Choosing Your Wet or Dry Shotcrete Equipment Wisely

By Raymond Schallom III

Contractors just getting into the shotcrete business or inexperienced contractors may buy the wrong equipment just because the specification calls for it or a good salesman talks them into it. The seasoned, experienced shotcrete contractor already has the equipment for their proficient crews and knows what system (wet or dry) will work best for the project. Experienced shotcrete contractors and crews know that pneumatically applied concrete material projected at high velocity onto the surface will flow around the reinforcing bars and has excellent surface bond.

Fig. 1: Fireproofing nozzle setup

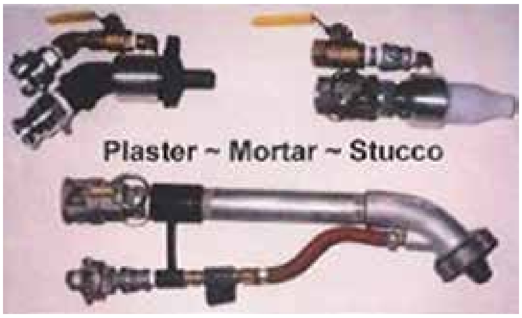

Fig. 2: Plastering nozzle setups

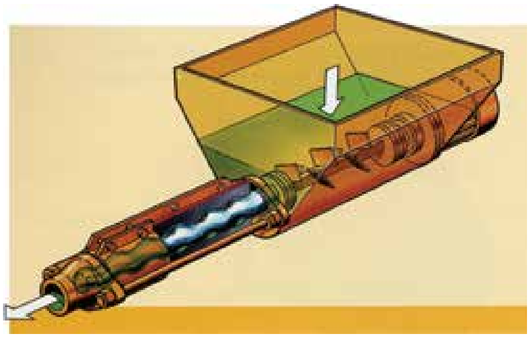
Fig. 3: Rotor stator pumps were designed for plaster, stucco, fireproofing, and later to replace the hawk and trowel for patches vertically 1 in. (25 mm) thick with no reinforcement. These nozzles and pump are not recognized by ACI as shotcrete equipment

Low-velocity applications, which are sometimes specified and advertised as a shotcrete system, were developed for spraying plaster, stucco, fireproofing, and the replacement for the hand-applied hawk-and-trowel method of 1 in. (25 mm) thick or less vertical patching with no reinforcement. The low-velocity method cannot pump any type of macro- or microfibers through the machine or through the nozzle tip, does not have the material velocity to wrap around the reinforcement properly, and has a limited pumping distance from the pump to the nozzle of 150 ft (46 m) before it starts to wear on the rotor. The low-velocity system cannot spray overhead without having the nozzle 2 to 4 in. (50 to 100 mm) from the surface and cannot properly encase reinforcement vertically or overhead due to the lack of material velocity. Figures 1 through 3 show different plaster and fireproofing nozzles and a rotor stator pump, which only pumps fine aggregate mixtures to cut down on the rotor wear. The air hose to the nozzle is typically 3/8 in. (9 mm) ID diameter with a 1/4 in. (6 mm) ID pipe into the tip of the nozzle for adjusting a splatter type spray pattern held at 2 to 4 in. (50 to 100 mm) from the surface. Not enough air volume (cfm) is able to pass through the 3/8 in. (9 mm) hose and 1/4 in. (6 mm) pipe to increase the speed of the material to reach a high-velocity spray pattern.

The article "Proper Selection of Equipment and Nozzle for ACI Shotcrete Nozzleman Certification"[1] talks about what ACI recognizes as the correct nozzle setup and equipment required for nozzleman certification. The American Concrete Institute (ACI) C660 Shotcrete Nozzleman Certification Committee put together the CP-60(09),[2] "Craftsman Workbook for Shotcrete," which covers the equipment, nozzle setup, and distance from the receiving surface. The ACI Shotcrete Subcommittees have written many documents over the years which outline the areas discussed previously. ACI documents[2-6] also provide guidance on selecting the correct high-velocity shotcrete equipment and nozzle setup. There is even a section on air requirements for both wet and dry shotcrete in ACI 506R-05,[4] Table 3.1, and Sections 3.4, 3.4.1, and 3.4.2.

Over the last 40 years I have used a checklist from my article "What You Need to Know before Selecting a Wet-Mix Shotcrete Pump"[7] to help choose the right manufacturer or dealer of wet pumps, dry machines, and systems needed for either shotcrete process. Although originally formulated for wet-mix equipment, the same format of the checklist can be used for selecting dry-mix equipment as well.

Once you have selected the right manufacturer or distributor, the next step is to choose the right pump/gun to meet your job requirements. The price of the equipment will likely play a key role in your selection. It is important to research the performance and maintenance history of the wet- or dry-mix equipment under consideration. More time and money may be spent on repair and maintenance for a less expensive model than for one that is more rugged with a good track record. The checklist can be used for any civil or mining projects. Following, you will see a comparison between both processes. Advancement in material, admixtures, and equipment has made both processes almost equal. (Figures 4 through 10 are of dry-shotcrete equipment; Fig. 11 through 15 are wet-shotcrete equipment.) There are three areas you need to look at: 1) which process do you want to get into; 2) the right high-velocity nozzle setup; and 3) the correct material hose for safety and nozzlemen efficiency. Auxiliary/accessory equipment may be needed depending on project requirements. An article found on the ASA website called: "The Value of Shotcrete Accessories"[8] explains the accessory equipment.

Checklist for Choosing the Right Manufacturer

(reproduced from Shotcrete*, Summer 2009[7])*

- Check the years of shotcrete knowledge and experience of the manufacturer's or dealer's sales staff.
- Research the equipment's field track record from a production standpoint.
- Evaluate the manufacturer's or dealer's customer service. This is helpful for troubleshooting pump- or gun-related problems or other shotcrete-related issues.
- Check on the availability of repair parts and the sales staff's knowledge of the inner workings of the concrete pump/gun (for troubleshooting problems). The manufacturer or dealer should offer on-site setup and testing prior to startup (to make sure there is no gunning or pumping problems with the mixture proportions selected for the job).
- The manufacturer or dealer should be able to offer hands-on shotcrete training as an option (check to see how many years of hands-on training experience the trainers have).
- Identify accessories the seller offers (hoses, clamps, reducers, concrete pipe, shotcrete nozzles, or fittings and accessories needed to equip the pump/gun for a robotic arm or robotic unit or accelerator dosing systems if the job requires it).

Dry Machines

The dry equipment shown ranges from the high-velocity dry nozzle setup to all three types of dry guns (ACI lists two classes of guns: pressure vessel and rotary guns). Figure 7 is the newer version of the N-gun (pressure vessel), which was introduced back in 1909 by Carl Akeley. The Cement Gun Company commercialized the N-gun in 1910 and the word "gunite" was coined in 1912. The N-gun has 105 years of field use and is still commonly used up and down the East Coast and many other countries globally. With the sealed pressure vessel, the N-gun has shot long distances over 1000 ft (300 m) and heights of over 500 ft (150 m) without the aid of an inline booster. They have very few wear parts and older version N-gun parts can be replaced with the new present-day parts. It was built to last for at least 100 years. It takes a well-trained gun runner to run the machine. Often the nozzlemen and gun runner switch positions daily.

The rotary barrel-type gun (Fig. 5) comes in two sizes depending on the output (low production of up to 6 yd^3/h (4.5 m^3/h) and the larger gun (Fig. 8) with outputs of up to 15 yd^3/h (11.5 m^3/h). The rotary barrel has over 50 years of field experience. It is very simple to run, has direct feed, and can handle any type of synthetic fibers (micro and macro) to steel fibers with the correct barrel size. It has an external exhaust chamber that allows any excess air to bypass without bubbling up through the hopper. Dust collectors have been designed to eliminate the exhaust dust. Distances for materials up to 1000 ft (300 m) horizontally and with inline material booster distances of over 2500 ft (762 m) have been achieved. Vertical material heights of 400 ft (120 m) have been achieved without an inline material booster. These rotary guns were constructed for the civil and mining projects where the equipment wear and tear is at its highest. This type of machine was designed for a less skilled worker, who just has to feed the hopper of the machine (gun) during operation.

The bowl-type gun in (Fig. 6) has over 50 years of field experience. It is a production-type gun for sand and cement. The U-shape bowl design makes it tough to push macro-synthetic and steel fibers up through the bowl pockets into the material hose proficiently. Due to its low cost, most contractors choose this type of gun. In most setups, a 2 in. (50 mm) inline air is reduced to a 1 in. (25 mm) pipe attached to the top of the clamping plate and rubber pad seal. From there, the 1 in. (25 mm) air volume pushes the material through the U-shape bowl backup to 1-1/2 in. (38 mm) or 2 in. (50 mm) material hose. This alone reduces the volume of air flow and material velocity to distances of

Dry-Process Nozzle Setups

Fig. 4: These dry-process nozzles are designed to handle the high material velocity and produce adequate spray patterns; also shown are different hose coupling sets. Six of the nozzle setups have water rings with 8 to 16 small 1/16 in. (1.6 mm) holes that create a cone when the water is turned on; as the material passes through the water, the material is partially mixed as the nozzleman builds up the layers. The 2 in. (50 mm) setup water ring has 16 straight holes in it and requires more water pressure and air volume to properly mix and compact the material

500 ft (150 m) horizontally and 100 ft (30 m) vertically, even though a few contractors have pushed past the manufacturer's rated distances. Bowl guns have a short life cycle due to the wear items and the light-duty gear boxes that need constant upkeep. The missing external exhaust chamber in some bowl guns results in air being discharged back through the hopper, causing bubbling of the material and excess dusting. This type of machine was also designed for a less skilled worker, who just has to feed the hopper of the machine (gun) during operation.

Remember, it requires more volume of air to successfully convey the material through the rotary dry guns. The higher air volume is also needed to run the air motors of the machines without causing blow by (bubbling up in the open hoppers) when gunning horizontal and vertical runs, which is commonly not experienced when operating a pressure vessel type of gun. Remember to consult your manufacturer when attempting to push material horizontally and vertically long distances if you experience bubbling material up through the hopper. ACI 506R-05[4] lists the compressor capacities and material hose diameter (refer to Table 3-1 in the document). All open vessels need a minimum of 600 CFM (17 m^3/min). Some manufacturers say you can use a 365 ft^3/min (10 m^3/min) compressor provided the unit is hydraulically driven and you only have 50 ft (15 m) of 1-1/2 in. (38 mm) material hose while gunning horizontal surfaces. When the nozzle is above the hopper of the open vessel guns, the air requirement will always be higher due to the extra air volume needed to convey the material out and up through the mixing nozzle. The air motor on the rotary guns takes as much as 185 ft^3/min (5.25 m^3/min) of air to run it properly.

Dry-Process Machines

Fig. 5: Rotary guns have over 50 years in the field use. This dry gun barrel-type gun is an air over/hydraulic unit for more consistent material flow and has an external air exhaust to keep it from bubbling up through the hopper during material discharge. This gun type can push macro- and micro-steel and synthetic fibers through the gun. These guns have pushed material over 400 ft (120 m) vertically and over 2500 ft (760 m) horizontally

Fig. 6: Bowl guns have been used over 50 years in the field use. It has no external exhaust, allowing the excess air to bubble up through the hopper. The U-shaped bowl makes it difficult to push macro-synthetic and steel fiber mixtures up and through the material outlet and limits the horizontal distance the material can be pushed

One of the biggest issues that is faced by the shotcrete contractor since the early 1970s is that

Fig. 7: N-gun or pressure vessel has 105 years of field use. It is based off the original gun design from 1907-1910 and is called the double tank or chamber. This gun allows the material to continuously flow because the bottom chamber stays fully pressurized while the top chamber is being filled. With very few wear parts, these guns are built to last forever. The pressure is still used for pushing material 500 ft (150 m) vertically and 1000 ft (300 m) horizontally

Fig. 8: This auger-feed predampener and rotary barrel gun combination is used in civil tunnels and mining projects. This is an electric feed machine for consistent material flow, along with a peristaltic accelerator dosing pump that injects the metered liquid into the water line to the nozzle for early set times of the in-place dry shotcrete material

Fig. 9: From the original design, this rig is the original predampener and mixing rig for the N-gun and has a 50-year field experience based off the original Micon rig design. This rig can mix moist sand and cement or predampen prebagged material

Fig. 10: From the original design this rig is a shorter version of the original predampener and mixing rig with a rotary barrel-type gun and hydraulic water booster pump designed to fit into low spaces, such as parking garages. This rig can mix moist sand and cement or predampen prebagged material

most specifiers started writing prepackaged completely dry bagged materials in their repair specifications. This alone has deviated from the patented bulk moist sand pile and cement mixture designs that had worked for over 50 years by the Cement Gun Company and their licensees. With the use of the dry bagged material instead of using moist sand and cement mixture, it became necessary to predampen the material before it entered the gun. By mixing moist sand (with 3 to 5% moisture) and cement together, it would start the hydration process, making it easier for the nozzleman to regulate the water at the nozzle and reducing the potential for building up static electricity from material moving through the hose. By using completely dry material with no moisture, the hydration process did not start until the dry material reached the nozzle water ring. This author learned the hard way—getting hit by static electricity. I wrapped the nozzle hose with an inner tube; grounded the gun, couplings, and the hose and water valve at the nozzle; and even switched water pumps to increase the water pressure at the nozzle, which I thought would solve my problems. It never dawned on me the one key element missing was the moisture in the mixture before entering the gun. By taking a mortar mixer and a water spray nozzle to predampen the dry material, we made a crude predampener, which brought the material back to the original consistency (moist sand and cement). By predampening the mixture, it made the static electricity disappear and also made adjustments to the mixing water at the nozzle easier to control. It wasn't until later in my career that I was introduced to an actual continuous auger-fed predampening machine. This eliminated shoveling the mixed material into the gun (a back saver). Figure 8 is an electric combination predampener/rotary barrel gun (GM-060 for production) and a peristaltic accelerator pump for use on civil and mining work, where early set times were required. The electric version allows for consistent material flow from the mixing to the delivery. Air-driven machines fluctuate with the air demand from other equipment on the same air source.

From the original Micon mixing rig design, the rig pictured in Fig. 9 was developed as the first mixing and predampening rig available in the mid to late 1960s. In the picture, an N-gun was mounted under the material holding hopper, allowing the gun operator to continually feed the top chamber of the N-gun while the bottom chamber still stayed pressurized. With the spray bar located in the mixer, it allowed the batchman to predampen the dry sand or dry bagged material back to the desired 3 to 5% moisture. Once the batch was mixed, the batchman would open the mixer door, allowing the material to travel up the conveyor into the holding hopper above the gun. Some contractors have modified their rigs to rotary barrel-type guns for continuous feed and simplicity (Fig. 10). The art of running an N-gun (pressure vessel) is now down to well-established contractors that have several of the N-guns in their fleet.

Wet Concrete Pumps

Wet mix was introduced back in 1955 in North America and was later called the wet-mix shotcrete process by ACI. Like the dry process, the evolution of the wet-mix concrete pumps have come a long way from the mid-1950s. Pictures of the old pumps can be found in earlier versions of the ACI 506[2-6] documents.

The concrete pump shown in Fig. 12 is a medium-to-low volume swing tube pump that is capable of pumping through a 1-1/2 to 4 in. (38 to 100 mm) diameter hose depending on the project. This size of pump is an ideal shotcrete pump that can pump concrete up to 20 yd^3/h (15 m^3/h). It has a mixer on the back end to remix concrete mixtures from a truck or site mix bagged material. This wet-mix pump is designed to handle lower-volume output for repair and grouting applications as well. The pump should be capable of reducing the material outlet to a 1.5 in. (38 mm) diameter hose for repair and have the option to do low-pressure grout work. The electronic setup in the pump allows the swing tube to switch quickly between cylinders, reducing the delay between strokes and cutting down on the line surge at the nozzle.

For medium- and large-volume projects, consider using a piston-type pump with outputs of 20 to 60 yd^3/h (15 to 45 m^3/h). A remixer in the hopper helps agitate and push low-slump mixtures toward the cylinders. Grates with vibrators on the grate help with low-slump mixtures or mixtures with fibers (special grates are available that have vibrators attached and smaller openings to help keep larger rocks out of the mixture while letting stiff mixtures or mixtures with fibers pass through it). An accelerator dosing system can be connected to the concrete pump, which can be designed to inject the proper accelerator dosage per cylinder stroke or as a standalone unit with flow control devices into the wet nozzle setup. ACI 506R-05[4] Chapter 3, Fig 3.1, and Section 3.4 on air requirements will help you establish required air needs. For the wet-mix pumps, the fibers are part of the aggregate in the concrete mixture and have an impact on how much cementitious material is required in the mixture to bind it together during pumping. How far from the actual work area will the material be conveyed? How many times will the crew have to stop/start or move throughout the day? These are just a few items to consider in planning the setup of your equipment.

There are several factors that dictate the proper selection of a concrete pump: type of project;

Wet-Mix Nozzle Setups

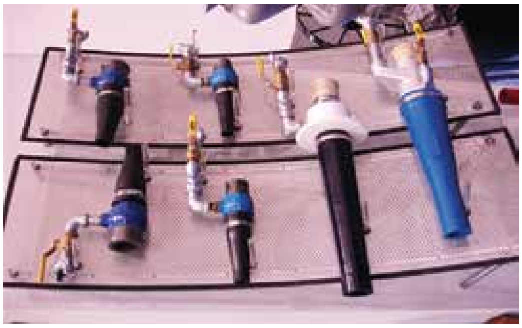

Fig. 11: Wet-mix shotcrete nozzle setups have a minimum of 3/4 in. (20 mm) air line running into them with 8 to 16 small 1/4 in. (6 mm) air holes in the air ring for maximum material velocity. Accelerator is introduced into the air stream at the nozzle and is driven into the material by the air flow (much like the dry-process water ring). The nozzle setup at the far right has an inner material ring and outer air ring. This nozzle needs the air volume to swirl the material coming out of the nozzle tip. With the separate accelerator port, the air volume is crucial to mix it into the material as it swirls out the tip. If the air flow is low, only the outside of the swirled material will have the accelerator in it (this nozzle is a newer version of the early technology)

Wet-Mix Pumps

Fig. 12: An Allentown Powercreter 20 is shown with a hydraulic mixer attachment. The attachment is being used as a remixer for concrete supplied by a mobile, or a volumetric mixer for site batching to achieve a consistent mixture for pumping operations. A vibrating screen was installed to reduce the risk of plugging the 1.5 in. (38 mm) hose due to randomly occurring large aggregate particles. The electronic control technology produced a continuous flow of concrete material that allowed the nozzleman to apply a uniform shotcrete layer to the walls with very little line surge. The unit can pump concrete containing up to 1 in. (25 mm) stone mixes through a 4 in. (100 mm) hose

Fig. 13: Reed C50HP concrete pump can be reduced down to a 2 in. (50 mm) hose for shotcrete work or up to a 5 in. (125 mm) hose for concrete pumping

pumping distance; hose size; type of application; quantity of material to be pumped; production rate desired; and use for the multiple applications other than shotcrete, such as grouting or concrete placing.

All three trailer-mounted concrete pumps (Fig. 13 through 15) are for medium- to large-volume output projects. Remember, all concrete pumps were designed to pump large aggregate mixtures. There are pumps on the market that were designed to pump harsh stiff mixtures and small aggregate mixtures, which also can pump large aggregate mixtures. You have to look at the line surge between strokes, how well the mixture can be drawn into the cylinders for discharge, whether the hopper has an agitator remixer, and a grate

Fig. 14: Schwing 750 trailer pump setup for easy maneuvering in and around the jobsite can be reduced down to a 2 in. (50 mm) hose for shotcrete work or up to 5 in. (125 mm) for concrete pumping

Fig. 15: Allentown Powercreter Model 40 pump with hydraulic outriggers can be reduced down to a 2 in. (50 mm) hose for shotcrete work or up to 5 in. (125 mm) for concrete pumping. The electronic swing tube control allows for faster shifts between cylinders, thus reducing the line surge to the nozzleman

that has a vibrator (a vibrator on the hopper face only compacts the concrete, allowing all the water to rise to the top). These are just a few issues with the wet pumps. One needs to keep in mind that only about 18 yd^3/h (14 m^3/h) can be pumped through a 2 in. (50 mm) hose unless you are pumping cement grouts. An average manually applied shotcrete application produces between 6 and 15 yd^3/h (5 and 11 m^3/h) of pneumatically applied concrete. Hose sizes of 2, 2.5, and 3 in. (50, 65, and 75 mm) are typically used for robotic applications. The outputs for robotic applications range from 20 to 30 yd^3/h (15 to 23 m^3/h).

Shotcrete Application Breakdown between Both Processes

The breakdown comparison between processes in Table 1 may help with your decision making. The dry-mix process requires more volume of air than the wet-mix process, but is easier to stop, start, and move than the wet-mix process. All areas other than the equipment and maintenance costs of dry-mix are about the same. Admixture technology has

Table 1: Shotcrete Application Breakdown between the Wet- and Dry-Mix Process

Wet-mix 50-plus-year track record	Comparison	Dry-mix 50- to 105-year track record
****	Equipment costs	**
****	Operation	**
****	Material distance	****
***	Maintenance	*
****	Performance	****
****	Material volume	***
****	Quality control	****
**	Flexibility	****

made the wet-mix process more desirable on larger projects because it requires smaller air compressors, produces no dust, has substantially higher output production, and produces less rebound.

An article on "Equipment Maintenance"[9] contains three checklists of spare parts and wear items, which routinely cause the most delays or job shutdowns. This short article has many helpful suggestions to prevent what this author once went through in using shotcrete equipment in field conditions. Using the "Daily Wet-Mix Shotcrete Checklist"[9] from the article as a template, one can create a dry-mix daily checklist as well. If you have ever been on a job where the work came to a stop because no one had spare wear items near the pump or gun, and the crew had to wait for someone to bring them the spare wear parts, not only do you lose production time but it's also the equipment and labor time that really adds up.

Summary

The purpose of this article is to inform specifiers or contractors about choosing the right wet-mix or dry-mix equipment for the project size. It can be a valuable selection guide for those who are looking to purchase wet-mix or dry-mix equipment for the first time or for the experienced shotcrete contractors looking to purchase new equipment. It can give specifiers guidance on equipment characteristics that may be appropriate for a particular project. Dry-mix shotcrete has over a 105-year track record and wet-mix shotcrete has a 50-plus-year track record. Both processes are well-proven methods of placing concrete at high velocity and at an economical sustainable price. Logistics play a key role in the process that will work the best for the project. The means and methods of shotcrete placement should be left up to the contractor. In the end, it does not matter which process is used as long as the material specification is met. Ultimately it is the owner of the project who benefits the most from the quality and economy of using shotcrete on their job.

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