State-of-the-Art Refractory Shotcrete Techniques and Practices

by Bill Allen

The use of low-moisture, low-cement castables as a substitute for certain brick installations and traditional gunning applications for working linings and maintaining vessels is a well-known and accepted practice. Although the form-and-cast method of placing refractory is still widely used by the industry, the refractory shotcrete process has steadily gained more popularity as the investment in equipment and manpower has produced more profitable installations. Today more than ever before, the material science and equipment technology behind conventional castables, low-cement castables (LLC), and ultra-low cement castables (ULCC) for refractory shotcrete are opening doors for the unprecedented number of refractory shotcrete installations. Nearly every integrated steel mill will use refractory shotcrete as a part of its refractory program. These refractory shotcrete linings are also more practical in many instances due to speed of installation, reduced down time, and faster turnarounds when compared with form-and-cast linings. Contributing to the drive in this movement was the development of a high-volume, high-pressure hydraulic piston pump and combination 1.7 ton (1.5 metric ton) mixer approximately 5 years ago—which still leads the industry today in production rates, capacity, power, and portability. Also, advances with chemical admixtures such as high-range water-reducing admixtures, rheological modifiers, and high-range water reducers have allowed the formulator to design mixtures with greater mobility and plastic properties to accommodate the performance characteristics and requirements of the installation equipment and projects. The wet-process shotcrete generally results in less rebound, resulting in less waste that has to be disposed of. There is almost no dust—an advantage when refractory must be placed in a confined area. Although nozzeling techniques for both dry- and wet-process shotcrete are different, nozzlemen find it easier and faster to master the wet process.

Shotcrete

Shotcreting is a process used for installing refractory concrete and traditional concrete. Shotcrete is defined by the American Shotcrete Association (ASA) as "Mortar or concrete pneumatically projected at high velocity onto a properly prepared surface."

Terminology

- Nozzleman: Craftsman who manipulates the nozzle, controlling air volume and sometimes the accelerator dosage in the wet-mix process. The nozzleman is responsible for controlling the final deposition of material.
- Pump operator: Worker who operates the refractory concrete pump.
- Rebound: Sprayed refractory concrete material that ricochets off the receiving surface.
- Overspray: Sprayed refractory concrete material deposited on remote surfaces from the intended receiving area.

Mixing

Batch mixers continue to be the preferred type of mixer by many people involved with refractory shotcrete applications because of exact control over the water used. The capacity normally ranges in size from 0.5 to 1.7 tons (0.5 to 1.5 metric tons) and can be either a traditional drum-type mixer, or a planetary (pan)-type mixer. In the author's opinion, the planetary mixer offers greater shear force with less stress on the entire mixing assembly, including the main shaft and paddles. This is due to the material lying on the bottom of the pan and the paddles plowing through the material rather than it sitting in a drum and being picked up by the revolution of paddles moving through it. Mixing times range anywhere from 3 to 8 minutes, depending on the refractory material. Generally speaking, most refractory pumps built today have a large hopper and are capable of holding at least 1.7 ton (1.5 metric ton) batches plus some reserve while it is being charged again to ensure continuous operation.

Continuous mixers still appear to have some promise for certain applications such as tundish, but many problems can have a negative impact on this type of mixing system, including drops in water pressure, segregation in the material bulk sack, the lack of ability to mix at the lowest water percentage desired, and generally not knowing exactly what the water content is.

Concrete trucks are still occasionally used when only traditional concrete pumping equipment is available. In these cases, when the mixture design and project requirements will permit the volume capability for mixing, special precautions must be followed that include precleaning of the truck mixer and careful control of water additions and mixing time.

Pumping Equipment

Volume requirements of the pump also need to be based on the mixing capability. More often than not, people purchase a pump with twice the output capability than what they can mix. The new generation combination mixer/pump machines have effectively matched routine mixing capacities used in the field by sizing the pump and mixer accordingly. The high-pressure, high-volume, 4.5 in. (112 mm) pumping systems are able to intake the materials more easily and make the necessary reductions to 2 in. (50 mm) pipeline and hose for shotcrete. For producers not yet able to design mixtures that will make these reductions, then lower-volume 3 in. (75 mm) pumping systems are still effective with marginally pumpable mixtures, making them easier to shotcrete.

A pump designed for shotcrete operates on the same principle as a twin cylinder reciprocating engine. One cylinder draws refractory from the hopper on the return stroke and another pushes it on the forward stroke into the swing valve then the line. Pistons in both cylinders operate in opposite directions, so there is uninterrupted flow and constant pressure on the refractory in the line. The pistons are driven by hydraulic cylinders and a hydraulic pump. Power options include diesel, electric, or air.

A synchronized swing valve enables refractory from the two cylinders to go into one pump discharge line. This swing-tube valve switches or rotates in front of the discharge cylinder, and material is pushed through the valve and the outlet at high pressure. Output-pressure efficiency is maximized when the reduction from the material cylinders, through the swing-tube, and to the placement line is minimized; but advances in material technology and rheology make this less of an issue now than in the past. At the end of the cylinder stroke, the pump automatically switches the swing tube to the opposite cylinder.

An important point to consider is how fast the swing-tube valve can switch from one cylinder to another. Pumps designed for shotcrete use an accumulator to accelerate the switch-over of the swing-tube, regardless of the stroking speed of the pump, accomplishing the shift in about one-tenth of a second. This provides a smooth flow of material into the pipeline or hose, reducing pulsing of the refractory concrete at the nozzle, which helps to reduce operator fatigue. There is additional proprietary technology available from at least one producer of refractory equipment that will further reduce and compensate for pulsation at the nozzle and improve the quality of life for the nozzleman.

These combination mixer/pumps have filled an important void between freestanding batch mixers and pumps by eliminating the transportation and logistical requirements of two pieces of equipment. Combination machines are integrated mixer/pumps that are completely self-contained and many only require a water connection for the mixer.

Nozzles

When using wet-process shotcrete for refractory installation, a single high-volume combination

Shotcrete repair of refractory brick lining in the tuyere section of the blast furnace mixer/pump is capable of delivering refractory already mixed with a predetermined water percentage to 1 to 2 shooting nozzle(s) at a rate of up to ~700 lb/minute (~300 kg/minute). Compressed air traveling at 150 to 200 ft per second (46 to 61 m per second) is then introduced at the nozzle. Also inside the nozzle, a precise dose of fluid accelerator or set agent is usually injected into the propellant air. The mixture of air and dosing liquid breaks up and interrupts the flow of concrete inside the nozzle, intensely mixing the refractory with the dosing liquid. The propellant air drives the refractory out of the mixing nozzle at the ejection velocity required for compaction (typically 150 to 200 ft per second [46 to 61 m per second]), and then guides it through the nozzle tip to the surface. The nozzleman can vary the amount of air introduced but has little control over the in-place properties of the refractory. It cannot be overstated, however, how important proper experience and training is for the nozzleman as well as the entire shotcrete crew. One would never dream of boarding an aircraft with a flight crew and captain that had not trained for thousands of hours before being allowed to take off with passengers on board. Why would one then allow someone without the proper training to shotcrete a lining inside of a vessel—perhaps an iron transfer ladle—that, if a breakout were to occur, could result in loss of life. Shotcreting is serious business and the people who hold the nozzle are responsible for the quality of the installation—they must be trained and qualified to perform this very important function. Nozzleman certification is being specified more often on many civil construction projects and the certification process is conducted by the American Concrete Institute (ACI). In addition, ASA provides training for qualified nozzlemen to become certified.

Shotcrete repair of the refractory brick lining in the lower stack section of the blast furnace

Dosing

Shotcrete mixtures are typically designed to be flowable, pumpable, and sprayable for easier application. But because many vessels require application of refractories to vertical and overhead surfaces, these flow characteristics must be reversed almost immediately after the refractory leaves the nozzle to assure that the material adheres to the vessel surface. Set accelerators or coagulating admixtures introduced at or near the nozzle are used to alter the set characteristics of refractory in a matter of seconds. A common option available with most refractory pumps used for shotcreting is a separate pump unit for conveying accelerating agents to the nozzle. Accurate accelerator dosing is essential. The dosing pump can be synchronized with the output of the main refractory pump through an optional electronic control console. More common, however, is for the nozzleman to control the output of the accelerator depending on the requirements of the receiving surface and the behavior of the material as it is being placed.

Material and Conveying Line

In a typical high-pressure conveying line used for shotcrete, refractory moves in the form of a cylinder, or slug, separated from the conveying line wall by a lubricating layer of water, cement, and other fines—the past components of the mixture. The refractory mixture must be designed so the slug can pass through reducers and go around bends in the line. With refractory shotcrete, however, the mixture must also be designed to be pushed through a 2 in. (50 mm) hose and have adequate reducibility. Hose blockages typically occur in the reducers. In practice, all refractory pumps have a reducer near the outlet, which can catch a problematic mixture before too much material is pumped into the pipeline and hose. Unfortunately, the passage of refractory through a reducer involves two phenomena that increase the likelihood of problems: the relatively higher paste volume required to maintain the lubricating layer and the acceleration of the refractory required to increase velocity. There is still debate today as to which place is best to position the reducer(s)—

nearest the pump's outlet or nearest to the nozzle. There are many pros and cons to each side of the debate and more work is needed to collect data. For the purpose of this article, I will simply state that a project worthy of further research is required for the prediction of pumping pressures as a function of refractory flow, using the measured tribological and rheological properties of plastic refractory and moving the reducer at different points in the conveying system.

The working range from a pump is maximized by using hard pipe (slick line or steel pipe) from the reduced section to the flexible whip hose of the nozzle. Slick lines have only one-third the flow resistance as flexible hoses; flexible hose should only be used where flexibility is needed.

A pump needs to develop enough pressure to overcome the resistance created with the individual application. The focus is on six primary factors that impact pressure requirements:

- Mixture design (discussed in the following)
- Reductions
- Conveying system (steel versus rubber)
- Nozzle
- Head pressure
- Pumping output rate/velocity

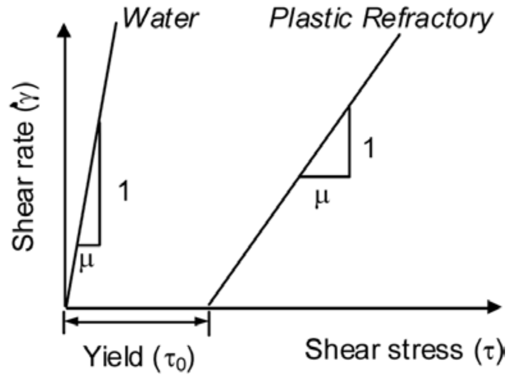
Mixture Design

It is widely accepted that fresh concrete obeys the laws of the Bingham rheological model. I maintain that refractory concrete falls in the same category, and this will hold true, but data is limited due to the proprietary nature of the industry.

$\tau = \tau 0 + \mu\, \gamma$

—Yield stress ($\tau 0$)

—Plastic viscosity (μ)



There are many aspects of rheological characteristics that will influence pumping behavior and that is outside of the scope of this article. Mobility of the refractory in the conveying lines under varying conditions, however, is extremely important. If the mixture is not robust enough to perform under a variety of field conditions, the material will eventually present problems when pumping and shotcreting.

Challenges of Refractory Shotcrete

Many industrial contractors' shotcrete crews have roots as brick masons or in traditional pneumatic gunning. Because of the complexity of today's equipment and wet-process shotcrete projections, as well as safety issues and access problems associated with this work, it is becoming increasingly difficult to maintain a pool of qualified personnel. Installation contractors must know as much about how to lay out the equipment and the associated conveying line as they do about the refractory being installed. The complex sequence of material handling, mixing, pumping, and dosing require a high level of skill on behalf of the foreman or superintendent to ensure the lining is properly installed. Knowing how to stop and start also requires a fairly high level of competency

During the tap of the blast furnace, iron slag is directed into a slag pot and experience. Cleaning the equipment and conveying system has a direct bearing on how well the next installation, next day, or even the next shift will go.

Other factors important to successful refractory shotcrete installations include:

- A clear understanding of the refractory and mixing requirements;
- A properly prepared surface and anchor system to ensure bonding of the refractory and proper depth of the lining;
- Careful planning of the material handling in relationship to mixing, pumping, and conveying line system based on the logistics of the project;
- A familiarity with the conditions and safety requirements of the high-pressure pumping equipment; and
- Proper and ample training and experience. This is not a do-it-yourself application method!

Conclusion

Refractory shotcrete can perform many important functions in refractory installations because the application offers such versatility. It can be adjusted to accommodate the demands of the vessel and turnaround requirements; therefore, it is as flexible as the needs of the owner or contractor. As in any other area of construction, successful and proper application requires both sound and theoretical knowledge and a great deal of practical experience. Every effort is made here to describe the many variables that affect the shotcrete installation. However, I must stress that universal success can never be guaranteed because of the wide variety of conditions that may occur. The more experience each company gains through embracing this technology will enable them to carry on with fewer problems as time passes. The shotcrete process has been used to install millions of tons of refractory material over the last 15 years and the market is growing every day.

References

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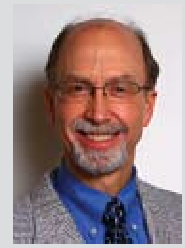

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