Technical Tip

Overcoming Pumping Problems

There is probably nothing as frustrating to even the most tolerant wet-mix shotcrete placing contractor or crew as problems related to pumping. While the following comments are specifically related to shotcrete placement, many of them are also applicable to normal concrete pumping applications. The rheology of shotcrete mixtures is affected by the pumping process, which typically involves repetitively compressing a shotcrete mixture and forcing the mixture to the point of final placement under pressure.

by Neil McAskill

The most common systems used in wet-mix shotcrete placement are positive displacement piston pumps. In this system, wet-mix shotcrete is repetitively drawn into cylinders from an open hopper and forced along the pump line through a swing tube located in the concrete hopper. Figure 1 illustrates a schematic diagram of a typical concrete pump. The pressure on the concrete at this point varies but is typically in the range of 1000 to 1500 psi (7 to 10 MPa). At these pressures the volume of entrained air in the mixture is compressed to about 1/100 of the volume at normal atmospheric pressure, and if the mixture has a tendency to bleed, this property will be exacerbated by the increased pressure. Both of these factors can have a profound effect on the workability of a shotcrete mixture as it is being pumped. Other factors, such as: 1) the constituent materials, including the gradation and shape of the aggregates; 2) mixture design, including supplementary cementing materials (fly ash, silica fume, etc.) and fibers; and 3) the age of the mixture and the condition of the pump, can all have a profound effect on the ability to pump a shotcrete mixture. The effect these factors have on the ability to pump shotcrete mixtures is discussed in this article.

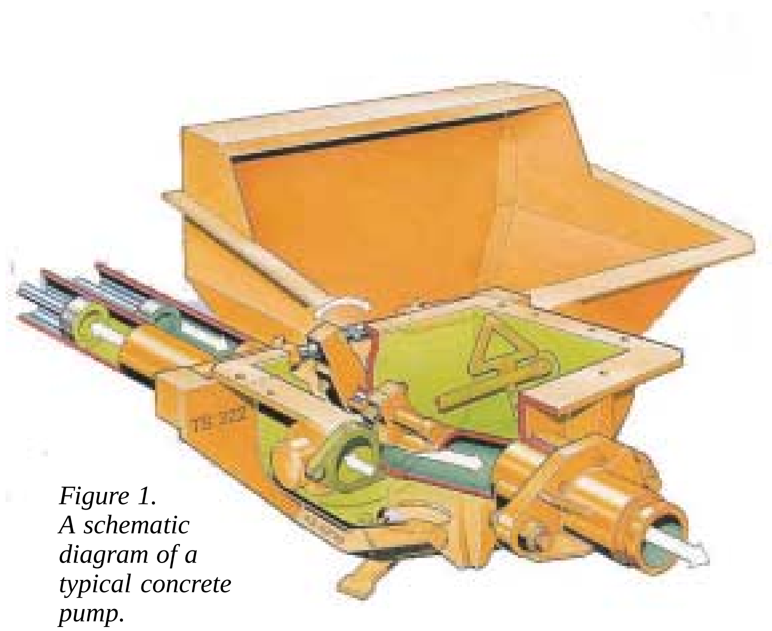

Figure 1. A schematic diagram of a typical concrete pump.

Mixture Design

Shotcrete mixtures, like concrete mixtures, need to be designed carefully in order to be pumpable and placeable and still have the desired engineering properties. Shotcrete mixtures generally contain normal portland cement, sand, and coarse aggregate (3/8 in. [10 mm]) and, in addition, may also contain steel or synthetic fiber, silica fume, and fly ash. Chemical admixtures are often added to control water demand, setting time, and air entrainment; and new admixtures are currently under development to reduce drying shrinkage and minimize corrosion of embedded reinforcing steel. These constituent materials all have an effect on pumpability.

Pump Line

Maintaining pump lines as short as possible and avoiding sharp bends and kinks will minimize pumping pressure. Using steel slick line where possible will significantly reduce line friction. Steel slick line has about 1/3 of the friction of rubber hose. Larger diameter hose (2 to 2-1/2 in. [51 to 64 mm]) has less friction than smaller diameter hose (1-1/2 in. [38 mm]); however, the advantages of using larger diameter hose must be weighed against the potential disadvantages of material waste and cleanup costs and the extra effort required in handling.

Material	Effect on Pumpability
Cement	A basic ingredient of shotcrete which generally enhances pumpability
Sand	Aggregates are a basic ingredient of shotcrete and can cause major pumping problems if the combined gradation is not within the ACI 506, "Guide to Shotcrete" Table 2.1 Gradation 2 limits. For easiest pumping, the aggregate should be rounded to sub rounded. Fly ash and/or silica fume is often used to enhance pumpability if aggregates are more subangular or angular.
Coarse Aggregate	
Silica Fume	Silica fume generally improves pumpability, particularly in mixtures with poor sand shape or gradation. Silica fume also reduces a shotcrete mixture's tendency to bleed and enhances mixture cohesion and adhesion properties. Silica fume is typically used in shotcrete at addition rates ranging from 5 to 12% by mass of cement. Lower addition rates reduce bleeding and enhance pumpability while higher addition rates enhance cohesion and adhesion to substrate, reduce rebound, and improve the thickness of buildup in a single pass. High-range water-reducers (superplasticizers) should always be used with silica fume in order to control the water demand of the mix.
Fly ash	Fly ash is used as a supplementary cementing material. Because of the round shape of the fly ash particles, it generally improves pumpability. In many cases, adding 35 to 70 lb/yd^3 (20 to 40 kg/m^3) of fly ash can make an otherwise unpumpable mix pump successfully.
Fibers	Both steel and synthetic fibers are added to shotcrete mixtures to enhance toughness, ductility, and impact resistance, as well at to control shrinkage-induced cracking . Fibers, particularly synthetic fibers, require additional paste to coat the increased surface area of the fiber. Additional cement, fly ash, or silica fume is often added to improve pumpability if high volumes of synthetic fibers are used.
Chemical admixtures	**Water reducers:** Reduce the overall water content of the mix and generally reduce bleeding. Reduced water also reduces paste volume. **Superplasticizers**: Used with silica fume to control water demand and can be used with other high performance shotcrete mixtures but not at a dosage that may cause sagging or sloughing of the shotcrete. **Air-entraining agents**: Used where freeze-thaw durability is required. Generally about one half of the entrained air is lost during the shooting process. Thus, for freeze-thaw durable shotcrete, the mixture should have a plastic air content of about 10% before shooting. The reduction in air content during shooting reduces the slump of the in-place shotcrete, thus enhancing the thickness of buildup and reducing sagging and sloughing. (See Technical Tip in Vol. 2, No. 1.)

Condition of Pump

The condition of the pump is critical to being able to pump shotcrete mixtures. Piston seals, wear plates, and swing tube seals need to be checked frequently. The loss of shotcrete paste through worn or damaged seals will reduce the plasticity of the shotcrete mixture and increase the potential for hose plugs. The pump hopper and agitator should be kept as clean as possible in order to prevent pieces of hardened concrete or shotcrete from becoming dislodged and getting caught in the reducer or hose.

Troubleshooting Tips

How do I slick the line to avoid blockage at the start of pumping?

The preferred method of slicking the line is to place the slicking slurry (cement, fly ash, bentonite, or proprietary slicking agent) in the reducer downstream of the pump. This procedure will maximize the effectiveness of the slicking agent, prevent the shotcrete from becoming contaminated by the slicking agent, and minimize the shotcrete wasted at the end of the hose, thus reducing costs and clean-up time.

How can I tell where the hose is plugged?

Often the location of a hose blockage can be determined by observing the response of the hose to alternating pumping pressure and relief of pressure. The hose will move where it is subjected to pressure and will not move downstream of the blockage. Note that line pressure must always be relieved before attempting to open hose connections.

How can I tell if the seals in the pump are in good condition? As discussed earlier, the condition of the seals in a pump is critical to the ability to pump shotcrete mixtures. By partially filling the hopper with water, closing off the outflow end of the pump with a fitting with a pressure gauge, and operating the pump, leakage and pumping pressure can be observed. If the pump pressures out at the specified pressure and no significant leakage is observed at the seals (swing tube or piston seals or reducers) the seals are likely in good condition. If large amounts of leakage occur and the pump continues to cycle, this is an indication of excessive leakage and the seals should be replaced.

Will increased water addition to the mixture assist in pumping? Increasing the slump of a mixture generally reduces pumping pressure; however, shotcrete mixtures need to have a relatively low slump (2 to 4 in. [51 to 102 mm]) for proper application. Increasing the slump beyond this level will impair placement. Replacing rubber hose with metal slick line, adding a small amount of fly ash to the mixture, and reducing the output volume are better ways of reducing pumping pressure.

What is the best way to clean the pump? There are a variety of ways of cleaning the pump. The following is the author's preference. As placement nears the end, allow the hopper to be drawn down as low as possible without sucking in air. At the conclusion of pumping, open the hatch in the bottom of the hopper and allow the contents to drop onto the ground or into a suitable container. Then disconnect the hose from the reducers and suck the concrete back from the reducers into the hopper (and into the collection container). Remove the reducers and rinse carefully. Rinse the swing tube while operating the pump in reverse until clear water comes out of the piston tubes into the hopper. Clean the hopper and close the hatch in the bottom of the hopper. Fill the hopper with water. Reconnect the hoses to the reducers. Place a sponge in the still full concrete line and pump the concrete out of the line with water. The sponge is a necessity in this procedure in order to avoid getting a plug of loose gravel in the hose, as a result of washed-out concrete. The hose should be flushed twice in this manner. Disconnect and carefully clean all clamps and rubber seals. Greased seals will extend the life of the seal, minimize pinching of the seal, and reduce leakage of paste at the seal, which will minimize hose blockages.

Neil McAskill is a principal technologist with AMEC Earth & Environmental Limited. He has been with AMEC and its predecessor companies for over 30 years and has extensive experience in concrete and shotcrete technology. He is an American Shotcrete Association approved Shotcrete Nozzleman Certification Examiner and has conducted numerous shotcrete nozzleman training schools and certification examinations throughout North America. He has provided shotcrete troubleshooting and consulting services on a wide variety of projects in North and South America and Australia.