozzle water. If you do this, you need to make sure that both the accelerator and the water booster pumps are pumping at close to the same pressures to avoid pushing either material back into its respective hose.

Wet-mix shotcrete is much simpler to accelerate. The accelerator is added to the nozzle. Wet-mix nozzles with accelerator ports can be purchased from most shotcrete supply companies. Some nozzles have the accelerator port integrated into the air line, whereas other nozzles have separate accelerator ports. When using nozzles with a separate accelerator port, the mixing of the accelerator into the mixture is not always as thorough as when it is integrated into the air port (refer to Fig. 1 and 2).

Accelerator Chemistries

There are two classes of shotcrete accelerators on the market today—one being an alkali material and the other being alkali-free. The original alkali accelerators have a sodium silicate base. These accelerators do speed up the setting time of the cement in the mixture, but not nearly as quickly as the alkali-free accelerators available today. The main advantage of alkali accelerators is to gel up the water in the mixture, giving it a cohesive property. This method of accelerating shotcrete has been around since the 1960s. A sodium-silicate-based accelerator is quite alkali, with a pH of around 11. The mist from these accelerators can irritate the skin on people working near the spraying, especially in enclosed spaces.

Alkali-free accelerators are all manufactured from fairly strong acids, with a pH range between 2 and 3. Most brands of alkali-free accelerators use a sulfate base and often add amines to enhance the rate of acceleration. When added to the mixture in the nozzle, the high alkali content of the mixture will neutralize the acidic properties of the accelerator. Alkali-free accelerators are much faster than the sodium-silicate-based accelerators and are most frequently specified on today's projects that use shotcrete.

The only real disadvantage with alkali-free accelerators is that they are corrosive. When handling alkali-free accelerators, be sure to read the material safety data sheet (MSDS) thoroughly and comply with the personal protective equipment that is recommended. Alkali-free accelerators should never be put into a mild steel tank. This can cause potentially explosive hydrogen gas to build up. Always store these accelerators in plastic or stainless steel containers or tanks. All fittings on tanks, hoses, and pumps should also be stainless steel or galvanized at the very least.

Oftentimes, a shotcrete mixture will contain a retarder or set stabilizer to extend its working time because of long transport distances or hot climates. When using an accelerator at the nozzle, make sure that a set stabilizer is used and not a simple concrete retarder. The difference between a retarder and a set stabilizer are that retarders may use a sucrose or sugar base, whereas set stabilizers use an acidic base and do not contain any sugars. If you use a sucrose-based retarder, the accelerator and the sugar will fight each other. When a set stabilizer is used, it is much easier for the accelerator to overpower it.

When using accelerators in shotcrete mixtures, there are many factors that must be considered and evaluated. Each accelerator should be checked with the particular cement that is to be used in the mixture. Low-alkali cements, such as sulfate-resistant cements (Type V) are not nearly as fast to react with alkali-free accelerators. Although alkali-free accelerators have a common base chemistry among all manufacturers, there are variations in solids contents and secondary chemistries that enhance the base, so various brands can react differently in a particular shotcrete mixture. The most common test specified is ASTM C1398 but this is not always the most practical test. Some accelerators are very high in viscosity and will do well with ASTM C1398 because it is thoroughly integrated in a mixer, whereas in the field application, the accelerator may not blend into the mixture as well at the nozzle. Oftentimes, a lower viscosity accelerator will blend into the mixture in the nozzle better and work at a lower concentration than the high viscosity but will not test as well using ASTM C1398.

Another test that should be done when using accelerators is to determine the 28-day strength of the mixture with the amount of accelerator that is to be used on the project. Accelerators added at the nozzle to a shotcrete mixture can cause the 28-day strength of a mixture to be up to 50% lower than without the accelerator; therefore, the proper amount should be determined before it is applied. Alternatively, you can over-design the compressive strength of the mixture to account for the expected strength loss, but this is not necessarily the most economical method. The reduced 28-day strengths with accelerators are one reason why coring in-place work is often used to evaluate shotcrete strengths.

Fig. 3: Pocket penetrometer test

Fig. 4: Using a Proctor penetrometer to gauge initial set

Many accelerated shotcrete specifications will list an initial set at between 2 and 12 minutes and final set before 30 minutes. The only way to test this is with a penetrometer, of which there are many types. Two of the more common ones are shown in Fig. 3 and 4.

Accelerator Pumps

The selection of an accelerator pump and the way it is set up is the most important factor in successfully accelerating a shotcrete mixture. Because of its low cost, it is common for inexperienced shotcreters to grab a diaphragm pump and use it as an accelerator pump. The problem with this is that a diaphragm pump has a lot of pulse to it and if it is a large enough pump, it delivers "batches" of accelerator to the nozzle. Also, pulsation from the shotcrete pump can complicate the matter, especially when the pumps are out of sync, as illustrated in Fig. 5 and 6.

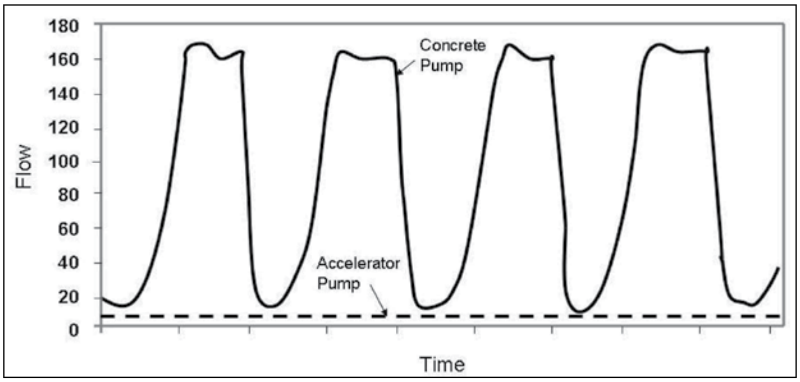

Fig. 5: Graph of typical accelerator pump

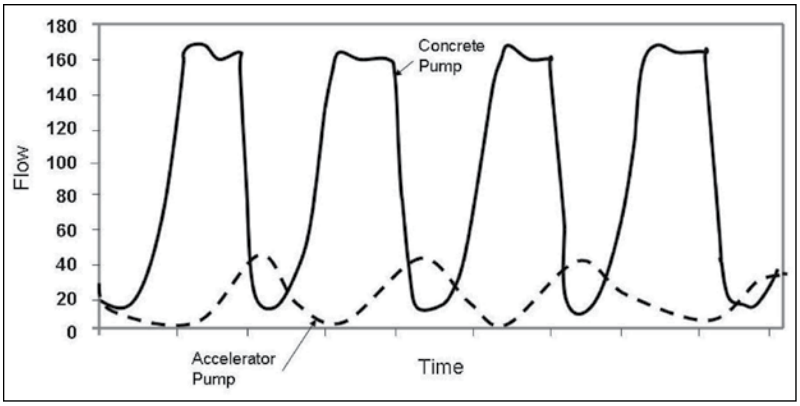

Fig. 6: Graph of large out-of-sync diaphragm pump

Fig. 7: A portable 110V AC peristaltic accelerator pump

Imagine doing an overhead application and the shotcrete pump delivers a slug of mixture while the diaphragm pump is on an exhaust stroke—the shotcrete is not accelerated and falls off the ceiling. Then, while the shotcrete pump is transitioning between strokes, the diaphragm pump delivers a slug of accelerator—this is too much accelerator for the amount of shotcrete being delivered so it sets the mixture up before it even hits the ceiling and it does not stick. Now, with accelerator, you have 50% of the material that is not sticking to the substrate. Sure, this is an extreme example, but it does happen and even a small out-of-sync situation can give unevenly accelerated in-place material that will cause it to be a variable strength material.

Piston pumps can be used but typically wear faster than peristaltic or rotor-stator pumps and are not quite as smooth. Peristaltic pumps (refer to Fig. 7) or squeeze pumps are the most accurate method of metering accelerator to the nozzle. These pumps will deliver a steady flow with very little pulsation. The output of the pump is directly proportional to the rpm of the shaft and this relationship is extremely linear. Another advantage of using a peristaltic pump is that the accelerator does not contact any metal parts except for the hose fittings.

As with most other types of pumps, the peristaltic pumps can easily be purchased with AC or DC electric motors, air drive motors, or hydraulic drive motors, depending on specific needs. The electric drive motors have variable speed drives to control the speed of the pump. Some equipment manufacturers also integrate accelerator pumps into the control panel of the shotcrete pump so that you simply enter the specific gravity and percent dosage of the accelerator, and the pump will dose the accelerator to match the concrete output of the machine. The only downside to this type of setup is the higher cost.

When shopping for an accelerator pump, you need to be sure that it will pump at sufficient pressure to overcome the air pressure to the nozzle. You can always slightly turn down the air pressure to the nozzle, provided you are able to maintain adequate air volume.

Dosage Rates and Calibration

A typical recommended dosage range for a shotcrete accelerator is between 3 and 8% by weight of the cementitious material in the mixture. Take a mixture that contains 600 lb (273 kg) of cement, 150 lb (68 kg) of fly ash, and 75 lb

(34 kg) of silica fume per yd³. The total cementitious material is 825 lb (375 kg), so at 6% accelerator, 49.5 lb (22.5 kg) of accelerator per yd³ of shotcrete mixture is required. A typical alkali-free accelerator weighs around 11 lb/gal. (1.32 kg/L), so when you divide the weight, you come up with 4.5 gal. of accelerator per yd³ (22.25 L/m³) of shotcrete mixture.

The first step in calibrating would be to determine the output of your shotcrete pump in yd³/min. This will vary depending on several factors. First, you calculate the volume of a pumping cylinder and then multiply the volume by the strokes per minute of your machine.

For example, if you have a pump with a 5 in. (127 mm) diameter pumping cylinder and it has a 30 in. (762 mm) stroke, then the cylinder volume is

$(\pi r^2 S)/46{,}700$

where r is the radius (in this case, the radius of 5 in. is 2.5 in.); S is the stroke (in this case 30 in.); and 46,700 is the number of in.³ in yd³.

$(3.14 \times 2.5^2 \times 30)/46{,}700 = 0.0126$ yd³ (0.00965 m³) per stroke

In this case, let's assume that the pump is pumping at 28 strokes per minute; 28 times the volume per stroke equals 0.354 yd³/min (0.271 m³/min). The number of strokes is indicated on a readout on some pumps and, if not, can be counted by listening for the swing tube to change directions and counting how many of these changes occur per minute.

There is an additional step necessary in calculating the output of your pump: the fill factor of the pumping cylinders. There are two things that must be considered here. If you are pumping a 10 in. (255 mm) slump mixture without any fibers in the mixture, then you can assume a 100% fill factor regardless of the diameter of the pumping cylinders. When lower slump mixtures are used, a lower fill factor is to be expected. With a lower slump, the pumping cylinder diameter becomes a significant element. For example, if you are pumping a 1.5 in. (38 mm) slump with a 4 in. (100 mm) diameter pumping cylinder, your fill factor could be as low as 50%. It is a good idea to pump 1 yd³ box full of material with your pump at the slump and speed that you normally pump and count how many strokes it takes to fill the box. You can then back-calculate your fill factor. If you use a very low slump, have someone consolidate the mixture in the box with a pencil vibrator while you are pumping.

Let's assume a 100% fill factor and take the aforementioned example. At 0.354 yd³/min (0.271 m³/min) and at an accelerator requirement of 4.5 gal./yd³ (22.5L/m³), the accelerator pump must be pumping 1.6 gal./min (6.1 L/min).

The accelerator pump is all that is needed to accurately meter the accelerator into the mixture. Some contractors want to put a regulator valve on the nozzle to allow the nozzleman to control the amount of accelerator. But this is not wise, as it is then impossible to know what the actual dosage of the accelerator is in the placed shotcrete. Besides, a good accelerator pump calibrated to be in sync with the shotcrete pump is the best method of ensuring a consistent application.

References

1. Jolin, M., and Beaupre, D., "Understanding Wet-Mix Shotcrete: Mix Design, Specifications, and Placement," *Shotcrete*, V. 5, No. 3, Summer 2003, pp. 9-10.

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