How It's Made: Wet-Mix Shotcrete Equipment

By Andy Kultgen

In the shotcrete industry, we occasionally inform or remind people that shotcrete is a method of placing concrete. This is very evident in wet-mix shotcrete, where everything about the process, from the concrete truck to the end of the hose, is common with "small-line" concrete pumping. It is only in the nozzle where the wet concrete is accelerated to a high velocity that the process becomes wet-mix shotcrete. Steel pipeline, reducers and bends, heavy-duty rubber hose, and the appropriate couplings make up this concrete delivery system. Each of these components have evolved through the decades as the concrete pumping industry has developed more capable and powerful equipment, more demanding concrete mixture designs, and greater performance requirements set forth by specifiers. Manufacturing methodology has progressed to keep pace with the advancing designs and customer demands.

Past articles have covered wet-mix concrete pumps and air compressors. This article will cover manufacturing methods for all the components and accessories of the wet-mix shotcrete system. The next issue of *Shotcrete* magazine will include an article with a deeper discussion on heat treating of steels, including processes such as "quench and temper" and "case hardening" that you may hear used to describe equipment.

Fig. 1: A newly formed seamless steel tube rolls out of the seamless mill. The stabilizing rollers and piercing bar can be seen on the right. The solid billet, heated to 2250°F (1230°C), is forced in at the top right while being pressed and rotated. The tubing rotates, being pressed and stressed by the piercing rollers, while the piercing bar opens the inside diameter (Photo courtesy of ArcelorMittal Shelby)

A NOTE ON TERMINOLOGY

Within the concrete pumping industry, slickline is often referred to as "pipe." Technically, "pipe" refers to a specific set of sizes and wall thicknesses, defined by ASME B36.10M-2015, Welded and Seamless Wrought Steel Pipe, and manufacturing methods defined by ASTM A53/A53M, or other specifications for increasingly demanding applications. Other materials are referred to as "tubing." For the purpose of this article, the words "pipe" or "pipeline" may denote materials that are either pipe or tubing. Note that "3-inch pipe" may refer to pipeline built from 3 in. (75 mm) Nominal Pipe Size (NPS) schedule 40 pipe, 3 in. NPS schedule 80 pipe, or 3 in. inner-diameter tubing. All three of these options have different inner diameters. Mixing these pipes would create small steps from pipe to pipe, potentially creating pumping difficulties.

STEEL PIPELINE

Most pipeline used for concrete pumping consists of steel pipe and raised flange end connectors. The ends are typically welded to the pipe, either in a factory setting or in the field at a local shop or jobsite. The pipe can be made in two basic ways: seamless and welded. Whether it is made seamless or welded, all pipe begins as large blocks of cast steel in the specified chemistry, or recipe, from a steel supplier. To manufacture seamless pipe (Fig. 1), the block is heated and formed into cylindrical blanks. At "yellow-hot" temperatures above 2000°F (1100°C), the cylinder is rolled and put under enough pressure to create a tear in the center. That tear is driven over a mandrel and the blank is shaped to create a hollow pipe of the required outside diameter. For welded pipe, the block of steel is rolled into sheet corresponding to the required wall thickness of the pipe (Fig. 2(a)). At the pipe mill, the sheet is rolled into a tube with a seam on one side or wound into a tube shape with a seam that spirals around the pipe (Fig. 2(b)). Next, continuous welding machines weld the seam together. Both kinds of pipe can then be further processed to refine the dimensions, finish, or material structure (Fig. 3). Seamless and welded pipe both have advantages and disadvantages compared to one another.

The pipe that is typically available in the smaller diameters used in shotcrete is single-walled, mild carbon steel chemistry, and delivered in a relatively soft but tough state.

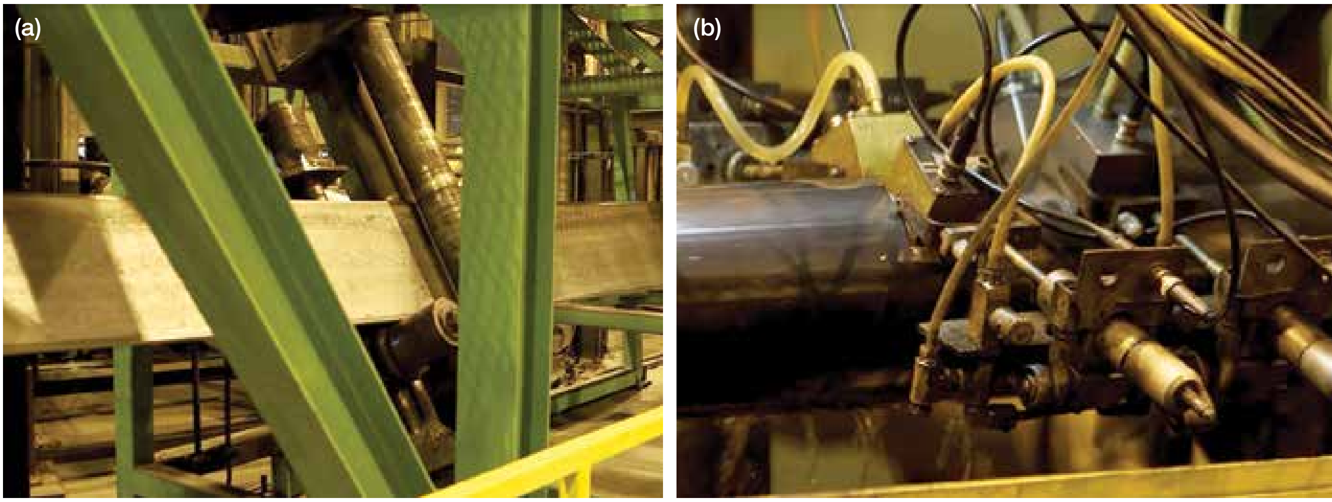

Fig. 2(a) and 2(b): A continuous ribbon of steel, up to 11/16 in. (17 mm) thick at this mill, is unrolled and fed into the tube welding mill. Rollers progressively curl the sheet into a tube. Induction coils heat the edges of the ribbon and rollers press the edges together to the final tubing diameter, creating a weld seam. Sensors monitor weld seam quality immediately after the tubing is welded
(Photos courtesy of ArcelorMittal Shelby)

In larger-diameter pipe intended for use in large projects or on truck-mounted boom, there are a wide variety of single- and dual-walled pipes of varying chemistries and heat-treatment states available.

MANUFACTURING PIPELINE

Grooved ends were once used in all diameters of concrete pumping pipe because they were widely available for commercial building mechanical purposes (for example, water and fire suppression). However, increasing pumping pressures rendered those types of pipe connections obsolete in larger pipe. Grooved ends are still occasionally used in small line pumping and shotcrete. Manufacturing pipe with grooved ends involves cutting the pipe to length and cutting or rolling the groove into the ends of the pipe, either one end at a time, or in cases of larger volume production, both ends at the same time.

Pipeline with raised ends are typically made by welding specially machined flanges onto the pipe. The raised ends are machined separately. At larger manufacturers, commonly used high-volume designs are produced on powerful, high-speed, computer-controlled machine tools that can create a raised end in less than a minute. Piping is first cut to the required length. The common lengths found in the industry are 10 ft (3.05 m) and 3 m (9.84 ft). The raised ends are welded onto the ends of the pipe (Fig. 4). Larger pipe and higher-rated pressures generally require more specialized and tightly controlled welding procedures. Hardened pipe is adversely affected by the heat of welding. Making hardened pipe requires additional processes to protect the hardened crystal structure from the heat of welding, while still maintaining the required weld strength. The same process applies to bends and reducers. After being welded, components are typically inspected, painted, and labeled with a tag including the manufacturer, part number, working pressure, and weight as specified by ASME B30.27, Material Placement Systems.

Fig. 3: Tubing is pulled over a mandrel and through a die set. At this mill, powerful electric motors can pull the tubing with up to 1,000,000 lb (450,000 kg) of force. The drawing process thins the tubing wall and reduces the diameter, allowing for precise control of inside and outside diameters. This tubing is known as drawn over mandrel (DOM) or cold drawn tubing
(Photo courtesy of ArcelorMittal Shelby)

HIGH-STRENGTH HOSE

Concrete pumping hose requires specialized construction techniques. A pumping hose will typically have many layers but can be broken up into the following groups: the inner liner, the reinforcement, and the outer jacket. Hose is produced by wrapping the hose materials onto a long mandrel, sometimes several hundred feet long, from the inside out. First, a heavy layer of rubber is wrapped onto the mandrel to create the inner liner. This part of the hose is in contact with the concrete and the rubber is formulated to resist the constant wear of the abrasive concrete and the often-sharp edges of the large aggregate. Next, the reinforcing layers are wrapped onto the inner liner. Many materials can be used for hose reinforcement, including solid steel wire, wire rope, and a variety of textiles ranging from nylon to Kevlar, in the form of ropes or even woven fabrics. The next layer is the outer jacket. This layer is designed to protect the hose

Fig. 4: The raised flange end is welded onto cut-to-length tubing. This machine is semi-automated and welds both ends of the pipe simultaneously. Depending on the size and shape of the parts, some are welded by more automated robotic welders and some parts are welded by hand. Many different combinations of weld type (for example, TIG, MIG), weld wire, technique, and machine settings are used on different types of products
(Photo courtesy of Construction Forms, Inc.)

from jobsite hazards and during transportation. The jacket will also include identification, pressure rating, and weight information, similar to the steel pipe. The hoses, still on the mandrels, are put into an autoclave or oven to bond the layers together and cure the rubber compounds. The formulation of the rubber compounds, wrapping technique, and curing process are often closely guarded trade secrets, as they can drastically change the wear properties, flexibility, and life expectancy of the hose.

Fig. 5: A powerful crimping press inserts the hose barb into the hose, then compresses the ferrule onto the hose, securing the hose barb in place. This press is hydraulically powered and has eight dies that close simultaneously around the ferrule
(Photo courtesy of Construction Forms, Inc.)

PUMPING HOSE MANUFACTURING

After the hose is cured and removed from the mandrel, it can be used for manufacturing pumping hose. To connect the hoses to other pumping system components, they need raised ends. Usually this is achieved by inserting a machined hose barb, which includes the raised end into the end of the hose, along with placing a ferrule (sleeve) on the outside of the hose. Then the ferrule can be crimped down to secure the hose barb in the end of the hose (Fig. 5). For some hoses, this process is reversed, and the hose barb is expanded into the ferrule rather than the ferrule being crimped down onto the hose barb.

PIPE COUPLINGS

The pipe couplings that are generally available in the concrete pumping market are all similar in design, having two main halves that hold the raised ends (or grooves) on

Fig. 6: A foundry employee pours molten iron into sand molds on this semi-automated production line. This machine will typically produce a mold every 1 to 2 minutes. Each mold may have several cavities, producing several pieces of a part with each pour. A large weight is set on the top of each mold to keep the top half of the mold from floating up on the molten metal
(Photo courtesy of Alliant Castings)

the pipes together, and some means of keeping the two coupling halves together. In the simplest, but also the highest-strength cases, that means two to four bolts and nuts to hold the halves together. It is common, though, to find a wide variety of "snap couplings" that use a lever and connecting links to connect the coupling halves. The coupling halves are typically either castings or forgings in a variety of materials, including iron and steel alloys and aluminum alloys. A small number of specialty couplings are machined from blocks of steel or aluminum, called billets, but these are generally more expensive due to more extensive machining requirements.

Castings are the most basic form of metal production; all metal manufacturing begins with a casting. To make coupling halves, molten metal is poured into a negative mold made of either sand or ceramic (Fig. 6). The foundry must analyze the chemical makeup of the molten metal, as small changes in the contents of some elements can result in large changes in the performance of the finished product. The metal cools and solidifies, and the mold is removed. Excess metal is trimmed away. In some cases, the casting is heat-treated to gain the desired crystal structure in the metal. This changes the mechanical properties, such as strength and toughness of the metal.

Forging is the process of hammering metal into the desired shape. Forged coupling half production will begin with a block, bar, or rod of the desired material. The forging can happen at higher temperatures, known as hot forging, where the steel structure behaves more pliably, and the crystal structure can change (Fig. 7). The critical temperature where the crystal structure can change is different for each alloy, but in lower carbon-steel it is around 1330°F (725°C). If the forging is performed at lower temperatures, generally room temperature, it is referred to as cold forging. The metal blank is shaped by powerful forging machines. These machines use either hydraulic presses or large weights dropping under gravity to form the metal. The presses have dies in the negative shape of the coupling halve. These dies progressively shape the blank into the coupling half shape. Sometimes a punching die is used to create holes, trim off any excess material, and free the coupling half from any remaining metal blank. The coupling halves can then be heat-treated to gain the desired crystal structure, but as with castings this is not always necessary. Forging can create residual stresses in the metal, which can be advantageous in certain situations where the residual stress works in opposition to the stress being placed on the forging during regular use.

Fig. 7: A forge employee positions a hot steel blank to be formed into shape on a forging press capable of pressing with 2500 tons (3.3 million kg) of force. The press is several stories tall, reaching above and below ground. There are three progressive shapes in this die set; the blank will be moved from one impression to the next each time the press closes
(Photo courtesy of Cornell Forge Company)

The coupling halves, either castings or forgings, are then machined or have holes drilled if necessary. The couplings are assembled, inspected, and painted. The couplings should have the manufacturer, part number, pressure rating, and weight information, as do the other elements of the concrete pumping system.

SHOTCRETE NOZZLES

There are a wide variety of wet-mix shotcrete nozzles available in the marketplace. Many have evolved to meet the specific needs of certain segments of the shotcrete market, such as large-aggregate structural shotcrete, or refractory lining, and some have grown from similar industries, such as fireproofing. All these nozzles have the common goal of injecting air into the flow of concrete and accelerating the concrete in a controlled stream at high velocity to the receiving surface. Nozzles are composed of several pieces that can be disassembled for cleaning or replacement. The nozzle bodies and raised coupling ends are made from various steels.

Nozzle tips may be made from a wide variety of rubbers or plastics, or in some cases, steel. The air rings, or plenums, used in wet-mix nozzles can be made from a much wider variety of materials, as they generally do not come in contact with the abrasive concrete. The wide variety of types of nozzles and materials used mean there are a correspondingly large number of manufacturing methods used to produce them.

Generally speaking, the steel components are castings or tubing components that have been further machined (Fig. 8),

Fig. 8: A CNC-controlled lathe machines a shotcrete nozzle body. This lathe has eight tools in its magazine and can load steel blanks and unload finished parts automatically. Normally, the part would be covered in a stream coolant during machining. This nozzle body begins as a piece of steel tubing and has all its features machined into it. Additionally, these nozzle bodies are case-hardened after machining
(Photo courtesy of Construction Forms, Inc.)

and the nozzle tips are cast or injection molded into dies (Fig. 9). One design of nozzle may excel in certain situations and fall short of another design in other situations. The nozzle is very much up to the preference of the nozzleman, their application style, and type of work.

The concrete pumping system is a major contributor to whether your wet-mix shotcrete job will go smoothly or create difficulties along the way. The large variety of project types undertaken by concrete pumpers and shotcrete contractors produces a demand for a wide variety of equipment and accessory options. A basic understanding of these different components can help you best match your shotcrete system to your job requirements. Please check back in the next issue of *Shotcrete* magazine for an overview of metallic crystal structures and how different heat treatments can drastically change the performance of a material.

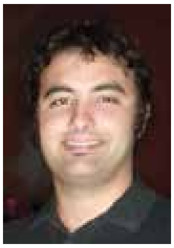

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Fig. 9: Rubber nozzle tips are produced by compressing a rubber block or injecting rubber into a mold. The rubber is heated and cured while in the mold, setting the final shape and properties
(Photo courtesy of Molded Dimensions Inc.)