What You Need to Know About Wet-Mix Shotcrete

by Ray Schallom and Mike Ballou

Wet-mix shotcrete is a mixture of cement, aggregates, and water that may contain admixtures, which is hydraulically pumped to the nozzle where compressed air is added to provide high velocity for placement and consolidation of the material on the receiving surface. The purpose of this article is to illustrate the uses of wet-mix shotcrete for small (repair), medium, and large output applications. There are several factors that dictate good wet-mix shotcrete practices: the right concrete pump for the job; a suitable mix design; the right nozzle (for the best material velocity); the distance the material has to be pumped; crew experience; good nozzling technique; and implementation of proper safety precautions for the pump and the hoses, including the clamps; and the overall safety of the workers.

Choosing the right wet-mix shotcrete pump for the job

Contractors often purchase one type of concrete pump thinking that it will be suitable for several different types of wet-mix applications. Most concrete pump outputs range from 20 to 50 yd^3/h (15 to 38 m^3/h). Such pumps are suitable for medium- to high-volume output of wet-mix shotcrete. However, for repair jobs using wet-mix shotcrete, lower output pumps are required; and because mixes with finer aggregate grading are used, smaller-diameter hoses are used. Typically a 1.5 in. (38 mm) hose and a smaller-diameter nozzle is needed. One needs to keep in mind that only about 18 yd^3/h (13.8 m^3/h) can be pumped through a 2 in. (50 mm) hose unless grout is being pumped.

An average hand-held nozzling application produces between 6 to 15 yd^3/h (4.6 to 11.5 m^3/h) of shotcrete. For robotic applications 2 in. (50 mm) and 2.5 (63.5 mm) in hoses are typically used. The outputs range from 20 to 30 yd^3/h (15 to 23 m^3/h) in robotic applications.

There are several good hydraulic swing-tube piston-type pumps that perform well. There are a few important things to keep in mind when choosing a wet-mix shotcrete pump. The total costs for purchasing the wet-mix shotcrete pump are substantially greater than for a dry-mix shotcrete system. Wet-mix shotcrete equipment can also be more complicated to maintain. The following is a list of some items that should be considered when choosing wet-mix pumps and systems:

- Customer service from the manufacturer or dealer in case of pump problems;
- Repair parts availability, sales staff knowledge with the inner workings of the pump (for troubleshooting problems). On-site set-up and testing from the seller (to make sure there are no pumping problems with the mix design selected for the job prior to start up); and
- Accessories the seller offers (hoses, clamps, reducers, concrete pipe, shotcrete nozzles, or fittings and accessories needed to equip the pump for a robotic arm if needed).

After the contractor has selected the right manufacturer or distributor, the next step is to choose the right pump to meet the job requirements. For repair work, the contractor will be looking at a lower output concrete pump that might have a batch mixer attachment for mixing specially blended dry-bag material, or the same pump without the batch mixer should be able to handle pumping fine aggregate ready-mix supplied shotcrete. The pump discharge line would have to be reduced to a 1.5 in. (38 mm) diameter line for repair work.

For medium and large output jobs, the contractor would typically require a piston-type pump with outputs of 20 to 50 yd^3/h (15 to 38 m^3/h), a remixer in the hopper (to help agitate and push low slump mixes toward the cylinders), a vibrator on the grate to help with low slump mixes or mixes with fibers (special grates are available that have vibrators attached and tighter grid patterns help keep the rocks out of the mix while letting stiff mixes or mixes with fibers pass through). For accelerated shotcrete, the contractor would require an accelerator dosing pump system that is connected to the concrete pump designed to inject the right amount of accelerator per cylinder stroke into the air stream at the nozzle.

A few types of pumps that have worked well on projects we have completed include: the Reed C series pumps (for medium- and high-volume jobs), the Schwing 750 and 1000 series pumps (for medium- and high-volume jobs), the Allentown Pro, Magnum, and Model 10 with and without the mixer on repair jobs. The Allentown Elite Models 20, 35, and 40 all have special grates with the vibrator attached, designed for fiber-reinforced shotcretes. They also have an accelerator pump system.

A few types of Robotic Spray Mobiles that have proven to be quite dependable and have been

provided with excellent maintenance service and technical support include: Meyco (Switzerland) and Master Builders/Driftec systems (Canada). The Meyco Cobra and Road Runner are used in both civil tunnels and mining. The MBT/Driftec MSV 2000 is being used in the Canadian mining market. All these units are equipped with their own air compressor, concrete pump, accelerator system, and a 100 gal. (380 liters) accelerator reservoir tank. These spray mobiles are also equipped with other essential equipment such as: pressure washer, lights to see the shooting surface, hydraulic leveling legs, tool boxes, and hose reels. Each job using robotic spraying equipment has its own specific equipment needs.

Mix Designs

Too often we find designers or inspectors who do not fully understand the sprayed concrete application process and tend to overspecify material properties. The key to achieving good shotcrete durability is through good mix designs and application and by keeping the details complete but as simple as possible. In different geographical locations across North America, different aggregates are being used in the mixes and the cements used may have different setting times. We have found through experience that mixes need to be tested using the wet-mix shotcrete equipment selected for the job, prior to start-up. This helps the contractor or the design team make any necessary changes to the shotcrete mix design before the job begins. Mix designs that work well for a contractor on the West Coast may have to be modified to work on the East Coast because of changes in aggregate types, shape, texture, and gradation.

Combined aggregate gradations should, however, fall within either the ACI 506R gradation No. 1 or No. 2 limits shown in Table 1.

For wet-mix shotcrete, the modifications to the mixture composition such as increasing the cementitious materials proportion and/or a reduction in the size and proportion of the coarse aggregates may be required to improve the pumpability of the shotcrete. As an example, Table 2 gives typical compositions of three different shotcrete mixtures, each having a water-cementitious material ratio (*w*/*cm*) of 0.45. The dosages of water-reducing admixtures, high-range water-reducing admixtures, or both, and air-entraining admixtures may have to be adjusted so that the desired slump and air content are obtained before pumping.

Because the maximum *w*/*cm* is usually specified at about 0.45, the desired workability or slump of 3 to 5 in. (75 to 125 mm) can typically only be obtained at a cementitious material content of about 765 lb/yd^3 (450 kg/m^3) or higher and with the aid of a high-range water-reducing admixture at an addition rate of approximately 0.5 to 1.0% by mass of cement. Midrange water reducers have also been used to provide the same slump requirements. For higher slumps, high-range water reducers may have to be added at the job site before shooting.

To obtain typically specified properties in fresh and hardened concrete, concrete admixtures are normally used in the wet-mix spraying method. Concrete admixtures are not new inventions. During the last 20 years, more stringent requirements for higher quality and production have accelerated the development, research, and utilization of admixtures in shotcrete. Water reducers are used to improve concrete workability and cohesiveness in the plastic state. They can provide a significant increase in slump at the same *w*/*cm*, or the *w*/*cm* can be reduced. Mixes

Table 1: Gradation limits for combined aggregates

Sieve size/US	Percentage by mass passing individual sieves	
Mesh	Gradation 1	Gradation 2
3/8 in.	100	90-100
No. 4	95-100	70-85
No. 8	80-100	50-70
No. 16	50-85	33-55
No. 30	25-60	20-35
No. 50	10-30	8-20
No. 100	2-10	2-10

Figure 1: Shooting test panels, bobsled and luge track, Park City, UT

Table 2: Examples of different wet-mix shotcrete mixture designs

Constituents	Wet-mix shotcrete, (*w/cm* = 0.45) with entrained air		
	Ordinary shotcrete	With silica fume	With fibers and silica fume
Water	180 kg/m³ 303 lb/yd³		
Cement	400 kg/m³ 674 lb/yd³	360 kg/m³ 610 lb/yd³	
Silica fume	—	40 kg/m³ 84 lb/yd³	
Sand	1250 kg/m³ 2106 lb/yd³		1225 kg/m³ 2064 lb/yd³
Coarse aggregate (maximum 10 mm)	500 kg/m³ 843 lb/yd³		475 kg/m³ 800 lb/yd³
Steel fibers (maximum 35 mm)	—	—	50 kg/m³ 84 lb/yd³
Air-entraining admixture	0.3 L/m³ 7.7 oz./yd³		
Water-reducing admixture	1.5 L/m³ 38.4 oz./yd³		
High-range water-reducing admixture	—	1.0 L/m³ 25.6 oz./yd³	1.5 L/m³ 38.4 oz./yd³
Slump before pumping	80 to 120 mm 3 to 5 in.		
Air content before pumping	7 to 10%		

with a reduced *w/cm* will have an increase in strength. Higher slump mixes can have improved pumpability.

The wet-mix method is attractive in that the concrete is mixed and the water is added under controlled and reproducible conditions, for instance, at a concrete plant. The *w/cm*, one of the fundamental factors in concrete performance, is under better control.

There are several producers of admixtures. One producer with good admixture performance predictability and technical support is Master Builders/Degussa (MBT). A number of their admixtures have been used all across America with considerable success: midrange water reducers include the Polyheed line. High-range water reducers include Reobuild 1000 and the new generation Glenium line.

For hydration control up to 72 h, Delvo Stabilizer or Delvocrete has been dependable and predictable. When using Delvo in the concrete mix, the typical 90 min window is no longer a concern for the contractor. Cleanup of the pump and the hoses has been reduced to once a shift.

Bagged materials have been mainly used in the repair market, but they have also been used in tunnelling and mining projects. Also, jobs in remote areas have used them. Most bagged materials are specially blended according to the job requirements. Most bagged mix designs are of a proprietary formulation, so we are unable to show a typical mix design for these materials. One, however, needs to know whether powdered plasticizers are in the mix or whether some liquid plasticizer needs to be added during mixing. While compressive strengths for these bagged materials are usually provided in the specification data sheets, field testing is still needed to record the actual in-place strengths and other specified performance parameters.

Accelerators are used for overhead shooting to increase the build-up thickness and to accelerate early strength development. The accelerator is added at the nozzle and the nozzle operator can vary the quantity being added with a valve, depending on the placing conditions. Metering pumps should be used to prevent over- or under-acceleration of the shotcrete that is placed. Accelerator is used in both vertical and overhead applications to help achieve the required thickness in the least number of passes. Vertical applications require less accelerator than overhead applications for the same thickness. Although accelerators have been used extensively in mining and tunnel work, there are also some works above ground that have used them as well.

During the past couple of decades, the construction industry has been demanding safer sprayed concrete accelerators with better performance. Today, well-functioning, liquid, alkali-free and noncaustic products are available, providing safe, high-quality, and cost-effective sprayed concrete applications. The choices of the wet-mix method, as well as the replacement of caustic and alkaline accelerators by noncaustic and alkali-free products, are big steps towards an improved working environment. Dust and rebound are dramatically reduced along with a marked reduction in skin burns.

There are several producers of accelerators. One producer with a good track record for in-place success who provides good technical support, including onsite testing and laboratory testing, has been MBT. The following MBT accelerators have performed well on a variety of different projects across North America: 766, SA 430, and SA 160. Different jobs require different types of accelerators and accelerator addition rates to satisfy application and early strength requirements.

Figure 2: Acme 1.5 in. (38 mm) nozzle/Las Vegas Mega Demo 2001

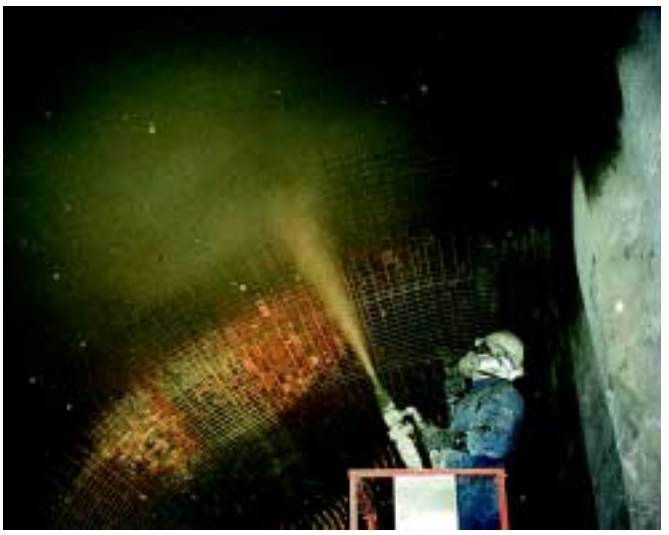

*Figure 3: Acme 2 in. (50 mm) nozzle/Staten Island Terminal Tunnel (*Photo courtesy of George Yoggy*)*

*Figure 4: Meyco 2 in. (50 mm) nozzle (*Photo courtesy of George Yoggy*)*

Figure 5: Meyco 2.5 in. (63.5 mm) nozzle/Seattle Rock Mechanics Demo

Nozzle types

Shotcrete nozzles for wet-mix applications play a key role in the placement of quality compacted shotcrete. There is a wide range of different types of wet-mix nozzles. They produce tight to wide spray patterns with low- to high-velocity surface impact. A few that work well and are reliable include Allentown's Acme 1.5 in. (38 mm) and 2 in. (50 mm) setup with or without the accelerator plumbing. Also, the Allentown/Meyco 2 in. (50 mm) Swiss nozzle setup, with or without the accelerator plumbing, and the Allentown/Meyco 2.5 in. (63.5 mm) nozzle setup work well. Both the 2 in. (50 mm) and 2.5 in. (63.5 mm) Meyco Swiss nozzles have been widely used on Robotic Spray arms.

A minimum air supply requirement for wet-mix shotcrete is a 185 cfm (5.2 m^3/min) compressor. It has been our experience that more air volume is better because a worker often connects some other tool to the compressor that always drops the air volume to the nozzle.

All the wet-mix shotcrete jobs we have been involved with have had an air supply of no less than 375 cfm (10.6 m^3/min). The velocity of the wet-mix shotcrete on ejection from the nozzle is usually around 65 to 100 ft/s (20 to 30 m/s).

Pumping distance has always been a concern because of the potential for plugs or the mix setting up in the line. With the advancement in admixture technology, pumping longer distances need no longer be a problem or a concern. Caution, however, needs to be taken when attempting this task. We recommend that you contact your admixture representative and ready-mix producer for the technical help needed to make pumping a success.

The versatility of the wet-mix shotcrete process has made it easier for contractors to use shotcrete in place of conventional concrete placing methods. Here are a few areas where wet-mix shotcrete has been used:

- Repair, restoration, and seismic retrofit of bridges, parking garages, dams, reservoirs, and marine structures;
- Ground support: stabilization, soil nailing, tunnelling, and mining;
- New construction: pools, tanks, domes, and retaining walls;
- Architectural: landscapes and zooscapes; and
- Specialty: bobsled and luge tracks, skateboard parks, and refractory.

Figure 6: Bobsled and luge track, Park City, UT

Figure 7: Ground support/Henderson Mine

Figure 8: Artificial rock mountain/Six Flags

Safety issues to consider with wet-mix shotcrete

Concrete line pressures can reach as high as 4000 psi (28,000 kPa) when a plug occurs. It is extremely important to follow the manufacturer's operation and safety manuals to prevent injury or even death. The Concrete Pumping Association has prepared a safety manual on concrete pumping that most manufacturers follow and have adopted. A safety checklist is usually provided in the equipment manual for the contractor and the crew to follow daily. Depending on what type of job you are on, some governing agencies may require even tighter safety controls in addition to the manufacturer's list.

A strong safety program for shotcrete preparation and application, as well as in all other areas of the operation, is imperative if accidents are to be prevented. Accidents and injuries are costly to the injured employee due to temporary or permanent disability and pain, lost income, and mental stress. Accidents and injuries are also costly to a company in direct lost production, lower productivity, fines, higher insurance costs, increased expenses in dealing with increased government inspections, lower employee morale, and decreased corporate reputation. In addition, MSHA (Mine Safety and Health Administration) and OSHA (Occupational Safety and Health Administration) ratings are being used to screen contractors with poor safety records during project prequalification.

Not all incidents may result in injury or equipment damage. They should, however, also be reported and monitored closely because they serve as an indicator of the potential for actual accidents. Whatever the case may be, one needs to be reminded that an injury only takes a split second to happen. The responsibility to improve the sprayed concrete application as well as the environmental and working safety lies with the owners, specifiers, and the contractor.

Summary

In conclusion, wet-mix shotcrete technology has reached a stage of maturity that allows the routine production of high-quality, durable sprayed concrete for a wide variety of applications. Further, substantial technical advantages are available when reinforcement is required and fibers are used. Other important advantages such as totally flexible logistics complete the range of reasons in favor of using the wet-mix sprayed concrete technology. It is not an experiment anymore—solutions are well-proven, safe, and cost-effective. It is our opinion that wet-mix shotcrete will continue to increase in popularity and that shotcrete contractors, suppliers, engineers, and testing agencies—working together—will assure its future.

References

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