

Shotcrete Spraying Machines for Immediate Support in Tunnels

by Michael Keienburg

Tunnels are important elements in modern industrial society. For preventing gridlock of traffic in population centers or for difficult topographical conditions, tunnels are increasingly chosen as problem solutions. Hydroelectric power projects to meet continuously rising energy demands often comprise water supply tunnels many kilometers in length. Population centers all over the world are linked by means of flat link low-gradient railway lines and road axes for safe and fast travel that require tunnels for crossings. In mining, rising raw material demands are requiring more and more complex underground extraction methods. Tunnels also contribute to taking care of the environment by protecting nature reserves and by reducing pollution caused by exhaust fumes and noise to which the population living close to the traffic axes is exposed.

Technical factors such as geology, dimensions, and design complexity greatly influence the construction of a tunnel. Tunnels are moreover costly structures requiring political and public input. The above-mentioned factors are principal

determinants of the construction period and resulting project costs. An accurate prediction of geological conditions to be expected along the tunnel alignment is not always possible, even by means of the most advanced methods and the costliest preliminary site investigation. Underground construction projects therefore remain complex structures, highly fascinating for all parties involved.

Excavation Methods

Tunneling methods have evolved with progressing industrialization. Rapid development of mechanization and increasingly elaborate logistics concepts enhance the competitiveness of tunneling contractors. Excavation methods have further evolved under these circumstances. For the excavation of tunnels, different methods can be used such as conventional drilling and blasting, tunnel boring machines (TBM), and other types of machine-assisted excavation. Advancing by drilling and blasting and TBM are the two most common and well-known methods. The main characteristics of these two excavation methods are outlined as follows.

Tunnel boring machines (TBM):

- advantageous cost/benefit ratio for long tunnels;
- shorter completion period compared with the other methods;
- structurally advantageous cross section; and
- in the presence of not very abrasive medium to hard rock types, the TBM can perform at its maximum.

Drilling and blasting:

- flexibility regarding shape and dimensions of the excavated cross section (changing geological conditions while advancing);
- lower investment costs; and
- adaptation of support measures and excavation method is much easier.

Shotcrete for Rock Support

After excavation, a layer of shotcrete is applied onto the surface of the created cavity. The functions of the shotcrete include sealing the surface and creating a supporting lining. In situations where a waterproofing membrane has to be applied subsequently, the shotcrete must also meet certain requirements regarding evenness and roughness, so that the waterproofing membrane can be installed without



Rotor machine Aliva-263



Shotcrete pump Sika-PM702

risk of damage and with a minimum of creases. Shotcrete is also used as final lining in some tunnels. The shotcrete in such cases must not only meet mechanical properties requirements but must also satisfy certain aesthetic criteria.

Shotcrete can be applied by different methods that can be subdivided in the two main groups: dry spraying and wet spraying. Dry spraying methods use pneumatic feed (thin stream method) of a dry-mix up to the spraying nozzle where water and possibly a set accelerator are added to the dry mix. The dry-mix shotcrete is most commonly conveyed by rotor machines.

In the case of wet spraying, the wet-mix shotcrete is fed to the nozzle either by the pneumatic (thin stream method) or by the hydraulic (dense stream method). A liquid set accelerator and compressed air for spraying is added at the nozzle. The wet-mix shotcrete can be conveyed either by a rotor machine or by a twin-cylinder piston pump.

Both application methods (thin stream and dense stream conveyance) have their own advantages, depending on the requirements at the project site, as outlined as follows.

Thin stream method:

- suitable for smaller cross sections;
- no waste material (dry-mix method) in the supply process;
- lower equipment investment costs; and
- shorter time to become operational and less clean-up time.

Dense stream method:

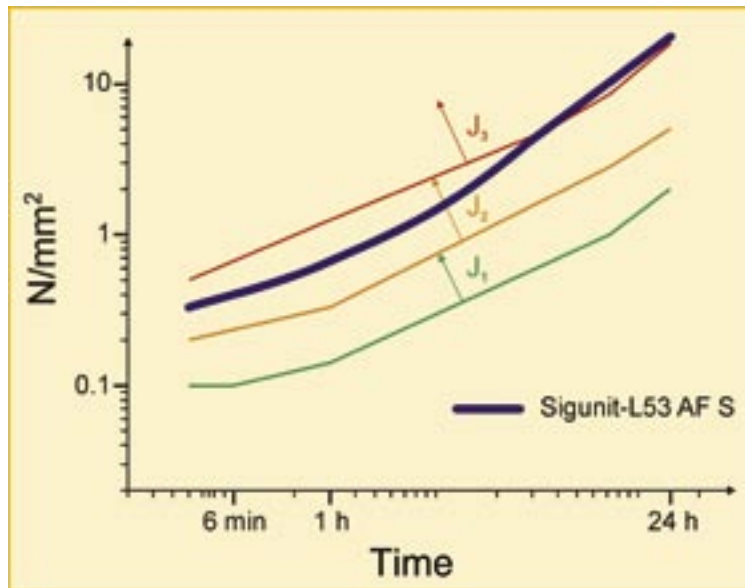
- lower costs related to wear;
- higher output;
- less rebound;
- less air consumption for application; and
- reduced dust formation.

Advanced Machine Technology

For highly mechanized tunnel construction, sophisticated spraying systems are used for the application of shotcrete. Such spraying systems include the following components:

- carrier vehicle;
- conveyance system (thin or dense stream);
- spraying manipulator (including hoses and nozzle);
- dosage unit for set accelerator;
- control unit; and
- compressor for compressed air supply.

The shotcrete spraying system's main task is supporting and securing the cavity created by excavation within the shortest possible time with a high-quality shotcrete layer. This requires a synthesis of men, machine, and concrete technology. The spraying machine can contribute its share to quality by optimally mixing the components (shotcrete, set accelerator, and air in the wet-mix process and water in the dry-mix process) at the nozzle and by spraying



Early-age shotcrete strength development



Sika-PM500PC shotcrete robotic arm at Gottard Base Tunnel (NEAT)

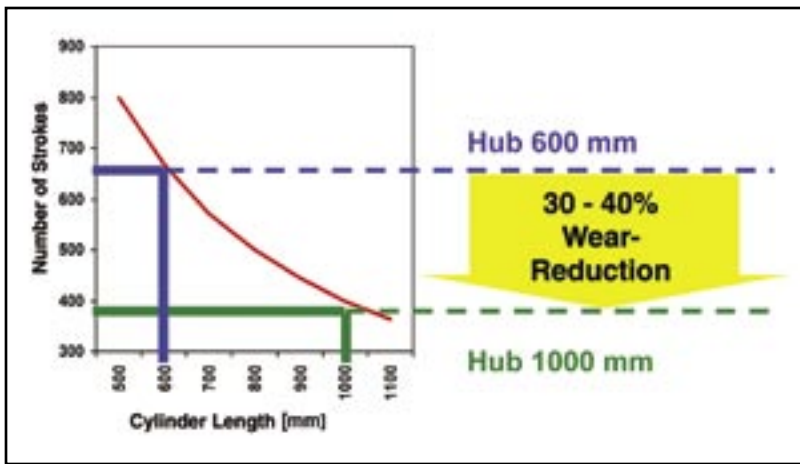


Diagram of wear reduction due to use of long-stroke twin-cylinder piston pump



Sprayed concrete for rock support—drilling and blasting

the shotcrete mix with the correct kinetic energy and without interruption onto the rock surface. Man can improve the quality of the shotcrete layer by correct positioning of the nozzle orthogonally to the surface to be coated. Proper orientation of the nozzle to the shotcreted surface is important to minimize rebound. For the nozzleman, the manipulation of the spraying boom must therefore be simplified as much as possible. First, the admixtures used must enable the applied shotcrete layer to reach sufficient early strength within the shortest time (hardening accelerator). This is necessary to assure safe continuation of tunnel advancement in the supported zone. Second, a long open time (time during which the shotcrete remains workable) must be provided (set retarders/high-performance plasticizers/hydration-controlling

admixtures) because shotcrete often has to be transported over long distances between the batch plant and application site, or sometimes there may be long delays from batching to completion of discharge.

Long-Stroke Pumps Produce Better Quality

In wet-mix shotcrete conveying machines, long-stroke pumps are more frequently used instead of short-stroke pumps. By using a long-stroke twin-cylinder piston pump, the quality of the shotcrete layer applied onto the rock surface is improved. This quality improvement is due in part to the reduced number of pulsations during spraying. Pulsation is caused by noncontinuous conveyance of the shotcrete and is influenced by different factors. Long shifting times between pump cylinders, as well as low filling ratios for the cylinders, have a negative influence on the duration of the pulsation. These factors cannot be eliminated completely from the system, thus the advantage of a longer twin-piston pump over a shorter one is that the number of pulsations per time unit is reduced and wear is considerably less.

The diagram on this page shows that, for the same output, wear for a long-stroke pump with a stroke of 3-1/4 ft (1 m) is reduced by 30 to 40% compared to a pump with a 27 ft (600 mm) stroke.

To summarize, both the wet-mix (thin-stream and dense-stream methods) and the dry-mix spray methods are being successfully used for shotcrete linings in tunnels and mines. The best system for any given project will depend on the specifics of the project.

Contributor:

Manuel Liebi

Mechanical Engineer FH
Product Engineer Equipment
Sika Tunneling & Mining



Michael Keienburg is the Key Account Manager, Mining Worldwide at Sika Schweiz AG Tunneling & Mining in Switzerland. Before that, he held the position of Regional Sales Manager for 2 years. Keienburg has 13 years of international experience in materials handling, mining, project management, sales, and special engineering.