

Dry, Pre-mixed Shotcrete Supply for Tunnels and Mines

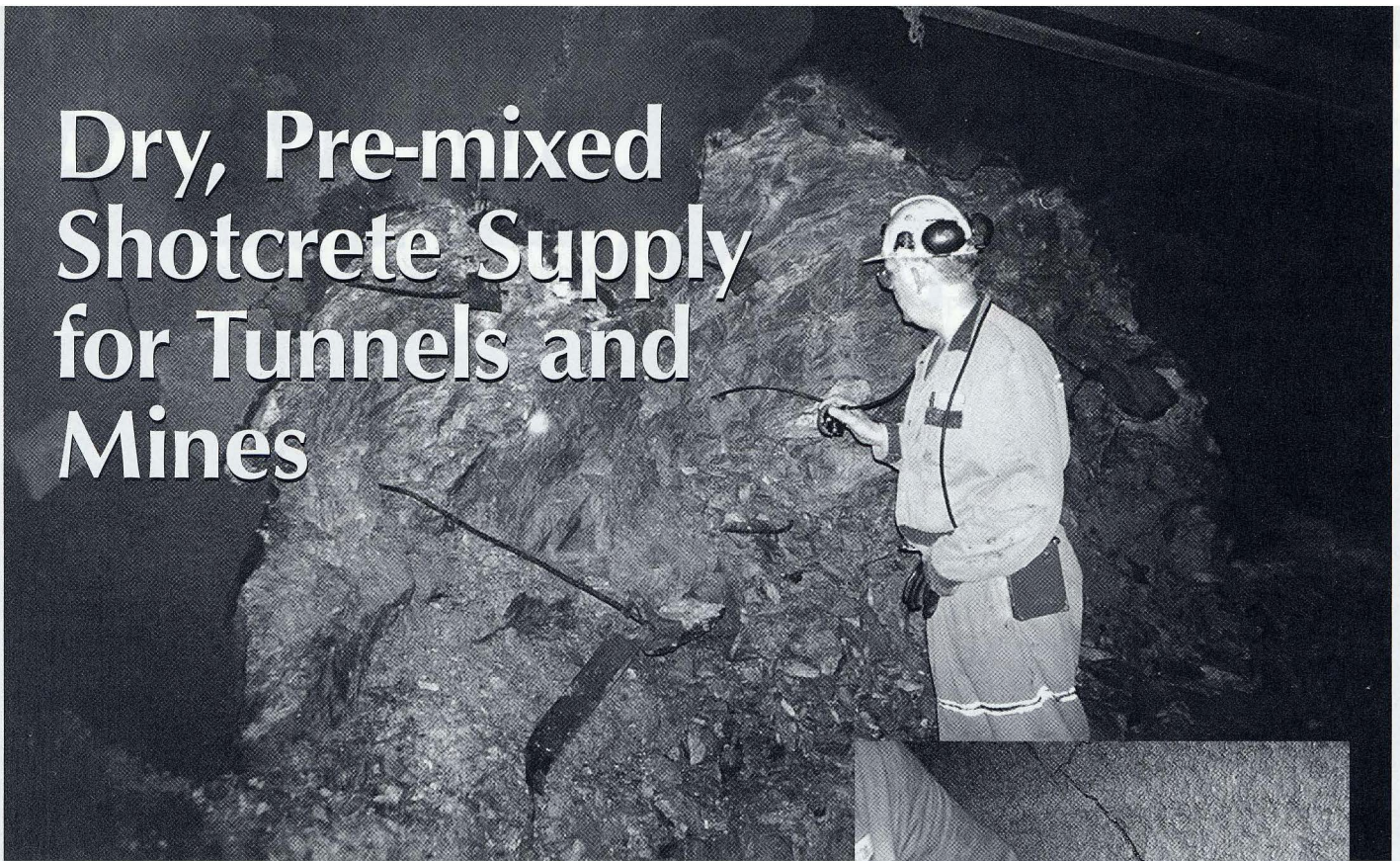


Figure 1. Damage to shotcrete due to ground movement at a mine in Canada.

Tunneling and mining projects use shotcrete primarily as a means of ground support. Immediate application of shotcrete provides stability of the working face, preventing loose rock from initiating movement and thus permitting incremental advances of underground openings even in the worst ground conditions (type V rock) or clays.

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The working cycle typically used to drive drifts in mines and tunnels consists of three phases: drilling, blasting, and removing the loosened material. Whenever ground conditions require, a fourth phase is added to introduce ground support before advancing with the excavation cycle. This ground support often consists of shotcrete (with or without steel fibers), steel mesh, and rock bolts. Speed of installation is important since any delay in the ground support phase implies lost time and possibly even a loss in the working day's excavation cycle, with obvious cost implications.

Ground movement, rock burst, and blast-induced stresses can cause significant damage to shotcrete in tunnels and mines (Figures 1 and 2). Therefore, the main requirements for shotcrete performance in the underground environment are:

- Ability to build up sufficient thickness overhead without the shotcrete falling out.



Figure 2. Damage to shotcrete due to blasting stresses in a Canadian mine.

- Fast strength gain to ensure safety of the working crew.
- Low dust emission.
- Adaptability to adapt to “start and stop” conditions at the working face, where several types of heavy equipment may have to alternate during critical time intervals.
- High long-term strength and durability for the final lining of tunnels and civil projects in general.
- High energy absorption capacity to accommodate rock bursts and ground movement.

Dry, Pre-Mixed Shotcrete

Dry, pre-mixed shotcrete consists of pre-blended aggregates (rock and sand) that are pre-dried to minimal moisture and mixed with accurate amounts



Figure 3. Small crane truck used to move bulk bags underground.

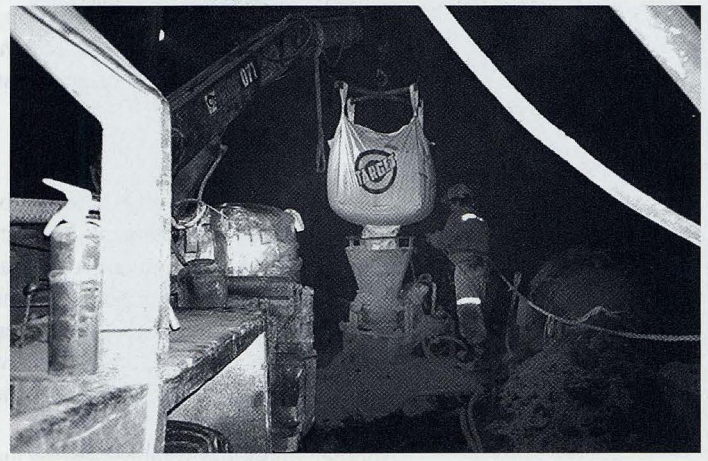


Figure 4. Shotcrete bag placed directly over the shotcrete machine.

of silica fume, set accelerator, steel fibers, and any other addition required. The main advantages of this technique are:

- Shelf life of up to six months as long as there is no contact with moisture.
- High build-up (up to 12 in.(300 mm) in a single pass is possible).
- Conformance to high production standards and liability on the supplier.
- Reliability of supply, with shotcrete available at all times to every working front.
- High early age strengths: 870 psi (6 MPa) at 6 hours; 1,700 psi (12 MPa) at 12 hours, and 2,600 psi (18 MPa) at 24 hours.
- Eliminates the risk that the shotcrete crew could add excessive accelerator, thus “killing” long term strength.
- Permits supplying remote projects or locations where the aggregates do not meet the specified requirements.

Dry, pre-blended shotcrete is usually associated with the dry-mix technique, however it can also be used with wet-mix equipment by adding water in a mixer truck immediately before shotcreting. This technique, used for instance at the Bonners Ferry Tunnel in Idaho, tends to combine the extended shelf life and reliability of supply of pre-dried shotcrete with the lower rebound and dust emission of wet-mix shotcrete.

Packaging and Logistics

Pre-dried shotcrete is usually packaged in bin-bags, typically one cubic yard (m³) in volume. These bags can be placed directly over the shotcrete pot using a suitable crane system (Figures 3 and 4) or, alternatively, emptied into an agitator truck or auger truck to be taken underground.

For large volume applications, bulk handling of pre-dried shotcrete is usually recommended. In this case, the shotcrete mix is stored in a silo, from which mixer trucks can be loaded at any time and taken directly to the working face with minimal delay (Figure 5).

For projects with several working faces operating simultaneously, bulk shotcrete supply can be complemented with bin bags kept in stock close to all faces. Therefore, if a mixer truck is not avail-

Shotcrete Properties	Test Method	Age (days)	Specified Limits
Maximum Water/Cementitious Materials Ratio		–	0.45
Air Content—As Shot	ASTM C 231	–	4% ± 1%
Slump at Discharge into Pump,	ASTM C 143	–	80 mm ± 30 mm
Minimum Compressive Strength	AASHTO T22	7 28	30 MPa 40 MPa
Maximum Boiled Absorption	ASTM C 642	7	8%
Maximum Volume of Permeable Voids		7	17%
Minimum Flexural Strength,	ASTM C 1018	7	4.0 MPa
Minimum Flexural Toughness	Ref. 1	7	Toughness Performance Level III
Shotcrete Core Grade	ACI 506.2	–	Mean Core Grade not greater than 2.5. No individual Core Grade greater than 3.

Table 1. Typical specification parameters for shotcrete used in tunneling and mining (from a project in Peru). [Ref. 1: From the Proceedings of Shotcrete for Underground Support VII, 1995, R. Morgan, L. Chen, D. Beaupre.]

able, the crew can always use a scoop, front end loader, or small crane truck to place bin bags over the shotcrete machine, without any waste of excavation cycle time.

Application

Application of pre-dried shotcrete can be done using different types of equipment. In the case of dry-mix shotcrete, it is recommended that a pre-moisturizing auger be used to pre-dampen the shotcrete to about 3% moisture content before entering the pot. This tends to minimize dust and provide a more homogeneous moisture content to the in-place shotcrete (Figure 6).

Another important requirement of underground shotcreting is the provision of proper lighting. It is usually recommended that the nozzleman have an assistant to move the lighting system as the nozzleman advances. This facilitates good

nozzlemanship and, with the proper shooting angle, results in minimized rebound.

In the case of bulk pre-dried shotcrete, agitator trucks can discharge directly into the pre-moisturizing auger that feeds the shotcrete machine (Figure 6). For most large underground tunnels, robotic-arm nozzling is used, allowing for productivity in excess of 10 cu. yds. per hour with minimal exposure of the nozzleman to unsupported ground conditions. These high productivity robotic systems are especially advantageous for situations in which there are large areas to be covered by shotcrete, especially final linings in civil tunnels. For these applications shotcrete is rapidly gaining popularity over traditional methods of cast-in-place slip-form concrete construction, because of its lower cost, greater speed of application, and non-obstruction of the tunnel section by formwork.

Successful examples of shotcrete used in final tunnel linings are found throughout Brazil, Canada, the USA, and elsewhere in the world.

Specialty Shotcrete

In the case of rock support, shotcrete is often pre-blended with steel fibers allowing for the elimination of the steel mesh. This technique results in double savings—in time not spent installing the mesh and saving from lower shotcrete consumption (since there is no need to apply shotcrete to cover the mesh).

In extremely unstable ground where ground freezing may be required, calcium aluminate cements can be used to provide shotcrete that sets even at sub zero temperatures. This same technique is used for underground support in cold regions (eg. Polaris Mine in Northern Canada).

Also, depending on the stability of the ground and the safety level required, shotcrete reinforcement can assume different patterns: steel fiber shotcrete, shotcrete with steel mesh, shotcrete with rock bolts, and even bolts and mesh over fiber reinforced shotcrete (Figure 7).

Conclusion

Shotcrete used for tunneling and mining plays a critical role in

Project Descriptions

Project: Cluff Lake Mine, Saskatchewan (Canada)

Owner: COGEMA Resources (France)

Project Requirements:

The mine uses shotcrete both as a means of ground support and as gamma radiation shielding for uranium mining. Pre-dried shotcrete in bulk bags had been used for several years. However, given the increase in shotcrete demand, the mine decided to shift to a bulk handling system in order to minimize the handling costs and increase application speed.

Solution:

A pre-dried shotcrete plant was built on site with elevated silos to load mixer trucks and auger trucks (Figure 8). The silos were designed with enough storage to permit shotcrete supply around the clock.

Project: Los Pelambres Project (Chile)

Owner: Compania Mineral Los Pelambres (Chile).

Project Management: Bechtel (USA)

Contractor: Zublin Chile

Project Requirements:

A 12 km (7.5 mi.) tunnel with up to nine working faces was driven through rock of varying quality. However the contractor was having difficulty supplying wet and dry shotcrete to all faces due to the short setting time, remote location and road access restrictions. As a result, shotcrete was not meeting the required 5,000 psi (35 MPa) at 28 days compressive strength and the project was significantly delayed.

Solution:

A pre-dried shotcrete plant was set up on site within 30 days of signing the contract. Shotcrete was supplied in bulk form from a 100 ton silo strategically located with respect to all working faces (Figure 5). In addition, shotcrete in 2,900 lb (1,300 kg) bin bags was stored at all working faces to ensure zero waiting time for shotcrete supply.

After this shotcrete supply method was adopted (along with other general improvements in tunneling methods) the speed of advance practically doubled. The compressive strengths obtained generally exceeded 5,000 psi (35 MPa) at 28 days.



Figure 5. Bulk shotcrete mix being loaded from a silo to a mixer truck in Chile.

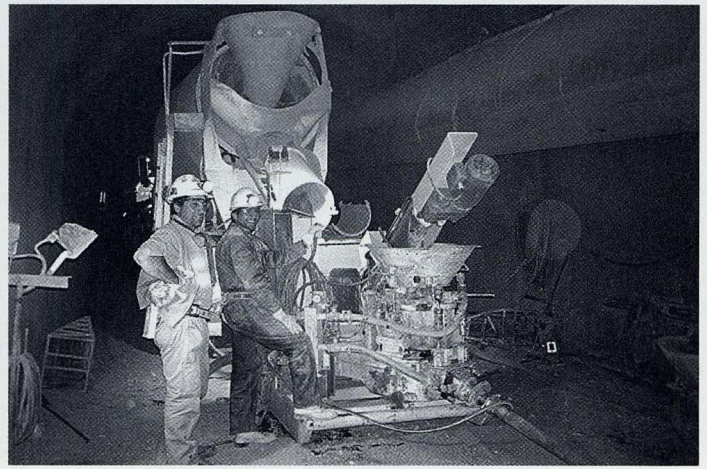


Figure 6. Mixer truck discharging directly into pre-moisturizing auger at the Los Pelambres project.



Figure 7. Rock bolts and mesh over shotcrete at a mine in New Brunswick, Canada.

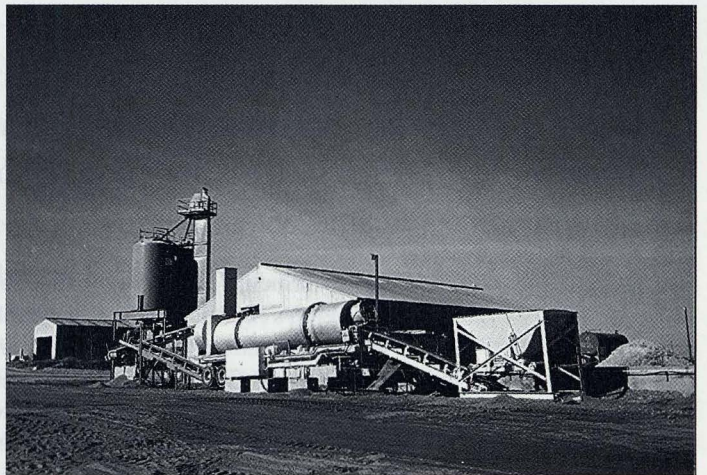


Figure 8. Dry-mix shotcrete plant at a mine in North Saskatchewan, Canada.

the safety and speed of development of underground openings. Dry, pre-mixed shotcrete, applied by either the wet or dry mix processes is a viable means to enhance shotcrete shelf life, reliability, and speed of execution. Special attention must, however, be paid to the shotcrete mix design and the logistics of shotcrete supply and application to take full advantage of this system. ■

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