Part II of a Two-Part Series on Wet-Mix Equipment Maintenance

Maintenance Fundamentals for Nozzlemen: Often Overlooked Equipment and Maintenance Essentials Can Dramatically Influence In-Place Quality

Do you know what they are?

By Oscar Duckworth

A skilled nozzleman's control of the nozzle during placement is one of the most important factors that will determine in-place shotcrete quality. But like many things, there is much more to the task of proper nozzling than simply controlling the nozzle.

Regardless of a nozzleman's skill and experience, it is impossible to properly place wet-mix shotcrete with poorly chosen or improperly functioning placement equipment. Because a nozzleman's placement quality is reliant on the correct functioning of many individual equipment components, it is vital that a nozzleman possess fundamental knowledge of the operation and maintenance of these components.

Wet-Mix Placement Starts at the Pump

Wet-mix shotcrete is commonly placed using specialty concrete pumping equipment. Pumps are used to push concrete through a delivery system. Nozzlemen should be familiar with how various pump functions influence in-place shotcrete quality.

Most concrete pumps are positive displacement type. They use pumping pistons in action with a valve to pressurize the delivery system. Typical concrete pumps create moderate pressure to push materials within a normal slump range. Shotcrete placement requires considerable additional pressure to convey low-slump shotcrete materials through the delivery system.

Although traditional concrete pumps have been used in shotcrete operations, many manufacturers offer pumps configured specifically for wet-mix shotcrete use. These pumps offer robust hopper, feed auger, and wear components, and cooling configurations that are designed to facilitate the placement of low-slump concrete materials. Shotcrete pumps will provide lower placement volumes but have a much higher pressure potential than traditional machines.

Pump choices affect all aspects of shotcrete placement. Common concrete pumping equipment used for shotcrete placement can lead to costly placement and reliability problems. Nozzlemen often experience erratic material delivery, insufficient cylinder filling, low power, overheating, or excessive plugging when using poorly chosen concrete pumping equipment for wet-mix shotcrete placement. Nozzlemen require an even flow of material from the nozzle to precisely control material placement. Gunning with an irregular or "choppy" flow will not generate acceptable in-place material. Insufficient cylinder filling is the primary cause of uneven flow to the nozzle. A functioning auger is necessary to properly fill the material cylinders during placement. Worn or nonfunctioning augers produce irregular flow rates that diminish in-place quality (Fig. 1 and 2).

Pumps must be kept full. Allowing a pump to run low on material creates strong airbursts known as slugging. Like other forms of uneven flow, slugging will reduce accuracy; displace in-

Fig. 1: Missing auger cannot provide adequate cylinder filling. Uneven nozzle flow will affect nozzle placement quality

Fig. 2: Uneven flow (slugging) has displaced in-place shotcrete. Note signs of sagging below the wire reinforcement

place material; and cause sagging, sloughing, and voids within the work. If irregular flow occurs, the nozzleman should stop placement, investigate the cause, and correct before continuing.

Regardless of the pumping equipment used, the pump must be calibrated to operate within a smooth and manageable range. Nozzlemen should choose a flow rate that feels right. Skilled nozzlemen always work within a speed range so that nozzle thrust does not interfere with the ability to accurately direct the flow.

Wear items within the pump (cutting rings, wear plates, seating surfaces, and outlet seals) will affect placement quality if excessive wear has compromised seal integrity. Because wet-mix shotcrete is a combination of cementitious materials, aggregates, and water, the pump must be able to convey material to the nozzle under pressure without altering the mixture. Because high pressure is required to convey the mixture through the delivery system, wear items within the pump or placement system that leak will allow moisture to be squeezed from the mixture and lost. Poor seal quality can lead to dry-pack placement line blockages, segregation, buildup within the concrete pump valves, and placement difficulties. Skilled nozzlemen should be capable of identifying excessively worn components and schedule repairs or replacement before excess wear affects placement quality or safety (Fig. 3).

Nozzles Require Constant Maintenance

It is the nozzleman's responsibility to operate and correctly maintain the shotcrete nozzle. But

Fig. 3(a): Worn wear components will allow moisture to be squeezed from the mixture during pumping

Fig. 3(b): Wear components in good condition

Fig. 3(c): Hardened buildup restriction inside the S tube is caused by worn wear components

occasionally, necessary maintenance of the nozzle is not completely understood, partially completed, or ignored. Many nozzlemen may not realize that poor or incorrect nozzle function can have a profound effect on a shotcrete mixture's plastic and hardened properties. Proper wet-mix nozzle function is primarily responsible for compaction and consolidation—the fundamental elements of shotcrete placement. Improper nozzle function limits a nozzleman's ability to provide acceptable in-place shotcrete.

Although wet-mix shotcrete nozzle designs vary, all nozzles must effectively diffuse the incoming mixture into fine particles, then highly accelerate the mixture's components to produce a high-velocity spray pattern. Shotcrete is defined as a method of placing concrete with high velocity to achieve compaction. Concrete requires compaction to be an acceptable building component. Typically, cast-in-place concrete is placed, and then consolidated by the use of a concrete vibrator. This standardized procedure generally produces well-consolidated concrete displaying good compaction and consolidation quality. Shotcrete, however, must be physically driven onto a receiving surface at high velocity to achieve similar or superior compaction/consolidation characteristics. To accomplish this, a nozzle must be properly chosen AND properly maintained or placement quality cannot be achieved.

Fig. 4: Note plugged air ring port on lower nozzle. A single plugged port will dramatically reduce in-place compaction/consolidation quality

Shotcrete nozzles are precision tools. With use, they require continuous maintenance. Inspection, disassembly, and cleaning of all air metering ports, and replacing worn components, must be performed daily by the nozzleman.

What Must Happen Within the Nozzle?

Nozzles possess air rings that use multiple small metered ports within the body. The air ring ports are designed to form high-energy air jets which must diffuse (break apart) the low-slump mixture delivered from the delivery system. Sufficient air volume and pressure is required to diffuse the mixture into individual fine particles as it passes through the nozzle plenum. After the mixture is diffused into small particles, it can be accelerated and focused into a high-velocity nozzle stream. Proper diffusion and acceleration of the mixture by the nozzle is critically important to successful shotcrete placement. The compaction/consolidation properties of the in-place material are highly dependent on the effectiveness of the nozzle's air ring port area to successfully diffuse and accelerate the concrete mixture. Air ring ports are prone to plugging through use or mishandling (Fig. 4).

If even one of the ports becomes restricted, a significant percentage of the material flowing through the nozzle will pass through the air ring area as a cohesive mass that is too large for the nozzle to properly accelerate. These larger particles will exit the nozzle lacking sufficient velocity to achieve satisfactory compaction and consolidation at the receiving surface. Reduced nozzle velocity and an uneven spray pattern will diminish in-place compaction/consolidation quality. Distinct changes in velocity or spray pattern are sure signs of port plugging. A knowledgeable nozzleman must be aware of these changes and stop to correct the problem. Port plugging is a constant risk to placement quality. When laying down a wet-mix nozzle, always leave the air valve slightly open to keep air ring ports clear.

Nozzle tips are a small cost when compared to other wear items. They must be regularly replaced to maintain proper nozzle function. When new, the nozzle tip's interior shape is designed to produce a focused, high-velocity spray pattern. However, nozzle tips wear quickly. They must be replaced when wear increases the tip's internal contour or diameter. Worn tips dramatically reduce nozzle velocity and focus. When shooting production work, nozzle tips wear to

Fig. 5: Cut-down tip

Fig. 6: Worn tip (right)

Fig. 7: Air supply line diameter is critical to maintaining adequate nozzle velocity

oversize within days. A worn tip should never be used during shotcrete placement. Never cut down or modify a nozzle tip. The common practice of "opening" or modifying the tip length to alter the spray pattern will result in unacceptable consolidation/compaction of in-place material. Both cut-down and worn tips should not be used for structural shotcrete placement (Fig. 5 and 6).

Air Supply Fundamentals for Nozzlemen

Nozzlemen must be aware of the strong relationship between air supply components and placement quality. A sufficient volume of dry, oil-free air at the nozzle is a primary requirement to generate satisfactory impact velocity. Both the compressor and air delivery system must be sized to generate sufficient nozzle velocity for the scope of work. The wet-mix process will normally require a minimum of approximately 200 ft^3/min (CFM) (6m^3/min [cmm]), depending on the nozzle type, the blow pipe orifice size, and placement volume per hour. Air supply lines must have a large enough diameter to provide adequate air volume to the nozzle. Regardless of the size of the compressor, an air supply line that is too small cannot provide enough air volume to facilitate proper nozzle function. The practice of splitting one 3/4 in. (19 mm) air line to supply both the nozzle and blow pipe, or routing 3/4 in. (19 mm) lines long distances will not provide sufficient air volume to the nozzle. Keep the air compressor lines as short as practical, or use 1 in. (25 mm) or larger air supply lines when longer air supply lines are needed (Fig. 7).

Sufficient Lighting is Necessary

Quality shotcrete is not possible without acceptable lighting. Lamps should be used in areas where shadows can obstruct vision such as under large overhangs, dark corners, or in underground applications.

The nozzleman and blow pipe operator must be able to clearly see the receiving surface. Nozzleman must have a clear view of the receiving surface when applying shotcrete to ensure that the material is being applied at the correct angle, at the correct distance from the receiving surface, at a proper consistency, and at the specified thickness.

Putting It All Together

Wet-mix equipment selection and maintenance procedures affect shotcrete in-place properties. A

capable nozzleman must possess sufficient knowledge and on-job experience to use the nozzle, and the many individual equipment components in a manner that will produce acceptable in-place material. Although nozzle skill is necessary for a quality shotcrete job, proper equipment function is a fundamental requirement. Quality in-place shotcrete is not possible without it.

*ACI Certified Nozzleman **Oscar Duckworth** is an ASA and American Concrete Institute (ACI) member with over 15,000 hours of nozzle time. He has worked as a nozzleman on over 2000 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He currently serves as ASA Executive Committee Secretary and newly appointed Chair of ASA's Education Committee. He continues to work as a shotcrete consultant and certified nozzleman.*

Nozzleman Equipment Maintenance Checklist

- Select a wet-mix pump configured specifically for wet-mix shotcrete use.
- Adjust the pump to produce an even flow of material, without excessive nozzle thrust.
- Perform necessary pump maintenance before worn sealing surfaces and wear components affect placement quality.
- Perform required maintenance on the nozzle. Inspection, disassembly, and cleaning of all air metering ports, and replacing worn components, must be performed daily by the nozzleman.
- Provide enough air volume to generate satisfactory impact velocity. Both the compressor and air delivery system must be sized to generate sufficient nozzle velocity.
- Use appropriate lighting to assure that both the nozzleman and blow pipe operator can clearly see the receiving surface at all times.
- Be aware that YOU are in control of a complex system which requires many individual equipment functions. An understanding of the proper function of all required equipment is critical to proper shotcrete placement. If any part of the system is not functioning properly, STOP, investigate, and correct the problem before continuing.